moray offshore renewables ltd

Environmental Statement

Technical Appendix 3.4 C - Metocean and Coastal Processes Impact Assessment

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Contents

APPENDIX 3.4 C

1. Introduction

ABP Marine Environmental Research Ltd (ABPmer) has been appointed by Moray Offshore Renewables Limited (MORL) to consider the physical processes aspect of the Environmental Impact Assessment (EIA) for three proposed wind farms, Telford, Stevenson, MacColl, on the eastern side of the Moray Firth Round 3 Zone.

An integral part in the determination of the potential impact of the proposed offshore wind farm and transmission cable infrastructure upon the environment is the assessment of its interaction with physical processes. The purpose of this study is to demonstrate a robust understanding of the potential interaction of the developments with wave, tidal and sediment regimes, to assess any direct, indirect and cumulative impacts and to propose mitigation and monitoring requirements. This assessment aims to utilise an evidence based approach, drawing upon previous EIA and monitoring studies. This report follows the baseline assessment (ABPmer, 2012).

1.1 The Moray Firth Round 3 Zone

1.1.1 Overview

The Moray Firth Round 3 Zone is located in the north of the Outer Moray Firth, 12 nautical miles (approximately 22 km) south east of the Caithness coast (Figure 1). It is one of two proposed offshore wind farm developments within the Outer Moray Firth, the second being developed by Beatrice Offshore Windfarm Limited (BOWL). The cumulative effects of these developments are also considered within this assessment.

1.1.2 Location and setting

The Moray Firth Round 3 Zone is located in the Outer Moray Firth on the southern flank of Smith Bank, a morphological high point in the region. The Zone as a whole (shown in Figure 1) is approximately 45 km long and 20 km wide at its widest point, 12 km wide in central parts and tapering further to the west with the long axis orientated around 055/235°N. Water depths across the Zone range from approximately 35 m below Chart Datum (CD) in the central northern, close to the crest of the bank, to 60 m CD along the western and southern margins. Greater water depths occur nearby but outside of the application site to the north where Smith Bank is separated from the Caithness coast by a relatively deep channel (up to approximately 75 m below Chart Datum (mCD)) and to the south and the west in the more uniformly deep (65 to 70 mCD) central parts of the Outer Moray Firth.

Figure 1 also indicates the 'near-field' and 'far-field' boundaries for the wind farms being considered in the present study, also referenced in the associated physical processes scheme impact assessment studies. The near-field boundary is essentially equivalent to the boundary of the three proposed wind farms, therefore encompassing the whole array of wind turbines and substructures and its immediate surroundings. The near-field of the transmission cable route is considered as the route itself and its immediate surroundings. It can be considered as the area in which direct effects to the physical environment are most likely to occur during the wind farm's lifecycle. The far-field boundary broadly delineates the wider area which might also be affected indirectly by the development, e.g. due to disruption of waves, tides or sediment pathways passing through the near-field area.

The characteristics of the wind farm, including the infrastructure details, have been provided within the Project Design Statement (PDS) (MORL, 2011a). Those characteristics pertinent to the physical process assessment are summarised below and in more detail in Section 2.5.

1.1.3 Turbine layout, substructures and foundations

The eastern part of the Moray Firth Round 3 zone will contain up to 339 wind turbine generators (WTGs) grouped into three sites. Each turbine will be supported between the seabed and the water surface by a foundation and substructure, of one of the following two types:

- Gravity Base Structure (GBS); or a
- Jacket on pin piles.

The dimensions of the particular structure will ultimately vary depending upon the rating (i.e. size) of the turbine it supports.

In relation to the Offshore Transmission Infrastructure (OfTI), up to eight offshore substation platforms (OSPs) may also be installed in association with the development as a whole. Two within each of the three wind farm sites and two within the surveyed are of the transmission cable route, using one of the following four foundation types:

- GBS;
- Jacket on pin piles;
- Jack up.

1.1.4 Scour protection

The risk of scour around foundations or exposed sections of inter-array or transmission cables is often mitigated by the use of scour protection. This may take various forms including: rock dump or gravel filter layers; geo-textile or frond matting; and concrete mattresses.

It is presently planned that scour protection might be used in conjunction with all options except permanent anchors used in conjunction with semi-submersible OSP foundations.

1.1.5 Vessels

A variety of vessels may be required during construction of the wind farm. Of relevance to the present study are vessels with jack-up legs or arrays of anchors (used to hold position and provide stability during operation) and dredging vessels (used to flatten and prepare the seabed surface to receive a GBS foundation in some circumstances).

1.1.6 Bed preparation for Gravity Base Structures

For stability, a GBS foundation must be installed onto a pre-prepared horizontal surface. The seabed is prepared by initially excavating an area of seabed 95 m in diameter, i.e. 15 m larger on all sides than the GBS base diameter, and 5 m deep from the original bed level. This excavation will be undertaken using some kind of dredging vessel or machinery.

1.1.7 Drilling to facilitate pile installation

Where soil conditions (or other situations limiting the use of hammer piling techniques) do not allow for piling to be used alone, a pilot hole may be drilled to facilitate the insertion of pin piles associated with piled jacket foundations.

1.1.8 Inter-array cabling

Inter-array cables are required to transmit the generated electricity from each of the turbines to substation(s) within the site prior to export onshore along the main transmission cables. Inter-array cables will exit individual turbines via j-tube structures in the foundation near to seabed level. Different circuit options are being considered but generally speaking each turbine will be connected to one neighbour, i.e. two entry/exit points per foundation. Up to six offshore substations with more cable entry points may be required to consolidate the electricity generated (two within each of the three wind farms) prior to onshore transmission. More details regarding the OfTI are provided in the following section.

For protection against snagging or the development of free-span sections, inter-array cables are usually (but not necessarily) buried using various methods, generally including various types of:

- Ploughing; and / or
- Jetting.

The target trench depth will be 1 m, although may be as deep as 3 m in some areas. The trench width affected directly by jetting is 1 m, although the majority of material is normally expected to remain in the trench profile. Ploughing does not energetically resuspend sediment as does jetting and in loose (e.g. sandy) soils will leave only a minor surficial furrow mark. However, in the worst case of stiff (e.g. clay) soils the passage of either jetting or ploughing tools may result in a ‘U’ shaped trench up to the maximum dimensions above (3m deep, 1m wide). A wider area of seabed (up to 6 m centred on the trench route) might be affected by some contact with the burial machine, but is not considered to contribute to the displacement of sediments.

Where seabed conditions do not allow for cable burial, concrete mattress or rock dump might be used to provide cover and protection to surface laid cables.

1.2 The MORL Offshore Transmission Works Cable

1.2.1 Overview

The offshore transmission works cable corridor extends from the eastern edge of the three proposed wind farms, 89 km to make landfall in the vicinity of Fraserburgh. The transmission cable route is shown in Figure 1.

An assessment of the potential impacts of the transmission cable upon physical processes in the marine environment through construction, operation and decommissioning phases are considered in this report.

1.2.2 Number and dimensions of cables

The transmission cable infrastructure will comprise two cable bundles following separate but parallel routes. A cable bundle will comprise two individual cables, order of 0.3 m in diameter. Due to their necessary metal content and construction, the cables are relatively heavy (order of tens of kilograms per metre of length).

1.2.3 Transmission cable burial

Offshore, cable bundle routes will be located several hundred metres apart (to facilitate servicing) and will be laid in separate (non-simultaneous) operations.

The cable bundles will be either buried or surface laid and protected using the same equipment, methodologies and to the same depths as described in relation to the inter-array cables in Section 1.1.8.

1.2.4 Transmission cable landfall

The cable will transition from offshore to onshore at the landfall location at Fraserburgh. The coastline at Fraserburgh is not subject to any special designations.

The most likely options for facilitating cable landfall are that either:

- The cable will be laid into a trench cut downwards into the beach surface and subsequently buried by backfilling the trench; or,
- A Horizontal Directional Drill (HDD) will be used to create an underground conduit for the cables, from a point onshore behind the beach, to a point offshore. The drilling will be initiated from the onshore end of the route and all drill arisings will be collected there.

2. Assessment Methodology

2.1 Consultation and Scoping of EIA Issues

An EIA scoping report for the proposed Moray Firth Offshore Wind Farm(s) was circulated to statutory and non-statutory consultees including Marine Scotland and Scottish Natural Heritage (SNH) by MORL (2010). A number of issues and particular concerns to address in the EIA were raised in the scoping responses (Marine Scotland, 2011). Those that are of direct relevance to the assessment of physical processes are presented in Table 1.

Table 1. Physical process issues and concerns expressed during the EIA consultation and scoping process

Physical Process Issue	Consultee			
	Marine Scotland	**SNH/JNCC/RSPB**	**Historic Scotland**	**MCA/RYA/Ports and Harbours**
Hydrodynamic regime		Impacts upon the extent, distribution, function or structure of marine and coastal habitats (SACs and SPAs). RSPB - especially the East Caithness Cliffs SPA.		Changes in the set and rate of the tidal stream. Ref MCA guidance MGN371 (MCA, 2008).
Sediment regime		Impacts upon the extent, distribution, function or structure of marine and coastal habitats (SACs and SPAs).	Impacts upon sites of potential archaeological interest	Potential for changes in sediment mobility that might affect navigable water depth. Ref MCA guidance MGN371.
Infrastructure – foundations and installation equipment		Impacts upon the extent, distribution, function or structure of designated marine and coastal habitats (SACs and SPAs).		
Infrastructure - cables	Concern regarding impacts on local (inc. intertidal mudflat) habitats. However, temporary and localised nature of any effect is acknowledged.			MCA - Concerns regarding depth of cable burial.
Cumulative/in-combination effects	To be considered	To be considered		To be considered

Although not identified in the stakeholders' responses, potential concerns regarding the quality of surfing waves on the Moray Firth coastline have also been anticipated, following the guidance provided in a publication by Surfers Against Sewage (2009).

Following the main wind farm scoping exercise, the scope for the assessment of cumulative and in-combination impacts was developed in conjunction with BOWL (Moray Firth Offshore Wind Developers Group, 2011). The developments identified for consideration are listed in Section 2.7.

A separate EIA scoping report was also submitted in relation to the offshore transmission cable (MORL, 2011b).

A draft Environmental Statement (including an earlier version of this technical annex) was submitted to Marine Scotland for review and comment in January 2012.

2.2 Physical Processes Receptors

Physical processes receptors identified in relation to the present study area are listed in Table 2.

Waves and tides do not represent environmental receptors that are inherently sensitive to the presence of the wind farm development. Rather, they are both factors that control local and regional rates and patterns of sediment erosion, transport and deposition. As such, any changes in the characteristics of the wave and tidal regimes may result in consequential changes in these rates and patterns. These rates and patterns directly influence net morphological change on the seabed and at the coast on varying time scales. As such, it is rather the morphological features that are sensitive receptors in the physical environment and the wave and tidal regimes are pathways that transmit the effect of the wind farm. In this context, Smith Bank (the major morphological feature upon which the proposed development will be located and where any near-field impacts may occur) is considered as the primary near-field physical receptor.

The majority of the physical (and ecological) receptors identified within the far-field study area are the conservation sites located along the Moray Firth coast (Table 2; Figure 2). The assessment of impacts of the wind farm will focus upon the potential for significant modification of the naturally occurring processes at these designated sites which could indirectly affect the habitats they support. The further assessment of effects upon the biological environment in terms of the faunal and floral populations found within the far-field will be informed by these results (but reported elsewhere by other contributors to the Environmental Statement (ES)).

Socio-economic receptors relate primarily to the locations of surf beaches along the Moray Firth coastline. Changes to baseline wave characteristics could potentially be detrimental to the quality or frequency of certain surfing wave conditions. Surf beaches within the Moray Firth region have previously been identified in a report by Surfers Against Sewage (2009) and are also listed in Table 2.

Table 2. Physical processes receptors identified within the study area

Receptor	Designation	Morphological 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	Sea-cliffs, 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 sand-flats and mud-flats, 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	Sandbanks, intertidal mud flats and saltmarsh.
Dornoch Firth	SAC	Extensive areas of mudflats and sandflats. Sub-tidally, 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
Frontal Systems	(Tidal front)	Vertical stratification front
Skirza	(Surf beach)	Sand beach (with particular wave climate).
Freswick Bay	(Surf beach)	Sand beach (with particular wave climate).
Keiss	(Surf beach)	Sand/ shingle beach (with particular wave climate).
Sinclair's Bay	(Surf beach)	Sand/ shingle beach (with particular wave climate).
Ackergill	(Surf beach)	Sand/ shingle beach (with particular wave climate).
Lossiemouth	(Surf beach)	Sand beach (with particular wave climate).
Spey Bay	(Surf beach)	Sand/ shingle beach (with particular wave climate).
Cullen	(Surf beach)	Sand/ shingle beach (with particular wave climate).
Sunnyside Bay	(Surf beach)	Rocky beach (with particular wave climate).
Sandend Bay	(Surf beach)	Sand beach (with particular wave climate).
Boyndie Bay	(Surf beach)	Sand/ Shingle beach (with particular wave climate).
Banff Beach	(Surf beach)	Sand beach (with particular wave climate).
Pennan	(Surf beach)	Rocky beach (with particular wave climate).
Widemans	(Surf beach)	Sand/ shingle beach (with particular wave climate).
Phingask	(Surf beach)	Sand/ shingle beach (with particular wave climate).
West Point	(Surf beach)	Sand/ shingle beach (with particular wave climate).
Fraserburgh	(Surf beach)	Sand beach (with particular wave climate).
St Combs to Inverallochy	(Surf beach)	Sand beach (with particular wave climate).

2.3 Best Practice and Current Guidance

In addition to the project specific guidance provided through the consultation process (Section 2.1), generic requirements for physical process studies, including spatial and temporal scales, are currently provided in the following eight main documents:

- 'Offshore wind farms: guidance note for Environmental Impact Assessment in respect of Food and Environmental Protection Act (FEPA) and Coast Protection Act (CPA) requirements: Version 2' (Department for Environment, Food and Rural Affairs (Defra), Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and Department for Transport (DfT), 2004); current at the time of reporting, to be updated by,
- '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).

It is noted that Marine Scotland recently commissioned a set of guidance documents to be produced for the marine renewable industry, specifically wave and tidal devices, which included reference to EIA requirements (EMEC & Xodus AURORA, 2010). It is considered that some elements of the advice offered can be transferred across to the Scottish offshore wind industry, and as such is referenced within this study. ABPmer is currently unaware of any similar guidance from the Scottish Environmental Protection Agency (SEPA).

2.4 Data Sources

As part of the planning, assessment and development of the three proposed wind farms,, a series of new data collection and historical data collation exercises have been undertaken. These have yielded a range of comprehensive datasets, including geophysical, benthic and metocean (meteorological and oceanographic) parameters:

- Metocean survey of the Moray Firth Round 3 Zone (Partrac, 2010a);
- Geophysical survey of the Moray Firth Round 3 Zone;
- Sediment grab survey of the Moray Firth Round 3 Zone (EMU, 2011 and Partrac, 2010a);
- Geophysical survey of the Moray Firth Round 3 Zone OfTI cable route;
- Sediment grab survey of the Moray Firth Round 3 Zone OfTI cable route (EMU, 2011b);
- Metocean survey of the Beatrice Offshore Wind Farm (Partrac, 2010b);

- Geophysical survey of the Beatrice Offshore Wind Farm; and
- Sediment grab survey of the Beatrice Offshore Wind Farm (CMACS, 2010 and Partrac, 2010b).

Additional information has also been obtained from other sources to complement that obtained from the geophysical, geotechnical, benthic and metocean surveys described above. This additional data includes:

- British Geological Survey (BGS) 1:250,000 surface sediment maps, used to provide a more regional indication of the seabed material. This has been broadly verified within the three proposed wind farms using the grab samples provided by the benthic survey;
- Modelled data generated by the Met Office European Waters, UK Waters (UKW) and Wave Watch III models providing up to 20 years wind and wave data time-series for the Outer Moray Firth;
- Extreme storm surge predictions from the Proudman Oceanographic laboratory (POL); and
- UKCIP '09 predictions of future changes to the hydrodynamic regime due to climate change (http://ukclimateprojections.defra.gov.uk/).

Further to the additional data sets acquired, a number of key reports have also been used which hold direct relevance to this project. These include, but are not limited to:

- Offshore Energy Strategic Environmental Assessment -- SEA 2 (DECC, 2011b); SEA 5 (Balson et al., 2001; Holmes et al., 2004);
- JNCC Coastal Directory Series: Regional Report 3 North East Scotland; Cape Wrath to St Cyrus (Barne et al., 1996);
- United Kingdom Offshore Regional Reports Series: The Moray Firth (Andrews et al., 1990); and
- Sand banks, sand transport and offshore wind farms (Kenyon and Cooper, 2005).

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 8.B, 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.

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.

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 8.B (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.

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.

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.

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.

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.

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).

2.5 Rochdale Envelope Considerations: Telford, Stevenson and MacColl

The following elements or aspects of the wind farm design and methodology for construction affect the potential impact upon coastal processes:

- Construction programme and lifetime of the development
- Foundations and Substructures:
  - Type;
  - Number;
  - Layout and corresponding dimensions;
- Foundation installation:
  - Seabed preparation methods for GBS
  - Drilling methods for jacket pin piles
- Scour protection;
- Construction vessels;
- Transmission and inter-array cable burial; and
- Transmission cable landfall.

In accordance with the requirements of the Rochdale Envelope approach to environmental assessment (IPC, 2011) the 'realistic worst case' characteristics of the proposed wind farm in terms of impacts upon coastal processes have been adopted within this investigation. In addition, other 'realistic case' characteristics of the development have also been assessed in order to provide a consideration of those wind farm characteristics that are perhaps more likely to be developed. No specific comments regarding the Rochdale Envelope in relation to physical processes were offered in the Scoping Opinion (Marine Scotland, 2011), however, it is recognised that the cumulative effect of the three sites, in addition other planned developments should be considered. The characteristics assessed for coastal processes are detailed in the following sections.

2.5.1 Anticipated Construction Window & Total Lifetime of the Development

It is anticipated that each of the three wind farms will take three years to construct (although these construction windows may overlap to some extent. The expected total operational lifetime of the development following construction is 25 years. This duration corresponds to the expected lifetime of the turbine generator units, which could potentially be extended by 'repowering', i.e. replacing or updating the units.

2.5.2 Foundations and Substructures

Foundation and Substructure Types

The substructure is defined in the PDS (MORL, 2011a) as that part of the support structure that is underwater but above the seabed (i.e. in the water column), whilst the foundation is the continuation of the structure below the seabed (e.g. piles). For the purposes of the present study, the whole support structure will be referred to generically in this report as the 'foundation' and separate reference will be made to specific component parts (e.g. piles, etc).

Two nominal foundation types have been proposed for use in supporting the WTGs and any OSPs in the Moray Firth Round 3 Zone, namely:

- Gravity Base Structure (GBS);
- Jacket on pin piles.

Example schematic images of each foundation type are shown in Figure 3. The GBS is of a conical shape, jackets are essentially four upright members with various cross-bracing. A jack up foundation type may be used in conjunction with OSPs but would have fewer legs and therefore would present a smaller obstacle/impact to physical environmental processes.

Foundation Number and Layout

The layout of WTGs within a wind farm is designed to optimise the inter-turbine spacing relative to the predominant wind direction. The level of turbulent interference between WTGs is managed as a multiple of the turbine rotor diameter, which varies in relation to the turbine power rating. Hence, the layout for a lower rated turbine with a smaller rotor diameter is typically more densely spaced than that for a higher rated turbine. Each layout also aims to maximise the total power production (up to 1500 MW for the zone). The layouts in each site are named according to the turbine rating they are designed for, namely:

- 3.6 MW (allowing up to 139 turbines per site); and
- 5 MW (allowing up to 100 turbines per site).

The number of turbines in each layout is indicated in brackets. An indicative relative distribution of turbines in each layout is shown in Figure 4. Each layout is consistent with the downwind and cross-wind spacing between turbines specified by MORL and based on the predominant wind direction (approximately 230°N). A larger (e.g. 7 or 8 MW) turbine might be used instead of the 3.6 or 5 MW options shown above but would lead to a correspondingly smaller number of foundations (of similar maximum dimensions) and potential effect, to remain within the maximum rated capacity of each site and/or the zone.

Table 3. Realistic worst case development scenarios considered

Development Scenario	Telford	Stevenson	MacColl*	Total
Primary Assessment (3 wind farms together)				
T3-S5-M5	3.6 MW (139 WTG)	5 MW (100 WTG)	5 MW (100 WTG)	1500 MW (339 WTG)
T5-S3-M5	5 MW (100 WTG)	3.6 MW (139 WTG)	5 MW (100 WTG)	1500 MW (339 WTG)
T5-S5-M3	5 MW (100 WTG)	5 MW (100 WTG)	3.6 MW (139 WTG)	1500 MW (339 WTG)
Secondary Assessment (3 individual wind farms)				
T3	3.6 MW (139 WTGs)	-	-	500 MW (139 WTG)
S3	-	3.6 MW (139 WTG)	-	500 MW (139 WTG)
M3	-	-	3.6 MW (139 WTG)	500 MW (139 WTG)
Sensitivity Assessment (2 Individual wind farms)				
T3-S5	3.6 MW (139 WTG)	5 MW (100 WTG)		1000 MW (239 WTG)

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T3-M5	3.6 MW (139 WTG)		5 MW (100 WTG)	1000 MW (239 WTG)
T5-S3	5 MW (100 WTG)	3.6 MW (139 WTG)		1000 MW (239 WTG)
S3-M5		3.6 MW (139 WTG)	5 MW (100 WTG)	1000 MW (239 WTG)
T5-M3	5 MW (100 WTG)		3.6 MW (139 WTG)	1000 MW (239 WTG)
S5-M3		5 MW (100 WTG)	3.6 MW (139 WTG)	1000 MW (239 WTG)

Various scenarios for the development of the three proposed wind farms both together and in various combinations have been tested in the present study. The realistic worst case for the development of three proposed wind farms that meet the total permitted zone capacity is that one site will be developed with 3.6 MW WTGs whilst the other two will be developed using 5 MW WTGs. The worst case for a single site is that with the greatest number of WTGs, i.e. the 3.6 MW scenario. The development scenarios shown in Table 3 are all considered to be realistic worst cases for different purposes.

The Western Development Area (WDA) comprises part of the MORL Zone, within which the three proposed wind farm sites (Telford, Stevenson and MacColl) are located. The maximum capacity to be installed in the entire Zone is 1.5 GW and MORL has applied for a maximum of 1.5GW within the three proposed wind farm sites. The WDA may be developed for a maximum of 500 MW of capacity if less than 1.5GW of capacity is delivered by the Project in the three wind farm sites. In total the consented capacity of the Project and the WDA will not exceed 1.5GW.

As part of the OfTI, two OSPs will be installed within each of the three wind farm site extents; two additional OSPs will be installed within the area of the OfTI cable route (i.e. maximum of eight OSPs in total). The actual final location of these very few additional structures does not influence the overall outcome of the assessments due to their relatively small scale when compared to the offshore wind farm infrastructure and so are not specified here.

Foundation Dimensions

Example schematic images of each WTG foundation type were shown in Figure 3. The key dimensions of the two foundation types proposed for WTGs are listed below in Table 4 and Table 5. The dimensions of the structure will ultimately likely vary in relation to the power rating of the turbine it supports but the present study conservatively considers only the largest potential values for all layouts. Uncertainty in the number of additional members that might be associated with additional cross bracing at the base of the structure and vertical risers or J-tubes is addressed by conservatively adding a further 50% to the calculated blockage in the modelling work.

Table 4. Dimensions of the Moray Firth Round 3 Zone GBS foundations for WTGs

Dimension	3.6 to 7 MW
Main column diameter (m)	12
Depth monopole starts below the surface (m)	5
Base diameter (m)	65
Thickness of base plate above seabed (m)	5
Diameter of ground preparation works (m)	95
Depth of ground preparation works (m)	5

Table 5. Dimensions of the Moray Firth Round 3 Zone jacket foundations for WTGs

Dimension	3.6 to 7 MW
Number of sides	4
Jacket top length scale (m)	45
Jacket base length scale (m)	60
Lattice primary member diameter (m)	2
Lattice secondary member diameter (m)	1
Angle of secondary members (deg)	45
Number of pin piles	4
Pin pile diameter (m)	2.5
Maximum depth of pin pile penetration by drilling (m)	60

The scale of OSPs, and therefore their foundations, will be larger than a WTG. The OSP dimensions may ultimately vary depending on whether the substation is handling Alternating Current (AC) or Direct Current (DC), with AC typically the smaller structure. One option for OSPs is a GBS, the conical type being the worst case for blockage (the cross-sectional area of the foundation presented to wave and/or tidal forcing). The base will however likely be square or rectangular in shape. The key dimensions of the larger DC OSP GBS foundation are given in Table 6 and will be those considered in the present study.

Table 6. Dimensions of the Moray Firth Round 3 Zone GBS foundations for OSPs

Dimension	3.6 to 7 MW
Main column diameter (m)	12
Depth monopole starts below the surface (m)	5
Length scale of base (m)	130
Thickness of base plate above seabed (m)	5
Length scale of ground preparation works (m)	160
Depth of ground preparation works (m)	5

OSPs may also utilise a jacket or jack-up foundation type, both of which are both similarly characterised as a lattice structure in the water column; of these, the jacket is considered to have the greatest relative cross-sectional area and blockage effect and so will be considered further in the present study. The base will be square or rectangular in cross-section. The jacket will be fixed to the seabed using four or six pin piles or suction caissons at

the end of each primary member. The key dimensions of the larger DC OSP jacket are listed in
Table 7 and will be those considered in the present study. Uncertainty in the number of additional members that might be associated with additional cross bracing at the base of the structure and vertical risers or J-tubes is addressed by conservatively adding a further 50% to the calculated blockage in the modelling work.

Table 7. Dimensions of the Moray Firth Round 3 Zone jacket foundations for OSPs

Dimension	DC OSP
Number of sides	4
Jacket base length scale (m)	100
Lattice primary member diameter (m)	3
Lattice secondary member diameter (m)	2
Angle of secondary members (deg)	45
Number of pin piles or suction caissons (if used)	6
Pin pile diameter (if used) (m)	3
Maximum depth of pin pile penetration (m)	60
Suction caisson diameter (if used) (m)	20

Worst Case Scenarios

The definition of a worst case will vary depending on the element of the coastal processes regime being considered. For example the greatest impact on hydrodynamics will occur as a result of the greatest blocking effect (typically the largest foundation type with a relatively dense layout) and the greatest impact on sediment dispersal will depend on both the total volume and rate of seabed disturbance required.

With respect to hydrodynamics (i.e. effect on currents and waves) the GBS presents the greatest total cross-sectional area to the flow for any given layout and therefore represents the 'worst case' in terms of blockage and any consequential impacts on sediment transport and morphology. The greatest total blockage arises from the 3.6 MW GBS scenario.

As jackets comprise a large proportion of the options available, a representative jacket structure (with pin piles) will also be considered, as a 'realistic' option, although it is not the worst of all cases. For OSPs, the choice of pin piles or suction caissons (for jackets and semi-submersibles) or anchors (for semi-submersibles only) does not affect the blockage presented above the seabed. The greatest total blockage for jackets arises from the 3.6 MW scenario because it is the largest number of representative jacket structures.

2.5.3 Seabed Preparation Methods for GBS

In the present study, the GBS base diameter is 65 m. However, the diameter of the excavation will need to be larger to allow for sloped pit edges and for margins of operational accuracy in the bed preparation and foundation installation process. The diameter of the dredged pit as part of bed preparation is given in the PDS (MORL, 2011) as 95 m (65 m GBS base diameter plus a 15 m buffer surrounding the target area). The depth of the pit required is 5 m. Conservatively discounting slopes at the pit edge, the realistic total volume of sediment to be excavated per foundation is estimated as 35,000 m^3.

The majority of this excavation is likely be undertaken by a dredging vessel (e.g. such a vessel was also used for bed preparation for GBS foundations at Thornton Bank Offshore Wind Farm). In the UK, trailer hopper suction dredgers (TSHD) are normally used for marine aggregate dredging in similar water depths and have a hopper capacity of around 5000 m^3, filling it in the order of 3 to 4 hours. Seven cycles would therefore be required to excavate the realistically required sediment volume. The dredging process draws up a mixture of sediment and water from the seabed using suction, depositing it in a hopper within the vessel at the surface. Excess water is returned back into the sea, usually with some residual sediment load. CIRIA (2000) summarizes UK spillway measurement losses for all-in loads as 27 kg/s, with specific measurements for a TSHD working at Hastings and Great Yarmouth having sediment loss rates of 14 kg/s and 20 kg/s respectively. A value of 30 kg/s is conservatively but realistically assumed for the present study. It is further conservatively assumed that all of the overspill material is fine material (silts and clays in 50 % : 50 % proportion).

Pin piled jacket foundations do not require seabed preparation prior to installation (drilled pilot holes for pin piles are not counted as bed preparation in this sense).

With respect to sediment (i.e. total volumes and rates of release) the GBS foundation type at the 3.6 MW layout disturbs the greatest and equivalent total volumes of sediment as a result of bed preparation activities. It should be noted that the sediment release rate is determined independently of the total volume because it is instead associated with the method used (i.e. dredging). Therefore, the effect of changing the pit diameter/volume is only to change the number of cycles of dredging required (duration of the release) at each location and the total volume of sediment eventually released; the rate of release is not affected.

2.5.4 Drilling Methods for Jacket Pin Piles

Each pinned jacket foundation requires four pin piles to be inserted into the seabed. The most efficient and preferred method for installation is to simply drive (hammer) each pile to the required depth. In some circumstances the soil conditions along some or all of the profile may pose too much resistance for driving alone and a pilot hole must be drilled ahead of the pile (a drill-drive methodology). The drill arisings (cuttings) will be brought to the sediment or water surface and then either released directly into the water column, or captured into a hopper and subsequently disposed of in a controlled manner.

The PDS (MORL, 2011a) states that four pin piles of 2.5 m diameter will be installed at each foundation (worst case a slightly larger 3 m diameter hole - to allow for insertion of the pile, 60 m deep). It is assumed to take 12 hours to drill one pile, a drilling rate of 0.00139 m/s, releasing 0.00982 m^3/s or 26 kg/s of arisings. An allowance of 3 hours is made for repositioning between piles and 12 hours between foundations.

The geophysical survey data show that the eastern part of the Moray Firth Round 3 Zone is generally characterised by a marine sand layer overlying a more consolidated till. The marine sand comprises, on average, 83 % sand, 8 % silt and 9 % clay material. The underlying till comprises, on average, 50 % sand, 20 % silt and 30 % clay material. The thickness of these layers has been determined, at each foundation location, using the subsurface geophysical

data. The proportion of each sediment fraction being released is adjusted in time, according to the thickness of the marine sand layer and the drilling rate.
In the present study, the worst case assumption used is that all sediments arise as a fully fluidised mixture. In practice, the nature of the arisings may vary considerably depending upon the exact geotechnical nature of the sub-soils and the drill head used. In practice, arisings may consist of larger chunks which will be very differently transported and (locally) deposited.

Conical GBS foundations do not require drilling (in addition to seabed preparation).

As the pile dimensions are assumed to be the same between jackets supporting differently rated turbines, the worst case is where the sediment releases occur in the closest proximity to each other. On this basis, jacket foundations will also be tested using the 3.6 MW layout for assessment of sediment release scenarios.

2.5.5 Scour Protection

The risk of scour is often mitigated by the use of scour protection. This may take various forms including: rock dump or gravel filter layers; geo-textile or frond matting; and concrete mattresses. Scour protection for foundations will typically extend up to 15 m from the edge of the structure. Scour protection for exposed cables will typically extend in the order of a few metres either side of the cable location.

2.5.6 Jack-up and Anchoring Vessels

Jack up vessels are characterised as having four to six long lattice or monopile column legs. The lower end of each leg will end in a solid foot or spud can with an area of 70 to 100 m^2, equivalent to a footprint of 8.4 to 10 m square or a circular footprint diameter of 9.5 to 11.3 m. Each leg will likely penetrate the seabed by 1 to 4 m, depending on the local ground conditions.

Anchors used by installation vessels are typically of smaller dimensions than the jack-up legs described above and exert their force differently onto the seabed. The length-scale of the main body of one such anchor is assumed to be in the region of 1.5 to 3 m. 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. Such vessels might utilise between four and six anchors at one time.

2.5.7 Inter-Array Cable Burial Methodology

The geology and geomorphology of the seabed will determine the cable installation method used locally (Royal Haskoning and BOMEL, 2008). Methods of cable installation specified in the PDS (MORL 2011) generically include:

- Ploughing;
- Jetting; and
- Mechanical cutting tools.

To date, the available information indicates that the majority of offshore wind farms use either ploughing or jetting methods to install cables, characterised as follows:

Ploughing
This method has been typically deployed in materials ranging from silt to structureless chalk (weak rock) (Royal Haskoning and BOMEL, 2008). The cable is buried by a passive tool mounted on skids, which is pulled through the seabed by a towing vessel. The plough is usually deployed in a simultaneous lay and trench mode, using cable depressors to push the cable into position at the base of the trench. Jet assist options are sometimes fitted to the plough in conditions of firmer soils and for deeper burial, for example either (i) rock penetrating tooth; or (ii) vibrating plough share. This method typically keeps soil disturbance to a minimum; however silt and structureless chalk may remain in suspension for periods of time. Cables at North Hoyle, Scroby Sands, Barrow, Arklow Bank and Kentish Flats have been buried using this method, in addition to telecom and power cable projects; and

Jetting
Water jets are used to fluidise or displace sediment in a narrow vertical profile; the cable then settles through the trench profile to the intended burial depth under its own weight. The physical result of jetting is dependent upon the soil type; in non-cohesive sediments (e.g. sands) material is typically fluidised, whilst in cohesive sediments (high proportions of fine material) material is typically eroded. Cables at North Hoyle, Nysted, Horns Rev and Scroby Sands have been installed using this method.

There is a considerable difference in the amount of sediment released by these two installation methods (ploughing and jetting) Whilst both methods may release some material into the water column (at the seabed), it is the more energetic jetting method that has the potential to result in greater volumes of suspended sediment as it intentionally fluidises the material. It is also however the intention of the operation to achieve burial of the cable and so whilst the machine is designed to fluidise, it is also designed not to eject large volumes of material from the trench.

Based upon the available evidence on the superficial sediments present along the cable route and the greater sediment mobilisation of jetting techniques, this approach will be assessed.

Based upon the PDS (MORL, 2011a) and the evidence base in this regard, (Royal Haskoning and BOMEL, 2008), the cable installation parameters are:

- The trench has a 'U' shaped profile 1 m wide and up to 3 m deep (1 m is the target depth).
- 100 % of sediment volume in the trench may be resuspended by any method;
- The material will likely arise as chunks but worst case assumption is that all sediments are fluidised as a fine suspension; and
- Cable bundles will be separately (not simultaneously) installed.

2.5.8 Summary

The range of characteristics adopted within the MORL physical process assessment, as detailed in preceding sections, are summarised in Table 8.

Table 8. Scenarios assessed for physical processes

Potential Impact	Scenario assessed*
Wind Farm: Construction and Decommissioning Phases	
Increase in suspended sediment concentrations as a result of foundation installation activities	Dredging overspill (silts and clays) at 30 kg/s during GBS bed preparation, 95 m pit diameter, 5 m pit depth, various layouts.. Drill arisings (sands, silts and clays) at 26 kg/s during installation of pin piled jacket foundations, 4 pin piles, 3.0 m diameter drilled holes, 60 m burial, various layouts.
Accumulation of sediment and change of sediment type at the seabed as a result of foundation installation activities	
Increase in suspended sediment concentrations as a result of inter-array cable installation activities	Trenching by energetic means (e.g. jetting). Single trench with cross-section of disturbance 1 m wide by 3 m deep in 'U' shaped profile. 100 % of material resuspended.
Indentations left on the seabed by jack-up vessels and large anchors	Jack-up legs 70 to 100m^2 footprint. Anchors 1.5 to 3 m length scale.
Wind Farm: Operational Phase	
Changes to the tidal regime due to the presence of the turbine foundations	1) GBS, various layouts. 2) Jacket, various layouts.
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	
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
* (1) refers to the characteristics identified as worst case; (2) refers to the characteristics identified as a realistic probable alternative case	

2.6 Rochdale envelope considerations: OfTI Transmission Cable

2.6.1 Transmission Cable Burial Methodology

The same details are used as previously presented in Section 2.5.7 in relation to inter-array cables. Transmission cables may comprise bundles of several individual cables, and up to three cable bundles will be separately trenched along the cable route. The trenches will be separated by tens or hundreds of metres and will not be laid simultaneously.

2.6.2 Transmission Cable Landfall Methodology

Once the transmission cables reach the landfall location, either open trenching or HDD works are planned (MORL, 2011a).

2.6.3 Summary

The range of characteristics adopted within the MORL physical process assessment, as detailed in preceding sections, are summarised in Table 9.

Table 9. Scenarios assessed for physical processes (OfTI Transmission Cable)

Potential Impact	Scenario assessed*
Transmission Cable : Installation and Operation	
Increase in suspended sediment concentrations as a result of transmission cable installation activities	Trenching by energetic means (e.g. jetting). Single trench with cross-section of disturbance 1 m wide by 3 m deep in 'U' shaped profile. 100 % of material resuspended.
Introduction of scour effects due to exposure of transmission cables and cable protection measures	Transmission cables and cable protection measures
Disturbance of coastal morphology at the landfall site	1) Trenching through the beach. 2) Directional drilling to facilitate landfall.
* (1) refers to the characteristics identified as worst case; (2) refers to the characteristics identified as a realistic probable alternative case	

2.7 Rochdale envelope considerations: Cumulative and In-Combination Effects

The scope for the assessment of cumulative and in-combination impacts has been previously presented in detail in a document by the Moray Firth Offshore Wind Developers Group (2011), with input from both MORL and BOWL. From this document, the following specific developments and activities are considered in relation to physical processes within this assessment report.

Cumulative effects are those which might arise from multiple offshore wind farms in close proximity. In-combination effects are those that might occur due to the offshore wind acting in-combination with other (non-wind farm) activities. Existing, operational infrastructure (e.g. oil and gas platforms, the Beatrice Demonstrator turbines, the SHEFA telecommunications cable are already present in the baseline environment and so are not included again here.

2.7.1 Cumulative Effects

The cumulative effects investigated within this study, (in addition to the Project and which have previously been identified and discussed during the scoping phase), include for the following offshore wind farm projects:

- Beatrice Offshore Wind Farm and associate Offshore Transmission Infrastructure;
- Forth and Tay offshore wind farm developments;
- European Offshore Wind Deployment Centre; and
- Beatrice Demonstrator wind farm.

And the following other marine activities:

- Marine renewables projects:
  - Marine energy developments in the Pentland Firth and Orkney waters;
  - Proposed SHETL hub;
- Cables
  - Proposed Scottish Hydro Electric Transmission Limited (SHETL) cable;
- Oil and gas industry infrastructure:
  - Beatrice and Jacky platforms and associated infrastructure;
  - The proposed Polly well;
  - 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.

Figure 5 presents the location of these developments relative to the Moray Firth Round 3 Zone and to each other.

2.7.2 Summary

The range of characteristics adopted within the cumulative and in-combination effects for the MORL physical process assessment, as detailed in preceding sections, are summarised in Table 10.

Table 10. Scenarios assessed for physical processes (Cumulative and In-Combination)

Potential Impact	Realistic worst case scenario assessed
MORL Construction and Decommissioning Phases	
Increase in suspended sediment concentrations and interaction of sediment plumes	Simultaneous occurrence at nearby locations along the boundary between the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm: a) Dredging overspill for GBS bed preparation; b) Drill arisings during installation of pin piled jacket foundations; c) Cable burial.
MORL Operational Phase	
Changes to the tidal regime	Effect of all marine renewable projects and new oil and gas infrastructure.
Changes to the wave regime	
Changes to the sediment transport regime	
Introduction of scour effects	All foundation types and layouts. Inter-array and transmission cables

2.8 Assignment of Significance

The significance of the potential impacts on the identified coastal process receptors (Table 2) will be assessed using the following method and terminology.

Firstly, the magnitude of any impacts will be quantified to the extent practicable, considering all the dimensions of the predicted impact including:

- The nature of the change (i.e. what resources or receptors are affected and the size, scale or intensity of any changes);
- The spatial extent or proportion of the area impacted;
- The temporal extent of the impacts (i.e. duration, frequency, reversibility); and
- Where relevant, the probability of the impact occurring as a result of accidental or unplanned events.

The magnitude of the impact will be considered in relation to the following spatial and temporal scales.

Spatial Scales::

- Onsite – impacts that are limited to the wind farm area or cable corridor (i.e. the near-field study area);
- Local – impacts that are limited to the wind farm area or cable corridor and generally within the area of one tidal excursion (or a similar 'buffer' around the areas);
- Regional – impacts that are experienced at a regional scale e.g. the Moray Firth;
- National – impacts that are experienced at a national scale; and
- Transboundary / International – impacts that are experienced at an international scale i.e. affecting another country or international water.

Temporal Scales:

- Short term – impacts that are predicted to last only for the duration of specific construction operations e.g. noise for piling and plume dispersion;
- Medium term – impacts that are predicted to last during the construction period (e.g. 1 to 3 years);
- Long term – impacts that will continue beyond the construction period but will cease in time (e.g. recovery of benthos, vessel movements);
- Temporary – impacts that are predicted to be reversible and will return to a previous state when the impact ceases or after a period of recovery;
- Permanent – impacts that cause a permanent change in the affected receptor or resource that endures substantially beyond the project lifetime;
- Continuous – impacts that occur continuously or frequently; and
- Intermittent – impacts that are occasional or occur only under specific circumstances

Secondly, the importance, value and/or sensitivity of the impacted receptors or sites will be estimated. In the context of physical processes and in this report, the sensitivity of the impacted physical environment will be evaluated in the context of the natural range of variability normally experienced in the parameter of interest. Further assignment of value or significance (e.g. to the consequential impact on ecological or socio-economic receptors) will be subsequently provided by other topic assessments.

Thirdly, the significance of an impact of a given magnitude will be determined on the basis of the magnitude and sensitivity as shown in Figure 6 and as follows:

- Negligible significance. Impacts that are slight or transitory, and those that are within the range of natural environmental variability;
- Minor significance. Impacts of small magnitude and /or associated with low or medium value / sensitivity receptors or sites, or impacts of medium magnitude affecting low value / sensitivity receptors or sites;
- Moderate significance. Impacts of small magnitude, affecting high value / sensitivity receptors or sites, or impacts of medium magnitude affecting medium value / sensitivity receptors or sites, or impacts of large magnitude affecting medium sensitivity receptors or sites; and
- Major significance. Impacts of large magnitude affecting high or medium value / sensitivity receptors or sites, or impacts of medium magnitude affecting high value / sensitivity receptors or sites.

For further use outside of this report, impacts of negligible and minor significance are considered to be not significant in relation to the present EIA regulations.

3. Impact Assessment: Wind Farm Construction and Decommissioning Phases

The full construction stage for the three proposed wind farms will last for the order of five years (approximately 2015 to 2020), however, the time scale for individual tasks within the development causing an impact will be much shorter (order of hours to days). At the time and location of certain installation activities, potential effects may arise through sediment release into the water column and the presence of the installation vessels on site. The following potential impacts are considered:

- Increase in suspended sediment concentrations as a result of foundation installation activities;
- Sediment accumulation and change of sediment type at the seabed as a result of foundation installation activities;
- Increase in suspended sediment concentrations as a result of inter-array cable installation activities; and
- Indentations left on the seabed by jack-up vessels and large anchors.

In this section, the working hypothesis is that effects are short to medium term and localised, representing a temporary and reversible modification to the baseline environment which also does not (significantly) exceed the normal ranges of naturally occurring conditions.

Effects caused by the transmission cable are considered in Section 5.

3.1 Potential Impact: Increase in suspended sediment concentrations as a result of foundation installation activities

The source of this potential impact is sediment released during construction operations, which will settle downwards through the water column at a rate depending upon its grain size. Two sources of sediment resuspension are considered here:

- Overspill of sediment at the water surface from a trailer suction hopper dredger vessel employed to prepare the seabed for the installation of a GBS.
- Drill arisings released at the water surface during drilling operations to facilitate the installation of pin piles for jacket structures.

As well as settling vertically downwards, sediment in suspension will be advected horizontally away from the release point by any currents present and dispersed laterally by turbulent diffusion. The maximum levels of suspended sediment concentration (SSC) are expected to be found near to the source of the sediment plume.

3.1.1 Baseline conditions

The baseline characteristics with regards to sediment mobility and suspended sediment concentrations, as detailed within ABPmer (2011), are summarised within this section. This information is derived from existing literature in addition to the calibrated numerical model and in situ measurements and observations.

Sediment mobility
In comparison to calm periods where tidal currents dominate, the combination of tidal and non-tidal currents and wave induced currents during storms results in considerably higher bed shear stresses. As a result, it is likely that medium-sized sand (250 to 500 µm diameter) is regularly (more than 10 times per year) mobilised across the Zone during storms. Owing to the combination of higher tidal current speeds and moderate water depths, it is likely that the central and north eastern areas of the Zone are most active in this way.

Suspended sediment concentrations
A small proportion of fines are present in the surficial sediments of the region. These will be resuspended into the water column by storm wave action and turbulence, and will persist in suspension for longer than the main medium sand fraction (order of hours to days). Qualitative proxy evidence for this occurring was found where the acoustic backscatter recorded by the acoustic current profiling devices deployed (Partrac, 2010) was consistently elevated (indicative of an increase in turbidity) both during and following storm events, but not in response to semi-diurnal or spring-neap tidal cycles. Levels of SSC in the upper water column (dominated by fine material) cannot be easily quantified using empirical formulae as the proportion of fines in the sediment is low and so there are only limited quantities available for resuspension. Finer material that persists in suspension will be transported in the direction of net tidal residual flow, i.e. south south west or south west into the Moray Firth.

The source of sediment in suspension is primarily the local seabed sediments within one tidal excursion of the location of interest (of the order 3 to 7 km in the eastern part of the Zone).

The grab samples collected within the three proposed wind farms (EMU, 2011) show that the main body of the sediments present comprise medium sands (250 to 500 μm diameter). Applying empirical relationships from Soulsby (1997) for estimating the vertical profile of SSC arising from such sediments under waves, resulting levels will be greatest near to the seabed (order of 100s to 1,000s mg/l in response to annually frequent and more extreme wave events, i.e. around 3 % of the time on average, in discrete events lasting in the order of hours to days), but reducing rapidly with height to low (near background) levels within the order of metres of the seabed.

The estimated values are consistent with the measurements made using optical devices and sediment traps deployed specifically to measure turbidity at the same locations as, and in conjunction with, measurements of waves and currents. These devices were necessarily mounted above the seabed at a height of 0.5 to 1 m, and so do not measure the very highest levels of effect, but did observe levels of SSC up to 100s and low 1000s mg/l. Once resuspended, sediments will be transported a short distance in the direction of ambient currents or locally down-slope under gravity before being redeposited. Due to their relatively high settling rate, individual grains of medium sand will likely only remain in suspension in the order of seconds.

3.1.2 Primary impact assessment

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

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. The plume model is essentially a particle tracking model, where individual particles represent small discrete packages of sediment mass. Multiple particles are released during each time step in the model to represent the overspill of sediment. The many individual particles are moved by advection and dispersion within the model, also settling vertically through the water column, depositing to the seabed and resuspending from the seabed according to the currents present and the physical properties assigned to the particle.

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

Foundations aligned in relation to the tidal axis would have the greatest potential for a higher net effect on SSC to build from consecutive installation events. The presently planned arrangement of the wind farm turbines is for a series of offset rows in either a regular grid or diamond grid pattern. The minimum separation distance between adjacent turbines will be 580 m in the crosswind axis (140°/320°N) and 812 m in the downwind axis (050°/230°N) for a regular gridded layout of 5 MW turbines. It is most realistic that an installation vessel making consecutive installations would do so along one or other of these axes. The spacing in both directions is larger for other turbine ratings and also in the downwind direction for a given turbine rating scenario (including 3.6 MW) if a diamond grid is used. The tidal axis within the

Moray Firth Round 3 Zone is however centred 0°/180°N (±5° and with some degree of tidal rotation during each flood or ebb cycle). Therefore, there is minimal chance that consecutive installations will be tidally aligned and interact in this way for any significant proportion of the tidal cycle.

Sensitive Receptor: Smith Bank
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.

The impact of predicted changes to SSC will also be assessed separately by other EIA topics in relation to other sensitive receptors (e.g. benthic ecology, natural fisheries).

Seabed preparation for GBS
The plume model was used to consider, for each of the three proposed wind farm sites:

- Ten consecutive GBS bed preparation events across a centrally located minor axis row; and
- Ten consecutive GBS bed preparation events along a centrally located major axis row;
- At each foundation location, a conservatively high sediment release rate of 30 kg/s 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 kg/s silt (60 µm) and 15 kg/s clay (2 µm); and
- 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 ~35,000 m^3 in maximum dredger loads of 5,000 m^3).

The time series results were analysed to yield the following:

- An example snapshot of the distribution of SSC around the time of the tenth foundation being installed is shown in Figure 7 – it shows that the signature of all preceding foundation installations is no longer evident;
- The maximum localised increase in SSC is predicted to be 30 to 35 mg/l, depending on the state of the tide and the local water depth at the time and location of the release. These maximum levels of effect are contained within 50 to 100 m of the dredger and only occur during sediment release;
- SSC in the advected main plume (centred along the downstream tidal axis) is reduced to 20 mg/l or less by 500 to 1000 m downstream and to 10 mg/l or less by 2000 to 3000 m downstream;
- The effects described above are only present during and up to 1 hour after the cessation of dredging, after which time SSC is reduced to < 4 mg/l due to dispersion and deposition of sediment to the seabed;
- 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;

- Material deposited to the seabed can be resuspended by stronger currents (> 0.3 to 0.4 m/s) during spring tides, or during storm events, leading to a dispersed low level increase in SSC of 1 to 4 mg/l;
- Material put into suspension by the dredging or by subsequent remobilisation is redeposited to the seabed (resulting SSC <1 mg/l) when current speeds fall below the locally critical value (i.e. typically during neap tides and around slack water periods during spring tides); and
- The dispersed low 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.

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 mg/l near bed and order 10s to 100s mg/l higher in the water column). Local effects around the dredger in the upper and middle parts of the water column may however be potentially in excess of the natural range of variability (a small magnitude of difference, in the order of 10s to 100s mg/l) but will be localised and temporary on short term time scales (order of hours to days).

This impact is therefore of minor significance.

Drilling to facilitate jacket pin pile installation
The plume model was used to consider, for each of the three proposed wind farm sites:

- Ten consecutive GBS bed preparation events across a centrally located minor axis row; and
- Ten consecutive GBS bed preparation events along a centrally located major axis row;
- At each foundation location, a total sediment release rate of 26 kg/s 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 and excavating soil with a bulk density of 2650 kg/m);
- Based on information about subsurface soil composition from the geotechnical survey, the proportional release of different sediment grain size 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;
- 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; and
- 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.

The time series results were analysed to yield the following:

- The maximum localised increase in SSC is predicted to be 30 to 40 mg/l, depending on the state of the tide and the local water depth at the time and location of the release. These maximum levels of effect are contained within 50 to 100 m of the dredger and only occurring during sediment release;
- SSC in the advected main plume (centred along the downstream tidal axis) is reduced to 20 mg/l or less by 500 to 1000 m downstream and to 10 mg/l or less by 2000 to 3000 m downstream;
- The effects described above are only present during and up to 1 hour after the cessation of drilling, after which time, SSC is reduced to < 4 mg/l due to dispersion and deposition to the seabed;
- In principle, the maximum length of the advected main plume is initially 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 drilling (release) event lasts less than one half tidal cycle;
- Fine material deposited to the seabed can be resuspended by stronger currents during spring tides (> 0.3 to 0.4 m/s) or by storm events, leading to a dispersed low level increase in SSC of 1 to 2 mg/l;
- Sands deposited to the seabed will join the naturally present sedimentary environment and pose no further impact if subsequently reworked;
- Resuspended material is mostly redeposited to the seabed (SSC <1 mg/l) when current speeds fall below the locally critical value (i.e. during neap tides and around slack water periods during spring tides); and
- 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.

The equivalent snapshot images of the SSC plume are similar in appearance to that shown previously for dredging in Figure 7.

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 mg/l nearbed and order 10s to 100s mg/l higher in the water column). Local effects around the drilling vessel in the upper and middle parts of the water column may however be potentially in excess of the natural range of variability (a small magnitude of difference, in the order of 10s to 100s mg/l) but will be localised and temporary on short term time scales (order of hours to days).

This impact is therefore of minor significance.

3.1.3 Secondary impact assessment

Given the similarity in physical processes and independence from the total scale of development, the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of each wind farm individually.

This impact is therefore of minor significance.

3.1.4 Sensitivity impact assessment

Given the similarity in physical processes and independence from the total scale of development the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of any given combination of two wind farms.

This impact is therefore of minor significance.

3.1.5 Mitigation

No mitigation is recommended.

3.1.6 Residual impacts

Residual impacts of dredging will be the same as the impacts reported in the 'Impact assessment' sections above.

3.1.7 Other comments

Should the increase in SSC or the location of eventual deposition pose a more significant impact on other sensitive receptors:

- The rate of overspill from dredging and drilling works will be minimised by applying best practice in terms of the methods and vessels employed;
- The drilling scenario tested conservatively assumes that all of the sediment arisings are freely released as an unconsolidated plume at the water surface. The SSC magnitude, extent and duration of the sediment plume could be reduced by capturing drill arisings into a hopper vessel, or by releasing the arisings in bulk or closer to the seabed; and
- In practice, drill arisings from the underlying till sediments (the main source of fine material) will likely take the form of larger still consolidated clasts, depositing more immediately to the seabed and proportionally reducing the resulting levels of SSC.

3.2 Potential Impact: Sediment accumulation and change of sediment type at the seabed as a result of foundation installation activities

The source of this impact is the sediment introduced into the water column, as described in Section 3.1, which settles to the seabed resulting in a spatially varying thickness of sediment accumulation. The thickness of sediment accumulating depends upon the total volume initially released and the rate and extent of dispersion from the source, which is in turn dependant on the grain size, water depth and any currents present. Where the grain size of the re-deposited sediment is significantly different from that of normally present at the seabed surface, the textural properties of the seabed sediments may be changed. The relative change will be in proportion to the thickness of the deposit and the degree of difference in grain size.

3.2.1 Baseline conditions

The baseline characteristics of the sediment transport and morphological regimes, as detailed within ABPmer (2011), are summarised within this section. This information is derived from existing literature in addition to the calibrated numerical model and in-situ measurements and observations.

Water depths
In the absence of tidal influences, water depths within the site naturally vary from approximately 35 to 60 mCD. Tidal water level fluctuations cause local water depths to vary twice daily by between 2 and 4 m, non-tidal influences can account for differences of up to 1 m from the predicted tidal water level (but not necessarily exceeding the astronomical tidal range) and mean sea level rise over the lifetime of the project might account for a further 0.08 to 0.14 m of long term variability.

Bed level change
Naturally occurring changes in seabed level within and adjacent to the application site are associated with:

- Migration of bed ripple features under current, wave or combined wave-current conditions of sufficient magnitude (order 0.01 to 0.10 m bed level change, based on evidence from drop down camera images (EMU, 2011));
- Partial resuspension or fluidisation of the upper seabed during storm events, followed by redeposition and consolidation (up to 0.3 m thickness of seabed was observed to be affected in this way by an approximately 10:1 year return period event from the north east, as inferred from the observed partial burial of equipment during the metocean survey); and
- Local net sediment accumulation or erosion due to spatial gradients and fluctuations in sediment transport rates (potentially highly spatially and temporally variable).

Larger relict seabed bedforms exist as a result of past processes (mainly glacial) and therefore are not maintained by contemporary physical processes. Of particular note are a series of tunnel valleys cut by high pressure flow beneath the former British Ice Sheet, along with glacial moraine ridges deposited between approximately 15,000 to 20,000 years ago. Linear, down-slope channels have been identified along the western margin of the application site which may also be of glacial origin.

Sediment type
On the basis of the drop down camera images (EMU, 2011), the character of the local sediment surface (sediment type or texture) can be either uniform (typically predominantly sandy) or can also be spatially variable (from predominantly sandy to predominantly gravelly) over small length scales (< 1 m). At a larger scale (10's to 100's m), sharp edged sand patches are observed in the geophysical data collected from the site, interspersed between areas of coarser seabed texture.

3.2.2 Primary impact assessment

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 re-suspension over time.

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 previous Section 2.5. The resulting thickness of sediment deposited is calculated as the equivalent sediment volume of particles deposited to the bed per local unit 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.

Sensitive receptors

An accumulation of sediment 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 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.

The impact of the expected sediment accumulation will also be assessed separately by other EIA topics in relation to other sensitive receptors (e.g. benthic ecology, archaeology, navigation).

Seabed preparation for GBS

The sediment plume model was used to consider, for each of the three wind farm sites:

- Ten consecutive GBS bed preparation events across a centrally located minor axis row (details as described in Appendix 3.4 B);
- Ten consecutive GBS bed preparation events along a centrally located major axis row (details as described in Appendix 3.4 B); and
- An instantaneous release of sediment at all foundation locations (development scenario M3-S5-M5), corresponding to the total volume of sediment overspill when installing one foundation (according to the details of release described in previous Appendix 3.4 B).

The resulting spatial patterns of accumulation of fine material (silts and clays from ten foundation installations) are shown in Figure 8.

The results of the ten foundation (time series) scenarios were analysed to yield the following, for fine material:

- 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 8, up to approximately 10 km south of the three proposed wind farms;
- The accumulation area is characterised by deeper water and lower peak current speeds (lower sediment mobility);

- The transport occurs on relatively short time scales (in the order of days to weeks);
- The Figure 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; and
- In the worst case that all fine material released from ten foundations should be very poorly sorted and accumulates in the discrete locations shown in Figure 8, the maximum local accumulation thickness could be 0.5 to 1 mm – in practice such a thickness would not be measurable in the field.

The resulting spatial patterns of accumulation of fine material (silts and clays from ten foundation installations) are shown in Figure 9.

The results of considering a sudden release at all foundation locations in development scenario T3-S5-M5 were analysed to yield the following,

- The only realistic application of these data is to demonstrate that the resulting spatial patterns of deposition in the short term following release are consistent between the scenarios tested irrespective of the programme of operations (following the major or minor axis of the site), the proportion or part of the site (ten foundations or all, southern or northern end), or the state of the tide at the time of release.
- In the unrealistic worst case that all fine material from all 339 foundations in the three proposed wind farms is released on a very short time scale and is very poorly sorted and accumulates only in the two discrete locations shown in (Figure 8 or) Figure 9, the maximum predicted local accumulation thickness is 1.4 mm; in addition,
- The thickness will be less in practice because the fine sediment fractions will be more evenly graded and therefore more evenly dispersed over the area indicated in the Figure; in addition,
- This worst case scenario remains unrealistically conservative because the fines would be subject to continuous erosion and dispersion by storm events during the construction period, dispersing the sediment further as it progressively accumulates.

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.

This impact is therefore of negligible significance.

Drilling to facilitate jacket pin pile installation

The evidence base shows that drilling in well consolidated but originally fine material at the North Hoyle, Lynn and Inner Dowsing Offshore Wind Farms resulted in the majority of drill arisings being large chips and shards that deposited directly to the bed with no measurable effect on SSC. On this basis, no significant effect is expected.

Making the alternative worst case assumption that the material will in this case instead arise as a fluidised mixture of the component grain sizes, the sediment plume model was used to consider, for each of the three sites:

- Ten consecutive Jacket installation events across a centrally located minor axis row (details as described in previous Section 2.5); and
- Ten consecutive Jacket installation events along a centrally located major axis row (details as described in previous Section 2.5).

The resulting spatial patterns of accumulation of fine material (silts and clays) are shown in Figure 10. Patterns are consistent between the jacket scenarios tested and with that observed for GBS bed preparation (Figure 8 and Figure 9), i.e. transport in a south by south westerly direction, accumulating in discrete sink areas outside of the application site boundary.

The results of the ten foundation (time series) scenarios were considered in addition to a desktop analysis of the drilling operation to yield the following, for sand sized material:

- Sands will rapidly deposit to the seabed locally around the point of release;
- Making a worst case assumption all sands (83% of the total volume 424 m^3, i.e. 352 m^3) from each pile installation are deposited within a small area, a conical distribution of sediment with slopes at the angle of repose (32°) would have a maximum thickness in its centre of 5.1 m and an overall diameter of 16.3 m, accumulating at a maximum rate of approximately 0.43 m per hour of drilling. If more evenly distributed over a larger area (e.g. 50 by 50 m, 250 m^2) the average deposition thickness would be relatively smaller (1.4 m in this example, accumulating at a rate of approximately 0.12 m per hour of drilling);
- However it is dispersed, the sediment deposited from each of the four piles (per foundation) may overlap or coalesce in some locations. Due to the separation between piles (equivalent to the jacket base length scale, 60m) is unlikely that this will result in the peak of conical deposits overlapping and therefore the maximum value of 5.1 m being locally exceeded;
- There will be significant spatial variability in the localised thickness of sand deposits depending upon many operational and environmental factors at the time of the operation (including the direction and speed of any currents present, which will vary in time during 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.

And for fine material:

- Fine material will tend to be transported by residual currents and is only predicted to accumulate in measurable thicknesses in the areas shown in Figure 10, i.e. up to approximately 10 km south of the Moray Firth Round 3 Zone,

- The maximum accumulation thickness of fine material as a result of installing ten foundations will be less than 0.5 mm;
- On the basis of Figure 9 and given the approximate similarity in total release volume - in the worst case that all fine material released from all 339 foundations accumulates in the two discrete locations shown in the Figure, the maximum local accumulation thickness will also be less than 1 mm;
- It is more likely that the thickness will be less than this value because the fine sediment fractions will be more evenly graded and therefore more evenly dispersed over the area indicated in the Figure; in addition,
- It is also unlikely that the total thickness will accumulate as the fines would be subject to further erosion and dispersion by storm events during the construction period.

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.

This impact is therefore of minor significance.

3.2.3 Secondary impact assessment

The far field effects assessed above in the primary impact assessment in relation to three wind farms together apply also to each wind farm individually with a magnitude proportional to the total number of foundations installed. Near field effects will be the same as previously assessed.

This impact is therefore of minor significance.

3.2.4 Sensitivity impact assessment

The far field effects assessed above in the primary impact assessment in relation to three wind farms together apply also to any given combination of two wind farms with a magnitude proportional to the total number of foundations installed. Near field effects will be the same as previously assessed.

This impact is therefore of minor significance.

3.2.5 Mitigation

No mitigation is recommended. However, a number of related comments are offered in Section 3.1.7.

3.2.6 Residual impacts

Residual impacts of dredging will be the same as the impacts reported in the 'Impact Assessment' section above.

3.3 Potential Impact: Increase in suspended sediment concentrations as a result of inter-array cable installation activities

Inter-array cables will be buried where seabed conditions allow. Where seabed conditions do not allow for adequate burial, cables may be partially buried or surface laid and protected with other means.

The source of the potential impacts 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 settle and disperse in the manner described previously in Section 3.1.

3.3.1 Baseline conditions

Baseline suspended sediment conditions have previously been described in Section 3.1.1.

3.3.2 Primary impact assessment

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.

The purpose and aim of cable burial is to achieve a certain depth of burial below the seabed surface and also, ideally, an equivalent thickness of actual sediment cover. As such, the machines and methods used in this operation will be designed to retain as much sediment as possible in the trench, reducing the magnitude of any impact outside of the footprint of the trench itself.

Sensitive receptor: Smith Bank
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.

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.

The impact of the expected increase in SSC and sediment accumulation will also be assessed separately by other EIA topics in relation to other sensitive receptors (e.g. benthic ecology, archaeology, navigation).

A study of cabling methods and typical impacts 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 impact 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 impact.

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

In order to quantify the likely estimated levels of effect in the present study, the following assessment presents a worst case scenario for energetic sediment release, expressed per metre of trench length.

- The maximum trench dimensions for all proposed burial methods are 1 m wide x 3 m deep with a 'U' shaped profile = 3 m^3/m sediment disturbance;
- It is assumed that in the worst case, all of the material disturbed will be ejected from the trench = 3 m^3/m sediment release;
- The porosity of the material is conservatively estimated as 20 % void = 2.4 m^3/m sediment release;
- The material is likely a quartz mineral with density 2650 kg/m^3 = 6360 kg/m sediment release;
- 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 11; and
- 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 11.

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.

Surficial seabed sediments are typically sands or gravelly sands within the three proposed wind farms, however, these are generally only present as a relatively thin surface layer (~0.5 m thick). The dominant grain sizes present in these sandy surface sediments are medium sands (250 to 500 μm diameter). In the sandy layers, the fine material content is known to be small (<5 %) and any gravel content will deposit directly to the seabed locally. The settling velocity of such medium sands is approximately 0.05 m/s (using equations from Soulsby, 1997).

Below the sandy veneer are till deposits, characterised as stiff clays with coarse inclusions. It is most likely that this material will arise as large chunks, depositing directly to the seabed locally without remaining in suspension. For the purposes of the present study, a worst case assumption is that all sediments arise as a fully fluidised mixture. The settling velocity of such fine material is approximately 0.0001 m/s (using equations from Soulsby, 1997).

The typical peak tidal current speed is 0.5 m/s on mean spring tides and 0.25 m/s on mean neap tides. The value 0.25 m/s is used here as a condition representative of most normal states of flow during individual tides and over the spring-neap cycle.

These values are applied in Table 11 below to quantify the total effect per metre of trench length dug. The table assumes that the total mass of sediment (6360 kg) is resuspended evenly up to a (variable) ejection height. The time required for sediment to settle (at 0.05 or 0.005 m/s) 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 (in a downstream direction), found as the product of the ambient current speed (0.25 m/s) 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 sediment (0.12 m^3) by the footprint (length scale of the effect x 1 m).

Table 11. Extent and magnitude of effect of open trenching in medium sands (settling velocity 0.05 m/s)

Ejection height (m)	Duration of effect (s)	Length scale of effect (m)	Indicative mean SSC (mg/l)	Average thickness of deposit (m)
1	20	5	2544000	0.4800
5	100	25	101760	0.0960
10	200	50	25440	0.0480
1	20	5	2544000	0.4800

Table 12. Extent and magnitude of effect of open trenching in fine material (settling velocity 0.0001 m/s)

Ejection height (m)	Duration of effect (s)	Length scale of effect (m)	Indicative mean SSC (mg/l)	Average thickness of deposit (m)
1	10000	2500	5088	0.001
5	50000	12500	204	<0.001
10	100000	25000	51	<0.001
25	250000	62500	8	<0.001

The assessment shows that cable burial will lead to:

- Levels of SSC may potentially be elevated above the natural range of variability, but:
  - Only over a small distance or area;
  - Only as a temporary effect and typically lasting only a short time.
- The resulting thickness of deposition may exceed the range of natural variability in seabed level, but:
  - Only over a small distance or area.

A low height of ejection will result in a relatively greater magnitude of increase in SSC and thickness of subsequent deposit, however, the effect will also be relatively shorter in duration and more tightly localised to the source of the effect (horizontally and vertically). Given the aim of cable burial to retain sediment cover, this is the more likely scenario in most sediment types.

Conversely, a greater height of ejection will result in a relatively lesser magnitude of increase in SSC and thickness of subsequent deposit, however, the effect will also be relatively longer in duration and more dispersed from the source of the effect.

An even greater height of ejection (e.g. equivalent to the full water depth) 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 less than 0.015 m.

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.

The effects of cable burial on SSC are of a magnitude potentially in excess of the natural range of variability. However, the effect will be localised and temporary. This is consistent with the evidence base in this regard, as described in Royal Haskoning and BOMEL (2008).

This impact is therefore of minor significance.

3.3.3 Secondary impact assessment

Given the similarity in physical processes and independence from the total scale of development, the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of each wind farm individually.

This impact is therefore of minor significance.

3.3.4 Sensitivity impact assessment

Given the similarity in physical processes and independence from the total scale of development the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of any given combination of two wind farms.

This impact is therefore of minor significance.

3.3.5 Mitigation

No mitigation is recommended.

3.3.6 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

3.4 Potential Impact: Indentations left on the seabed by jack-up vessels and large anchors

The source of this potential impact are the vessels involved in installing turbine 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.

3.4.1 Baseline conditions

Baseline conditions with regards to water depths, sediment transport and morphological regimes (including natural variability in seabed level) are described in a previous section (3.2.1).

Of particular relevance to this assessment, natural spatial variability in water depth within the application site is of the order 35 to 60 m, varying also temporally by 2 to 4 m on hourly timescales due to fluctuations in water level. The consolidated seabed level may vary naturally on similar timescales in the order of centimetres to decimetres, mainly during storm events due to bedform migration and seabed fluidisation / reconsolidation.

3.4.2 Primary impact assessment

Sensitive Receptor: Smith Bank
This impact might potentially affect the form and function of Smith Bank if the disturbance leads to a relatively large change (outside of the range of natural variability) in local or regional water depth, seabed sediment characteristics or sediment transport pathways.

There are no other physical environmental receptors present within the wider study area that are directly sensitive to the deployment of jack-up legs or anchors.

The further impact of the disturbances described will also be assessed separately by other EIA topics in relation to other sensitive receptors (e.g. benthic ecology, archaeology).

Jack-up barge legs

The PDS suggests that the lower end of each jack-up barge leg will end in a spud can with an area of 70 to 100 m^2, equivalent to a footprint of 8.4 to 10 m square or a circular footprint diameter of 9.5 to 11.3 m. Each leg will likely penetrate the seabed by 1 to 4 m, depending on the local ground conditions.

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.

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 12 m diameter depression, a stable slope angle would be achieved when the maximum depth in the centre is 3.74 m below the original seabed level. It is however noted that this is almost equivalent to the expected maximum depth of penetration, suggesting that initial refilling of the depression by avalanching of loose sediment will be minimal.

The scale of the depression left by a single leg soon after extraction is therefore characterised as a 12 m diameter conical pit, between 1 to 3.7 m deep from ambient bed level in the centre depending on the depth of penetration and soil conditions. The pit will possibly also be surrounded by a concentric raised area of seabed. The (positive) volume of sediment remaining above the original bed level will likely be similar to 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.

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 at least the upper 5 m of seabed over much of the area.

Over the short to medium term, the pits will tend to become shallower and less distinct as storm events resuspended the mobile fractions of 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 being transported through the area to accumulate in the pits if they are sufficiently deep to reduce nearbed current speed and/or wave action locally, however, this tendency will decrease rapidly as the pits flatten.

Rates of sediment transport associated with a range of combined wave and current conditions normally present within the site on sub-annual time-scales were estimated using total load relationships in Soulsby (1997) to be in the range 10^{-6} to 10^{-5} $m^3/m/s$. At such relatively low but frequently occurring rates, the total volume of the pits (38 to 141 m^3) would be refilled by ambient sediment transport in the order of 10^3 to $4x10^4$ hours of active transport

(0.1 to 4.6 years. This timescale will be reduced (due to higher transport rates) by additional contributions from 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 0.1 to 5 years following construction.

The effects of jack-up legs are therefore of small magnitude,, have only a localised effect, are temporary on medium term time-scales and do not impact upon the identified sensitive physical environmental receptors beyond the range of natural variability.

This impact is therefore of negligible significance.

Anchors
An array of four to six anchors might be used by some work vessels to hold position and provide stability during operations on-site. 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-scale of the main body of one such anchor is assumed to be in the region of 1.5 to 3 m.

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 impact 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.

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.

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.

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.

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.

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.

The effects of anchors are therefore of small magnitude, have only a localised effect, are temporary on medium term time-scales and do not impact upon the identified sensitive physical environmental receptors beyond the range of natural variability.

This impact is therefore of negligible significance.

3.4.3 Secondary impact assessment

Given the similarity in physical processes and independence from the total scale of development, the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of each wind farm individually.

This impact is therefore of negligible significance.

3.4.4 Sensitivity impact assessment

Given the similarity in physical processes and independence from the total scale of development the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of any given combination of two wind farms.

This impact is therefore of negligible significance.

3.4.5 Mitigation

No mitigation is recommended.

3.4.6 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

4. Impact Assessment: Wind Farm Operational Phase

The operational phase for the proposed wind farm will last, at a minimum, for the duration of the lease (nominally 25 years). During this time, potential effects of the built project may arise through persistent modification of the tidal and wave regimes, resulting from interaction with the structures of the wind farm. This may lead to small magnitude but long term effects on patterns of sediment transport, leading to net morphological change either within the application site extent or in other parts of the Firth. The potential impacts of the proposed wind farm during its operational phase are considered within this section, with reference to the tidal, wave, sedimentological and morphological regimes. The following potential impacts are considered:

- Changes to the tidal regime due to the presence of the wind farm foundations;
- Changes to the wave regime due to the presence of the wind farm foundations;
- Changes to the sediment transport regime due to the presence of the wind farm foundations;
- Introduction of scour effects due to the presence of the wind farm foundations; and
- Introduction of scour effects due to exposure of inter-array cables.

Effects caused by the transmission cable are considered in Section 5.

4.1 Potential Impact: Changes to the tidal regime due to the presence of the wind farm foundations

The source of this potential impact 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.

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.

4.1.1 Baseline conditions

The baseline characteristics of the tidal regime, as detailed within ABPmer (2011), are summarised within this section. This information is derived from existing literature in addition to the calibrated numerical model and in situ measurements.

Tidal water levels

The application site is situated within a meso-tidal setting and is characterised by a mean spring tidal range of just under 3 m and a maximum astronomic range (HAT to LAT) of approximately 4 m.

Tidal currents

Information available on the strength of tidal currents in this region shows that recorded (depth-averaged) peak spring current speeds (ebb and flood) are around 0.5 to 0.6 m/s, with the fastest speeds recorded in the north of the three proposed wind farms due to proximity with the Pentland Firth. Peak flood currents (directed approximately south or south by south west into the Moray Firth) occur approximately 1.5 to 2 hours before high water at Wick; peak ebb currents (directed approximately north or north by north east out of the Moray Firth) occur approximately 4 to 4.5 hours after high water at Wick. The exact phasing on individual tides varies slightly due the higher harmonics affecting tidal water levels in the region (causing consecutive high and low waters to modulate in height and range with a corresponding effect on peak current speed). Residual tidal currents (over a period of days to weeks) are directed south west or south by south west into the Moray Firth.

Non-tidal (surge) effects

Storm surges may cause short term modification to predicted water levels and under an extreme (1 in 50-year return period) storm surge, water levels may be up to 1.25 m above predicted levels, but will not necessarily coincide with a high or low water period.

Both storm waves and storm surges may cause short term modification (enhancement or reduction) to astronomically-driven tidal currents. During extreme storm events of a magnitude likely to occur within the lifetime of the development (1 to 50 year return periods), surge currents are likely to be in the range 0.5 to 1 m/s within the application site, with currents directed approximately south or south west, into the Moray Firth. Currents of this magnitude are greater than that observed during peak spring tidal flows and so may have a strong modifying influence on timescales of hours.

Expected future changes to the baseline

It is generally accepted as probable that relative sea levels will rise in this region during the course of the 21st Century. During the lifetime of the Moray Firth Round 3 Zone such a rise is likely to be limited to approximately 0.08 to 0.14 m (UKCIP, 2009). The tidal range about the new mean water level is not predicted to be measurably affected.

Climate change is therefore not expected to have any measurable effect on the local tidal current regime (currents are largely controlled by the corresponding tidal range) over the lifetime of the proposed development.

Climate change is predicted to cause some variability in the return period frequency of extreme (storm and storm surge) events over the lifetime of the proposed development; however, historical trends have shown that this variability may include both increases and decreases in the magnitude of given return period conditions on decadal timescales. On this basis, the statistically evaluated description of non-tidal effects above is considered appropriate for use over the lifetime of the development.

4.1.2 Primary impact assessment

The presence of the structure foundations has the potential to impact on the tidal regime as flows interact with the structures. The foundation structures have the potential to impact on the following tidal characteristics:

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

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 'with scheme' scenarios. 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.

Sensitive Receptor: Smith Bank
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). This potential impact is considered separately in Section 4.3.

Sensitive Receptor: Other Designated Coastal Locations
The physical characteristics of designated habitats elsewhere in the Moray Firth (identified in Section 2.2) 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.

Sensitive Receptor: Stratification fronts
The location or physical characteristics of frontal systems in the Outer Moray Firth (identified in Figure 2) may be sensitive to persistent changes in water depth and the tidal current regime outside of the baseline range of natural variability.

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

In relation to water levels, the assessment finds that for Jackets:

- Jackets do not affect water levels throughout a mean spring-neap cycle by more than 0.5 mm (i.e. not a measurable effect).

And for GBS:

- The maximum magnitude of effect in any location and at any time during a typical spring-neap tidal cycle is a 1.9 mm difference in instantaneous tidal water levels, associated with a small effect on the phase of the tidal signal locally (i.e. not a measurable effect, see Figure 11);
- The greatest (and maximum) effect 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);
- 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);
- The absolute effect on water levels is smaller in magnitude elsewhere (outside of the application site) and at other times (other than spring tides); and
- Given the similarity in processes, a similar (low) order of effect on non-tidal (surge) water levels is inferred.

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.

The effects of the array 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 impact upon any of the identified sensitive physical environmental receptors beyond the range of natural variability.

This impact is therefore of negligible significance.

Currents
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.

In relation to current speed, the assessment finds that for Jackets:

- Jackets do not affect regional currents throughout a mean spring-neap cycle by more than 0.01 m/s (<2 % of baseline conditions, i.e. not a measurable effect).

And for GBS:

- GBS do not measurably affect tidal currents (by more than 0.01 m/s) during neap tides. The following comments relate only to GBS during spring tidal periods;
- 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 (i.e. due to the phasing difference), the maximum difference in instantaneous current speed is 0.03 m/s and only within a small area of the application site (see Figure 12, differences are more typically 0.02 to 0.01 m/s or less);
- Independent of phasing effects, peak spring flow speed are not decreased by more than 0.01 m/s;
- The extent of the effect is largely contained within the boundary of the wind farm site although a very small magnitude of effect (< 0.01 m/s) 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 phasing; and
- The relative scale, pattern and extent of effect is similar on flood and ebb tides.

In relation to current direction, the assessment finds that:

- There is no measurable effect on instantaneous tidal current direction (i.e. differences are < ±5° for current speeds > 0.1 m/s)) as a result of either the Jacket or GBS scenarios during spring or neap tides.

Foundations aligned in relation to the tidal axis would have the greatest potential for any narrow wake effects from a single turbine to interact with that of a downstream neighbour. The presently planned arrangement of the wind farm turbines is for a series of offset rows in either a regular grid or diamond grid pattern. The minimum separation distance between adjacent turbines will be 580 m in the crosswind axis (140°/320°N) and 812 m in the downwind axis (050°/230°N) for a regular gridded layout of 5 MW turbines. The spacing in both directions is larger for other turbine ratings and also in the downwind direction for a given turbine rating scenario if a diamond grid is used. The tidal axis within the Moray Firth Round 3 Zone is centred on 0°/180°N (±5° and with some degree of tidal rotation during each flood or ebb cycle). Rows and columns formed in the layout will therefore not align with the dominant tidal streams. Where other rows of alignment develop as a result of a diamond grid pattern, they will be much more widely spaced (1000 m or greater). Therefore, there is minimal chance that individual turbines will be tidally aligned and interact in this way for any significant proportion of the tidal cycle.

The consequential impacts and associated significance of these changes to the tidal regime upon sediment transport and morphological receptors are discussed in Section 4.3.

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.

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

This impact is therefore of negligible significance.

4.1.3 Secondary impact assessment

The type and magnitude of effects assessed above in the primary impact assessment in relation to three wind farms together apply also to each wind farm individually with a proportionally smaller extent of effect, i.e. the area of the wind farm being considered.

This impact is therefore of negligible significance.

4.1.4 Sensitivity impact assessment

The type and magnitude of effects assessed above in the primary impact assessment in relation to three wind farms together apply also to any given combination of two wind farms with a proportionally smaller extent of effect, i.e. the area of the wind farms being considered.

This impact is therefore of negligible significance.

4.1.5 Mitigation

No mitigation is recommended.

4.1.6 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

4.2 Potential Impact: Changes to the wave regime due to the presence of the wind farm foundations

The source of this potential impact is the interaction between the wave regime and the foundations of the wind farm infrastructure. This may result in a reduction in wave energy locally that may also extend into the far-field. The effect of a single structure on individual waves is not easily measurable in practice but the total net effect of the array of many structures is generally accepted to be a slight reduction or redirection of wave energy (height and period). Persistent changes to waves may have a net effect over time on net patterns of sediment transport (rates and directions). Therefore, the importance of small changes to instantaneous wave parameters must be evaluated in the context of the wide range of natural temporal variability (and longer term trends) in the wave regime on hourly to decadal timescales.

4.2.1 Baseline conditions

The baseline characteristics of the wave regime, as detailed within ABPmer (2011), are summarised within this section. This information is derived from existing literature in addition to the calibrated numerical model and in situ measurements.

Wave regime
The wave regime in the Outer Moray Firth includes both locally generated wind waves and swell waves generated elsewhere in the North Sea.

Wave time-series data from the Met Office UK Waters and Wave Watch 3 models were used to characterise the long term wave regime for this region. Table 13 provides details of a series of key low-frequency high-energy wave events in the vicinity of the application site. The effect of limited fetch to the site within the Moray Firth is evident. The more detailed wave modelling undertaken further shows that the distribution of wave height during individual events may vary spatially over the extent of the application site; patterns will depend on the wind/wave coming direction and the variable degree of exposure provided by the adjacent coastline. The corresponding effect on the derived longer-term statistics is that relatively higher return period wave heights are found offshore, generally decreasing with distance in to the Firth. The variability in the 1:50 year condition across the site is found to be approximately 1 m across the extent of the Round 3 Zone.

Table 13. Extremes analysis of significant wave height (Hs) for the Moray Firth Round 3 Zone

Sector	Directional Sector (°N)	Return Period - Hs(m)			
		1:1 yr	1:10 yr	1:50 yr	1:100 yr
1	337.5 to 22.5	6.3	7.2	7.6	7.9
2	22.5 to 67.5	6.7	8.0	8.9	9.2
3	67.5 to 112.5	6.7	7.5	8.0	8.2
4	112.5 to 157.5	6.3	7.1	7.6	7.9
5	157.5 to 202.5	4.6	6.0	6.7	7.0
6	202.5 to 247.5	4.9	5.8	6.4	6.6
7	247.5 to 292.5	4.7	5.6	6.2	6.4
8	292.5 to 337.5	4.1	5.0	5.5	5.6
Maximum Hs (m)		6.7	8.0	8.9	9.2

From Table 13 it is apparent that the largest significant wave heights occur from the north east and east (corresponding to the greatest fetch lengths), and range in magnitude from 6.7 m (for a 1 in 1-year return period storm event) to 9.2 m (for a 1:100 year return period storm event).

A table showing the frequency or key statistics of baseline wave conditions at each of the surfing venues in the Moray Firth study area is also provided in Table 14.

Expected future changes to the baseline

Climate change is predicted to cause variability in the inter-annual wave climate over the lifetime of the proposed development (UKCIP, 2009); however, historical trends have shown that this variability may include both increases and decreases in mean storminess on decadal timescales. The magnitude of the predicted effects of climate change on the wave regime and inter-annual and inter-decadal variability elsewhere in UK waters is typically in the order of 5 to 10 %.

4.2.2 Primary impact assessment

The wind farm has the potential to impact on the wave regime as individual waves interact with the foundation structures. The foundation structures have the potential to impact on the following wave characteristics:

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

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.

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 development.

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.

Sensitive Receptor: Smith Bank

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 (the wave regime) 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 impact is considered separately in Section 4.3. 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.

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.

In relation to wave height and period within the application site, the assessment finds that for Jackets:

- Jacket foundations do not measurably affect wave height or period. i.e. the maximum differences in significant wave height are < 0.1 m (1.5 %) and in wave period < 0.1 s (1 to 1.5 %), confined to a small area in the near field. Values are even smaller elsewhere in the near- and far-field.

And for GBS:

- The main effect of the GBS foundations is to reduce the height of waves passing through the application site (see Figure 13 to Figure 17);
- When all 3 sites are present in these configurations the maximum reduction in wave height within the site boundary varies between 0.37 and 1.31 m or 6 to 18 % of the incident wave height for all directions and return periods. The greatest absolute effects are on the largest waves that also pass through the long axis of the three proposed wind farm sites (i.e. from 45 and 90°N). The highest proportional effects are on the largest and smallest waves (i.e. from 315 and 90°N); the smallest proportional effects are on waves from 270°N;
- The area of maximum effect on wave height in every case is relatively small (length scale of order 1 km) and is located where waves have transitioned through the greatest width of the application site in that orientation;
- 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;
- Behind the sites, any near-field 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); and
- The maximum effect on wave period in all cases is approximately 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.

In relation to wave direction, the assessment finds that:

- There is no measurable effect on instantaneous wave direction (i.e. differences are < ±1°) as a result of either the Jacket or GBS scenarios in the near- or far-field.

The consequential impacts and associated significance of these changes to the wave regime upon sediment transport and morphological receptors are discussed in Section 4.3.

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).

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.

Differences in wave climate will not impact directly upon the form or function of Smith Bank.

This impact is therefore of negligible significance.

Sensitive Receptor: Other Designated Coastal Locations

The physical characteristics of designated habitats elsewhere in the Moray Firth (identified in Section 2.2) 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.

In relation to wave height and period outside of the application site extent, the assessment finds that for Jackets:

- Jacket 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.

And for GBS:

- The main effect of the GBS foundations is to reduce the height of waves passing through the application site and to the receptor locations;
- When all three sites are present (development scenarios 4 to 7), in these configurations the maximum magnitude of effect on wave height for groups of designated sites are:
  - East Caithness Cliffs SAC: 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 <0.1 m (1 % of the incident wave condition) for other directions (70.4 % of the time).
  - Moray Firth SAC and Open Coastal Sites: 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 <0.1 m (up to 2 % of the incident wave condition) for other directions (46 % of the time).
  - Inner Moray Firth and Enclosed Water Bodies: <0.05 m (<1 % of the incident wave condition, i.e. no measurable effect) for all wave coming directions.
- Effects are only apparent in locations where waves have previously passed through the application site boundary – 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;

- GBS foundations do not affect wave period by more than 0.1 s (1 to 1.5 %) outside of the application site extent - this is not a measurable effect in practice;
- Beyond the application 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); and
- These residual effects extend in the direction of wave travel (with some lateral spreading).

In relation to wave direction, the assessment finds that:

- There is no measurable effect on instantaneous wave direction (i.e. differences are < ±1°) as a result of either the Jacket or GBS scenarios in the far-field.

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.

The greatest relative and absolute effects will be felt by the East Caithness Cliffs SAC as it is closest to the development 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 development;
- 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.

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

The effects of the three wind farms 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.

This impact is therefore of negligible significance.

Sensitive Receptor: Recreational Surfing Venues

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

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 scenarios 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 are repeated in Table 14 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 is shown below in Table 15 for GBS.

Jackets were found to have no measurable effect (> 0.01 m wave height or > 0.1 s wave period or > 5 ° wave direction) at any surfing location for any of the development scenarios considered.

Table 14. Frequency occurrence of baseline wave conditions at surfing venues in the Moray Firth study area

Surfers Against Sewage (2009) Description	Hs (m)	Tp (s)	Fraserburgh	Lossiemouth	Banff Beach	Sandend	Boyndie Bay	Inverallochy	Ackergill	Sinclairs Bay	Keiss	Freswick Bay	Skirza	Spey Bay	Cullen Bay	Sunnyside Bay	Pennan	Wisemans	Phingask	West Point
Small waves	1	7	47.7	31.0	36.9	36.9	36.1	36.1	29.3	29.3	39.0	43.6	41.2	36.1	60.4	29.3	39.0	43.6	41.2	40.6
Annual mean wave			1.11 m 7.2s	0.74 m 5.9s	0.88 m 6.4s	0.84 m 6.3s	0.87 m 6.4s	1.19 m 7.4s	0.68 m 5.8s	0.75 m 6.0s	0.95 m 6.4s	1.00 m 6.6s	1.02 m 6.7s	0.66 m 5.4s	0.84 m 6.3s	0.87 m 6.3s	0.99 m 6.7s	1.17 m 7.1s	1.16 m 7.2s	1.21 m 7.3s
	2	10	15.2	6.6	14.3	14.3	12.9	12.9	6.4	6.4	8.1	8.6	7.6	12.9	12.3	6.4	8.1	8.6	7.6	8.4
	3	12	5.2	2.3	6.2	6.2	3.1	3.1	2.6	2.6	1.4	1.6	1.3	3.1	0.7	2.6	1.4	1.6	1.3	1.9
	4	14	0.4	0.2	0.1	0.1	0.0	0.0	0.2	0.2	0.2	0.1	0.0	0.0	0.2	0.2	0.2	0.1	0.0	0.2
Large "classic" wave	4	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1:1 extreme wave height			5.01 m	4.01 m	5.39 m	5.14 m	5.20 m	4.37 m	4.41 m	4.75 m	6.01 m	5.25 m	6.31 m	3.29 m	5.05 m	5.34 m	5.35 m	6.52 m	6.57 m	6.51 m

Table 15. Difference in baseline wave conditions at surfing venues in the Moray Firth study area as a result of GBS foundations in three wind farms in the Moray Firth Round 3 Zone .

Surfers Against Sewage (2009) Description	Hs (m)	Tp (s)	Fraserburgh	Lossiemouth	Banff Beach	Sandend	Boyndie Bay	Inverallochy	Ackergill	Sinclairs Bay	Keiss	Freswick Bay	Skirza	Spey Bay	Cullen Bay	Sunnyside Bay	Pennan	Wisemans	Phingask	West Point
Small waves	1	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Annual mean wave			–	-0.03 m -0.1s	-0.01 m 0.0s	-0.01 m 0.0s	-0.01 m 0.0s	–	–	–	-0.01 m 0.0s	-0.01 m 0.0s	-0.01 m 0.0s	-0.02 m 0.0s	-0.02 m 0.0s	-0.02 m 0.0s	–	–	–	–
	2	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	3	12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Large “classic” wave	4	16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1:1 extreme wave height			–	-0.08	-0.05	-0.04	-0.03	–	–	-0.01	-0.01	-0.01	-0.01	-0.01	-0.06	-0.07	–	-0.01	–	-0.01

Note: ‘ – ‘ indicates no change.

The effects of the three proposed wind farms on waves at the surfing venues identified are of a very small magnitude relative to the range of naturally occurring variability and in the context of the particular measures of sensitivity for this receptor.

This impact is therefore of negligible significance.

4.2.3 Secondary impact assessment

The results for Jackets are the same as presented in the Primary Impact Assessment.

For single site GBS development scenarios:

- When only a single site is present (Figure 18 to Figure 20), the maximum reduction in wave height within the site boundary 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 effects are on the largest waves (i.e. from 90°N). The highest proportional effects are on the largest and smallest waves (i.e. from 315 and 90°N); the smallest proportional effects are on waves from 270°N;

- The maximum magnitude of effect on wave height for groups of designated sites are:
    - East Caithness Cliffs SAC: of the order 0.05 to 0.1 m (1 to 2 % of the incident wave condition) for waves from the east or south east (occurring 29 % of the time) and <0.05 m (<1 % of the incident wave condition) for other directions (70.4 % of the time).
    - Moray Firth SAC and Open Coastal Sites: of the order 0.05 to 0.1 m (1 to 2 % of the incident wave condition) for waves from the north, north east or east (54 % of the time) and <0.05 m (<1 % of the incident wave condition) for other directions (46 % of the time).
    - Inner Moray Firth and Enclosed Water Bodies: <0.05 m (<1 % of the incident wave condition, i.e. no measurable effect) for all wave coming directions.

- No measureable effect (> 0.01 m wave height or > 0.1 s wave period or > 5 ° wave direction) at any surfing location.

This impact is therefore of negligible significance.

4.2.4 Sensitivity impact assessment

The type and maximum (near field) magnitude of effects assessed above in the primary and secondary impact assessments also provide the envelope of effect for any given combination of two wind farms with a proportionally different extent of effect, i.e. the area of the wind farms being considered. Far field impacts will be of a proportionally intermediate spatial extent and magnitude.

This impact is therefore of negligible significance.

4.2.5 Mitigation

No mitigation is recommended.

4.2.6 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

4.3 Potential Impact: Changes to the sediment transport regime due to the presence of the wind farm foundations

The source of this potential impact is the interaction between the naturally present metocean regime (waves and currents) and the wind farm foundations. This interaction may result in a reduction in current speed and wave energy, and an increase in levels of turbulence, locally.

The effect on patterns of sediment transport immediately adjacent to individual foundations is to cause scour (considered in Section 4.4). Persistent and more extensive changes to wave and currents may have a net effect over time on net patterns of sediment transport (rates and directions). The sensitivity of these patterns to change will depend upon the relative importance of currents and/or waves, the magnitude and extent of any effect on them (described previously in Sections 4.1 and 4.2), and the degree to which the system is presently in balance (e.g. could a small change reverse the direction of net transport, or, is the present rate and direction of transport essential to the maintenance of a dynamic morphological feature).

There are no physical receptors present within the wider study area that are directly sensitive to a short term difference in the instantaneous rate of sediment transport if the modified condition remains consistent with the baseline range of natural variability. However, the natural morphology and surficial sediment character of Smith Bank or other designated habitats might potentially be modified by a sufficiently large and persistent change in sediment transport patterns.

4.3.1 Baseline conditions

Seabed Sediments

Seabed sediments across the application site generally consist of Holocene gravelly sand and sand; fine (silt and clay sized) particles are largely absent. A modal peak grain size at 430 µm (medium sand) was consistently found across almost all samples. Other grain sizes were also present in variable proportions across the application site, ranging from 27,000 µm (pebble gravel) to 110 µm (very fine sand). The proportion of shell in sediment samples from and nearby to the application site are frequently in excess of 50 % (EMU, 2010, Partrac, 2010; BGS, 1987).

Across much of the application site, surficial sediments are generally thin (~0.5 to 1 m) with the underlying glacial till very close to the surface. This thickness increases to 2 m or more closer to the crest of the Smith Bank (Holmes et al., 2004) in the north western parts of the Zone.

An extensive blanket of Quaternary deposits are present across almost the entire Moray Firth with sediment thicknesses in excess of 100 m commonly observed. Within the application site the Quaternary units are of variable thickness, ranging from <10 m to c. 150 m. These sediments are underlain by a thick unit of firm to very hard Lower Cretaceous clay.

Sediment Transport

The available evidence (described in ABPmer 2011a) suggests that bedload and suspended material is travelling into the Firth from the north, passing along the Caithness coast and towards the Inner Moray Firth. Tidal currents alone are largely incapable of mobilising anything larger than fine-sand sized material within the application site and only during periods of peak flow. As a result, there is only limited net bedload transport of sediment due to tidal currents alone.

The combination of tidal and non-tidal (wave and surge) currents during storms results in considerably higher erosive forces at the bed. As a result, it is likely that medium- sand sized material and finer is regularly mobilised across the application site during storm events. It is likely that the central and southern areas of the application site are most active in this way due to the presence of shallower water depths, increasing the relative exposure to wave conditions.

Sediment transport will only occur in response to ambient tidal currents alone if the current speed is above the critical value to initiate motion. This is approximately 0.45 to 0.50 m/s for medium sands – a condition that is typically only achieved in the application site near to peak current speeds on spring tides. The estimated maximum rate of sediment transport resulting from ambient tidal currents alone (using relationships provided in Soulsby, 1997) is of the order 10^{-6} $m^3/m/s$ in association with peak spring tidal current speeds.

The typical theoretical rates of sediment transport (using relationships provided in Soulsby, 1997) resulting from a range of typical tidal currents (0.1 to 0.5 m/s) in conjunction with typical and extreme wave events (1:1 to 1:50 year conditions) are of the order 10^{-5} $m^3/m/s$ (in association with peak spring tidal current speeds) or 10^{-6} $m^3/m/s$ (in association with weaker tidal current speeds); as such, the effect of the additional wave action is to increase the maximum sediment transport potential by one order of magnitude and to prolong the duration within the tidal cycle during which transport occurs.

Expected future changes to the baseline

Climate change is not expected to have any specific effect on the naturally occurring type or distribution of sediments within the extent of and over the lifetime of the proposed development.

4.3.2 Primary impact assessment

Sensitive Receptor: Smith Bank

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 4..1 that the development causes no measurable change to the speed or directions of tidal currents. It was shown in Section 4.2 that GBS foundations will cause a maximum local reduction in instantaneous significant wave height within the application site boundary of up to 19 % (but more typically 5 to 10 %) and up to only 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 (<1 %) on wave height. Neither GBS nor Jacket foundations will measurably affect wave period or direction.

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 remains available for transport).

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 Sections 3.2, 4.4, 4.5). 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 or reduction in the volume or thickness 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 planned development.

In order to further quantify and understand whether the effect of the wind farm on waves has the potential to affect the regional bed load transport process, the effect upon bed shear stress has been also been assessed. This parameter quantifies the forces acting upon the seabed which have the potential to mobilise sediments. This assessment uses the two years of wave model results (1st January 2007 to 31st December 2008) previously used in Section 4.2. Time series of wave height and period were extracted from the model results and converted (in conjunction with information about the local water depth and seabed conditions) to a corresponding bed shear stress. The data were filtered to identify the percentage of time steps where the bed shear stress exceeded the threshold value for mobility of a range of commonly present sediment grain sizes. This process was undertaken for a baseline scenario and repeated for development scenario T3-S5_M5 with GBS foundations present. The results are shown in Table 16 for a location in the shallowest part of the Moray Firth Round 3 Zone and in Table 17 for the deepest.

Table 16. Frequency of sediment mobility (shallowest part of the Moray Firth Round 3 Zone, 35 m, development scenario T3-S5_M5).

Grain Size (µm)	Baseline (%Time Mobile)	GBS (% Time Mobile)
4000	0	0
2000	0.99	0.65
1000	5.06	3.28
500	9.29	6.67
250	12	8.73
125	13.61	10.21
63	15.83	12.15

Table 17. Frequency of sediment mobility (deepest part of the Moray Firth Round 3 Zone, 60 m, development scenario T3-S5_M5).

Grain Size (µm)	Baseline (%Time Mobile)	GBS (%Time Mobile)
4000	0	0
2000	0	0
1000	1.18	1.16
500	3.03	2.96
250	4.27	4.22
125	5.85	5.47
63	7.2	6.82

The tables indicate that there will be an overall reduction in the proportion of time that different sediment fractions will be mobilised (as a result of the presence of the schemes). This effect is more pronounced in shallower parts of the site but much smaller in deeper parts.

The typical effect of GBS structures in the shallowest parts of the site (also coincident with the majority of the wind farm infrastructure) is to reduce the number of instances of sediment mobility by between 23 to 35 % of baseline values. The typical effect of GBS structures in the deeper parts of the site is to reduce the number of instances of sediment mobility by a much smaller amount between 1 to 6 % of baseline values. However, in both cases those instances affected will likely be those that were previously close to the threshold of having any effect. The overall level of net mobility will be biased towards the smaller number of more extreme events that are shown to still induce mobility in this location. The effect of the development on waves has been shown in Section 4.2 to be spatially variable and so the values shown in the Tables above are considered to represent the outer envelope of effect but an intermediate level of effect is expected elsewhere in the three proposed wind farms.

A corresponding slight decrease in the rate of sediment transport might also be inferred.

The predicted conceptual effect of a reduction in wave height on sediment transport pathways and resulting morphology is that:

- The central part of the site may tend to accumulate sediment at a slightly rate higher than would have otherwise occurred during the operational lifetime of the development; and
- 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 development.

However, as initially stated, the absolute difference in sediment transport attributable to the wind farm is less than the potential for natural variability over the same period.

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

This impact is therefore of negligible significance.

Sensitive Receptor: Designated coastal habitats
It was demonstrated above that there will be no significant effect on sediment transport rates through the application site as a result of the presence of the wind farm. The main effects on tidal currents and waves are generally confined to the application site extent and are of a lower magnitude elsewhere. Therefore, there will therefore be no corresponding effect upon the rate of sediment supply to other parts of the Moray Firth.

The effect of the wind farm array on wave height, period and direction at the location of designated coastal habitats has been considered in Section 5.2.2 and was found to be of negligible significance both in absolute terms and in the context of natural variability. There will therefore be no corresponding effect upon the rates or directions of nearshore sediment transport at these locations.

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

This impact is therefore of negligible significance.

4.3.3 Secondary impact assessment

The type and maximum (near field) magnitude of effects assessed above in the primary impact assessment in relation to three wind farms together apply also to each wind farm individually with a proportionally smaller extent of the effect, i.e. the area of the wind farm being considered. Far field impacts will be of a proportionally smaller spatial extent and smaller magnitude.

This impact is therefore of negligible significance.

4.3.4 Sensitivity impact assessment

The type and maximum (near field) magnitude of effects assessed above in the primary impact assessment in relation to three wind farms together apply also to any given combination of two wind farms with a proportionally smaller extent of effect, i.e. the area of the wind farms being considered. Far field impacts will be of a proportionally smaller spatial extent and smaller magnitude.

This impact is therefore of negligible significance.

4.3.5 Mitigation

No mitigation is recommended.

4.3.6 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

4.4 Potential Impact: Introduction of scour effects due to the presence of the wind farm foundations

The source of this impact 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.

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.

This assessment of scour takes a highly conservative first-order approach only intended for use in relation to EIA and is not intended for engineering design.

4.4.1 Baseline conditions

Scour features of the type being considered here are not present in the baseline environment as a naturally occurring feature. Details have been provided in previous Sections 4.1.1, 4.2.1, 4.3.1 and 3.2.1 for the baseline tidal, wave, sedimentary and morphological environments, respectively.

4.4.2 Primary impact assessment

The PDS (MORL, 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.

Effect of Scour around Unprotected Foundations

Appendix A provides further detail on the scour assessment summarised in this section.

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 18.

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

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

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

Table 18. 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	60m	65m	40 m	60 m	80 m
Equilibrium Scour Depth (m)						
Steady current	9.0	10.8	11.7	2.6	2.6	2.6
Waves	2.0	2.4	2.6	*Insufficient to cause scour*		
Waves and current	3.2	3.8	4.2	2.6	2.6	2.6
Global scour	0.0	0.0	0.0	0.8	0.8	0.8
Scour extent from foundation* (m)	14.4	17.3	18.7	4.2	4.2	4.2
Scour footprint excluding foundation* (m^2)	2,914	4,196	4,925	306	306	306
Structure footprint (m^2)	*1,963*	*2,827*	*3,318*	28	28	28
Scour volume (m^3)	12,136	20,971	26,663	11,107	22,435	37,783
Of which local scour	*12,136*	*20,971*	*26,663*	*324*	*324*	*324*
Of which global scour	*0*	*0*	*0*	*10,783*	*22,110*	*37,459*
* Based upon the scour depth for steady currents. Footprint and volume values per foundation						

Table 19. 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		Tubular Jacket and Pin Piles	
	Lowest Rated Option 65m (any primary assessment scenario)	Highest Rated Option 65m (3 sites @ 7 MW)	Lowest Rated Option 50m (any primary assessment scenario)	Highest Rated Option 65m (7 MW)
Number of foundations	339	214	339	214
Footprint on seabed of all foundations (m^2)	665,625	605,071	9,585	6,051
Proportion of site area (%)	*0.224*	*0.204*	*0.003*	*0.002*
Footprint on seabed of all foundations + scour (m^2)	1,653,516	1,503,090	113,463	71,626
Proportion of site area (%)	*0.557*	*0.506*	*0.038*	*0.024*

Overall, in terms of scour depth the GBS is predicted to cause the largest impact with a maximum equilibrium scour depth of, approximately, 9 to 12 m locally 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 consolidated till surface at approximately 0.5 to 2 m below the seabed is described as layered sandy silty clays of variable density and hardness, and therefore is likely to be generally cohesive, consolidated and largely more resistant to erosion than the non-cohesive (sandy) sediments upon which the predictive formulae are based. The presence of gravel in the upper sandy layers will also likely lead to bed armouring in the scour pit that will restrict the overall depth or rate of scour development.

The extent of scour from the edge of each foundation is also shown in Table 18. 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 turbine locations is approximately 580 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.

The footprint or area of the scour pit (excluding the foundation) is also provided in Table 18, 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 with a scoured volume of 26,663 m^3 per turbine. As already mentioned, this full volume will likely be limited to a depth of 0.5 to 2 m due to the presence of relatively erosion resistant till under the relatively thin upper layers of sandy sediment. The potential placement of scour protection materials as an integral part of the engineering design will also further limit the development of scour where used.

Table 19 summarises the total foundation and scour footprints and as a proportion of the area of the three proposed wind farms. The 3.6 MW layout results in the largest total footprint of scour.

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.

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 or water depths to be exceeded. The effects of scour are limited to only a small proportion of the area of the application site and an even smaller proportion of the area of Smith Bank.

This impact is therefore of minor significance.

Effect of Scour Protection Measures

Protection measures that might be deployed around foundations may take various forms, most likely including:

- Rock dump;
- Gravel filter layers;
- Geo-textiles; or
- Frond mattresses.

Protection measures are used to mitigate the engineering risk to the stability of foundations posed by the removal of underlying sediment support or lateral ground cover. Where used, the measures will prevent scour from developing around the foundation; 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.

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 (MORL, 2011), scour protection will be graded in elevation down to the level of the seabed (or below). The scour protection will only likely pose an obstruction within its own cross section to the flow and until sufficient sediment has accumulated within the scour protection material for onward transport to continue.

Alternatively, local conditions may not be favourable for sediment accumulation. 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 effect on overall rates.

The effects of scour 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 foundation and general area of the scour protection.

This impact is therefore of negligible significance.

4.4.3 Secondary impact assessment

Given the similarity in physical processes and independence from the total scale of development, the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of each wind farm individually.

This impact is therefore of minor to negligible significance.

4.4.4 Sensitivity impact assessment

Given the similarity in physical processes and independence from the total scale of development the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of any given combination of two wind farms.

This impact is therefore of minor to negligible significance.

4.4.5 Mitigation

The above assessments have been based on a 'worst-case' scenario that no scour protection is provided, at least for a sufficiently long time for scour to develop. As a matter of good engineering practice, the development of scour will likely be monitored and the project's detailed design will consider whether scour protection can reasonably be provided to further reduce any unacceptable predicted or actual impacts. 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 above). The design of the scour protection will likely take into account the transition from the scour protection to the natural seabed and the edges can potentially be profiled in some way to reduce secondary scouring (associated with the presence of the scour protection itself). The dimensions of secondary scour will be much smaller than that described in relation to the scour around an unprotected structure.

4.4.6 Residual impacts

Monitoring will not prevent the development of scour ((unless scour protection is consequentially applied) and so the maximum potential impacts are as described in the 'Impact Assessment' sections above.

Secondary scour might develop in association with and scour protection materials used. The extent and volume of secondary scour will depend on the design and scale of protection used but will be of a lesser magnitude than that described in the 'Impact Assessment' sections above.

Where scour protection is used, impacts will be of negligible significance.

4.5 Potential Impact: Introduction of scour effects due to exposure of inter-array cables and cable protection measures

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. Exposure and scour is primarily an engineering risk, often mitigated using cable burial and scour protection.

The inter-array cables will be buried where seabed conditions allow. Where seabed conditions do not allow for adequate burial, cables may be partially buried or surface laid and protected with other means.

The source of the potential impacts considered in this section are the interaction between the naturally present metocean regime (waves and currents) and sections of cable or cable protection measures exposed on the seabed surface during the operational phase of the development.

Exposure of the cable has the potential to cause localised scouring of sediment, leaving a depression and/or a relative change in sediment character that will persist until the cable is either buried or otherwise removed. The extent and depth of scour may vary over time and may be limited under certain physical conditions; however, a conservative approach will be applied to calculating the maximum expected dimensions independent of other factors. 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.

Cables can be buried to reduce the risk of snagging or other direct contact damage and therefore normally present no scour risk. Cable burial may not be possible at the j-tube exits of the foundations, in areas with unsuitable seabed soil conditions, or at crossing points with other cable or pipeline infrastructure. In these situations, scour protection measures are typically used to mitigate the risk of scour and other damage and will largely prevent scour developing. However, the area occupied by the scour protection might also be considered as a modification to the sedimentary environment and may result in localised secondary scour or (depending on the dimensions and orientation) pose an obstacle to local sediment transport pathways.

4.5.1 Baseline conditions

Scour features of the type being considered here are not present in the baseline environment as a naturally occurring feature. Details have been provided in previous Sections 4.1.1, 4.2.1, 4.3.1 and 3.2.1 for the baseline tidal, wave, sedimentary and morphological environments, respectively

4.5.2 Primary impact assessment

Sensitive Receptor: Smith Bank
This impact might potentially affect the form and function of Smith Bank if the disturbance leads to a relatively large change (outside of the range of natural variability) in local or regional water depth, seabed sediment characteristics or sediment transport pathways.

There are no other physical environmental receptors present within the wider study area that are directly sensitive to the deployment of jack-up legs or anchors.

The further impact of the disturbances described will also be assessed separately by other EIA topics in relation to other sensitive receptors (e.g. benthic ecology, archaeology).

Scour Effects

Inter array cables (33 kv) are typically between 0.09 and 0.16 m in diameter and weigh in the range of 18 to 48 kg/m (Royal Haskoning and BOMEL, 2008). Typically only one cable is required to connect two adjacent turbines, however, it is possible that more than one cable (and route) might converge at offshore substations.

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 almost entirely 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.

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 and cables due to sediment accumulation in the depression created, partially burying 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.

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. 0.09 to 0.48 m) and the maximum horizontal extent of any scour effect will be up to fifty times the cable diameter (i.e. 4.5 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.

The effects of scour potentially resulting from the exposure of inter-array cables are considered to be of a small magnitude relative to the range of naturally occurring variability. Effects are also largely localised to the cable route, short term and temporary.

This impact is therefore of negligible significance.

Effect of Scour Protection Measures

Protection measures that might be deployed onto surface laid or otherwise exposed sections of inter-array cable may take various forms, most likely:

- Rock dump; or
- Concrete mattresses.

Protection measures are used to mitigate engineering risks to the cable posed by the removal of underlying sediment support or lateral ground cover. Where used, the measures will prevent scour from 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.

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. The scour protection will only likely pose an obstruction within its own cross section to the flow and until sufficient sediment has accumulated within the scour protection material for onward transport to continue.

Alternatively, conditions may not be favourable for sediment accumulation. 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 effect on overall rates.

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.

This impact is therefore of negligible significance.

4.5.3 Secondary impact assessment

Given the similarity in physical processes and independence from the total scale of development, the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of each wind farm individually.

This impact is therefore of negligible significance.

4.5.4 Sensitivity impact assessment

Given the similarity in physical processes and independence from the total scale of development the effects assessed above in the primary impact assessment in relation to three wind farms together apply also to the case of any given combination of two wind farms.

This impact is therefore of negligible significance.

4.5.5 Mitigation

Where cables can not physically be buried and no scour protection is initially applied, monitoring of scour development will likely, but not necessarily, be undertaken to address any engineering risks.

If no scour protection is initially applied to exposed cable sections and scour development is compromising the safety of the cable (e.g. development of free-spans), then scour protection might be applied.

4.5.6 Residual impacts

Monitoring will not prevent the development of scour and so the maximum potential impacts are as described in the 'Impact Assessment' sections above.

Secondary scour might develop in association with and scour protection materials used. The extent and volume of secondary scour will depend on the design and scale of protection used but will be of an equivalent or smaller order of magnitude than that described in the 'Impact Assessment' sections above.

5. Impact Assessment: Transmission Cable Installation and Operation

The transmission cables will be installed during the construction phase of the development and will be buried where seabed conditions allow. Where seabed conditions do not allow for adequate burial, cables may be partially buried or surface laid and protected with other means.

At the time and location of burial activities, potential effects may arise through the release of sediment into the water column; the time scale of local impacts arising from the installation or decommissioning of buried cables will be short (order of seconds or hours). Longer term impacts might arise if the cable remains or becomes exposed on the seabed surface, or if protection materials are used to cover the cable. Disturbance might be caused to the coastal (littoral) morphology at the landfall location, depending upon the installation methodology used. To address the component aspects of the four installation options, the following potential impacts are considered:

- Increase in suspended sediment concentrations as a result of transmission cable installation activities;
- Introduction of scour effects due to exposure of transmission cables or cable protection measures; and
- Disturbance of coastal morphology at the landfall site.

In this section, the working hypothesis is that effects are short term and/or localised, representing a temporary and reversible modification to the baseline environment which also does not (significantly) exceed the normal ranges of naturally occurring conditions.

5.1 Potential Impact: Increase in suspended sediment concentrations as a result of transmission cable installation activities

The source of this potential impact is sediment resuspended into the lower water column by the machinery used to bury (sections of) the transmission cables. Once resuspended, the sediment will disperse and settle in the manner generally described previously in Sections 3.1 and 3.2.

A study of cabling methods and typical impacts 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 impact 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 impact.

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

5.1.1 Baseline conditions

A review of baseline SSC conditions may be found in Section 3.1.1.

5.1.2 Impact assessment

The purpose and aim of cable burial is to achieve a certain depth of burial below the seabed surface and also, ideally, an equivalent thickness of actual sediment cover. As such, the machines and methods used in this operation will be designed to retain as much sediment as possible in the trench, reducing the magnitude of any impact outside of the footprint of the trench itself.

A study of cabling methods and typical impacts 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 impact 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 impact.

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

An assessment methodology for sediment release resulting from trenching of inter-array cables was described in Section 3.3. Given the similarity in cable diameter and proposed operational methods, the same methodology is applied below for the transmission cable route. The assessment below considers only the worst case of open trenching (a 'V' shaped trench, 3m wide and 3 m deep with full sediment resuspension).

Table 20 to Table 22 below describe the result of trenching along the cable route, which may include a variety of sediment types, including nominally gravelly, sandy and muddy sections.

Table 20. Extent and magnitude of effect of transmission cable trenching in gravels (settling velocity 0.5 m/s)

Ejection height (m)	Duration of effect (s)	Length scale of effect (m)	Indicative mean SSC (mg/l)	Average thickness of deposit (m)
1	2	<1	38,160,000	7.200
5	10	3	1,526,400	1.440
10	20	5	381,600	0.720
25	50	13	61,056	0.288

Table 21. Extent and magnitude of effect of transmission cable trenching in medium sands (settling velocity 0.05 m/s)

Ejection height (m)	Duration of effect (s)	Length scale of effect (m)	Indicative mean SSC (mg/l)	Average thickness of deposit (m)
1	20	5	3,816,000	0.720
5	100	25	152,640	0.144
10	200	50	38,160	0.072
25	500	125	6,106	0.029

Table 22. Extent and magnitude of effect of transmission cable trenching in fine sediments (settling velocity 0.0001 m/s)

Ejection height (m)	Duration of effect (s)	Length scale of effect (m)	Indicative mean SSC (mg/l)	Average thickness of deposit (m)
1	10000	2500	7,632	<0.001
5	50000	12500	305	<0.001
10	100000	25000	76	<0.001
25	250000	62500	12	<0.001

With regards to sands and gravels the assessment shows that cable burial will lead to:

- Levels of SSC elevated above the natural range of variability, but:
  - Only over a small distance or area;
  - Only close to the seabed; and
  - Only as a temporary effect and typically lasting only a short time.
- The resulting thickness of deposition may exceed the range of natural variability in seabed level, but:
  - Only over a small distance or area.

With regards to fine sediments, it is more likely that if resuspension occurs, sediments will disperse throughout much of the water column and, as shown in Table 22, resulting levels of SSC and the thickness of any subsequent deposits would be very small and within the range of natural variability.

Consistent with the findings of Royal Haskoning and BOMEL (2008), locally redeposited sands and gravels will be of the same type as that naturally present and so will not cause any change to the seabed sedimentary character. Where fine material is deposited onto another sediment type in a sufficient thickness, it may temporarily affect sediment character until it is dispersed. Once deposited, all sediment will join the natural sedimentary environment and essentially ceases to present any further effect.

The effects of transmission 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.

This impact is therefore of minor significance.

5.1.3 Mitigation

No mitigation is recommended.

5.1.4 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

5.2 Potential Impact: Increase in suspended sediment concentrations as a result of OSP foundation installation activities

The baseline conditions, impact assessment, mitigation and residual impacts in relation to the installation of a small number of OSP foundations are already accounted for in the assessment provided for wind turbine foundations in Section 3.1.

On this basis, this impact is of minor significance and no mitigation is proposed.

5.3 Potential Impact: Disturbance of coastal morphology at the landfall site

The source of this potential impact is the operational method used to transition the transmission cables from the offshore to the onshore environment. The location identified for the cable landfall at Fraserburgh does not presently have any special designations or protections. Any direct disturbance or impact upon the morphological features of the landfall site during installation or decommissioning should ideally be of a low magnitude, temporary and easily and rapidly absorbed by natural processes, or avoided altogether. Furthermore, any persistent effects of the cables on coastal processes affecting beach morphology during the operational lifetime of the transmission cable infrastructure are considered.

5.3.1 Baseline conditions

A detailed description of environmental baseline conditions at the landfall site may be found in Appendix B.

5.3.2 Impact assessment

A more detailed impact assessment has been undertaken and may be found in Appendix B. The following is a summary of the main findings.

Two methods are being considered to facilitate landfall, namely,

- Open trenching; and
- Horizontal Directional Drilling.

Open Trenching
This technique involves mechanically excavating a trench through the beach and hinterland to the jointing bay. The cable is placed in the trench, which is then backfilled. Open cut trenching can be a fast, economical means of installing cables but the technique poses some difficult engineering challenges in a tidal environment to keep the trench open during tidal inundation. Open cut trenching is invasive and therefore also has the potential to temporarily alter the character of the beach and any hinterland dunes during the installation process.

Excavating a trench across the nearshore and intertidal zone has the potential to impact upon local morphology and sedimentary processes, including the relative bed level, seabed mobility and local longshore sediment transport. Trench excavation would be completed (potentially requiring ongoing excavations to maintain the trench opening and depth during subsequent tidal cycles) before the cable is installed and the trench backfilled. It is possible that the excavation will include both the removal of sand and cutting of rock in places to locate the cable below the minimum expected bed level. Given that operations will likely be undertaken during relatively calm conditions (when longshore transport rates are minimal) and the short duration of activities (expected to be no more than a few days), the only expected impact on coastal processes is likely to be a temporary and localised increase in suspended sediment concentration and the temporary presence of either a trench depression or furrow in the beach. With or without backfilling, a trench in sand will be quickly incorporated back into the natural environment within at most a few tidal inundations. No wider or longer term effect is expected.

To justify the assumption of no potential for long term interaction between open trenched cables and the coastal zone, the cable burial design must meet the following conditions during the expected lifetime of the installation:

- The cable must be suitably deeply buried from onshore to the depth of closure to prevent cable exposure; and
- Any fixed onshore infrastructure is located onshore of the high-water mark, which may move landward due to coastal retreat.

Horizontal Directional Drilling
Once the cable reaches landfall, HDD works can be used to create an underground conduit for the cable between the offshore and onshore parts of the route (MORL, 2011). This method has historically shown to cause minimal direct disturbance to the existing coastline and, if correctly designed, will also not leave any infrastructure exposed in the active parts of the beach (onshore or offshore) and so will not impact upon littoral processes.

To justify the assumption of no potential for interaction between the cables and the coastal zone, the HDD route design must meet the following conditions during the expected lifetime of the installation:

- The seaward exit point of the HDD is located as far offshore as practicable in the area of seabed normally exchanging sediment with the beach on seasonal and inter-annual time scales (the 'depth of closure'););

- The cable is also suitably buried between the seaward exit of the HDD and the depth of closure; and
- The landward exit point of the HDD is located onshore of the high-water mark, which may move landward due to coastal retreat.

The majority of drill arisings will be captured at the onshore end of the HDD route and so will not cause any impacts with regards to water quality during installation.

Generic Aspects/Impacts of Both Methods
A quantitative assessment (based on the sediment types present and the typical intra-annual wave regime at the landfall location, derived from the wave models) indicates that the beach closure depth at the Fraserburgh site is in the order of 11 m. It is conservatively assumed that this depth is relative to the Lowest Astronomical Tidal water level (LAT). It is therefore recommended that the offshore end of the HDD should be located offshore of the present day depth contour specified above. Climate change will lead to mean sea level rise and so will not affect the identified location on the basis of present day bathymetry.

Summary
The following recommendations should therefore be applied to the design of cable landfall operations and infrastructure.

- The design of an open trenching operation should account for the beach closure depth at approximately 11 mLAT, aiming to achieve sufficient burial in this area to avoid subsequent exposure due to naturally occurring seabed level changes (in the order of several meters). The design burial depth should be achieved below the summer seabed level (which is lower than the winter level) in the lower intertidal and subtidal areas, but below the winter seabed level (which is lower than the summer level) in upper intertidal areas.

- The design of a directional drill should account for the beach closure depth at approximately 11 mLAT, aiming to achieve burial in this area, either by the HDD or other means (i.e. other sub-tidal burial methods).

- Any onshore infrastructure (jointing bays, etc) should be sited at least 100 m behind the present day coastline.

- The route chosen through the hinterland dunes should be sensitive (where possible) to the existing morphology. Ideally the route should maximise the use of low lying areas and existing footpaths and un-vegetated areas.

The effects of cable landfall operations are generally of a magnitude consistent with the natural range of variation in beach morphology. The main effects during installation will be localised (order of metres). Effects of open trenching will also be temporary (order of hours to days) in most locations except where dune crests or vegetation are disturbed (order of days to months or years). During the operational phase, provided a sufficient burial depth is achieved and the landward jointing station is located sufficiently far back to account for rollback of the dunes in the lifetime of the installation, the cable landfall will have no further potential to impact on the morphology of the coastline.

This impact is therefore of negligible significance.

5.3.3 Mitigation

No further mitigation is recommended.

5.3.4 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

5.4 Potential Impact: Introduction of scour effects due to exposure of transmission cables and cable protection measures

The source of this potential impact has already been discussed in the context of the inter-array cables in Section 4.5.

5.4.1 Baseline conditions

Baseline conditions have already been discussed in the context of the inter-array cables in Section 4.5.1.

5.4.2 Impact assessment

Sensitive Receptors:
The transmission cable route starts on Smith Bank which is an identified morphological receptor in the present study. Other parts of the route (central parts of the Outer Moray Firth and the seabed adjacent to the landfall sites) are not considered to be sensitive physical environmental receptors.

No other specific sensitive physical receptors have been identified in relation to other sections of the cable route.

Scour Effects
The transmission cable has the same potential to cause a similar magnitude of impact locally as the inter-array cable, as discussed in Section 4.5.

The transmission cable diameter is likely to be different for HVDC (approximately 0.15 m) and HVAC (approximately 0.25 m) options. From Whitehouse (1997), a conservative estimate for all cases (current, wave or combined scour) is that the maximum depth of scour beneath a section of free-spanning cable will be between one and three times the cable diameter (i.e. order of 0.15 to 0.75 m) and the maximum horizontal extent of any scour effect will be up to fifty times the cable diameter (i.e. order of 7.5 to 12.5 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 by predominantly sandy material following recovery of the seabed if self burial of the cable occurs.

The effects of scour potentially resulting from the exposure of transmission cables onto the seabed are considered to be of a small magnitude relative to the range of naturally occurring variability. Effects on morphology or sediment surface texture will be localised to the cable route.

This impact is therefore of negligible significance.

Effect of Cable Protection Measures

Protection measures that might be deployed onto surface laid or otherwise exposed sections of Transmission cable may take various forms, most likely:

- Rock dump; or
- Concrete mattresses.

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.

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. It is considered unlikely that the thickness of the protection will be significantly greater than the diameter of the cable. Therefore, the combined elevation of the cable and protection may be in the order of 0.2 to 0.5 m. The total width of the protection material will be in the order of 2 to 3 m either side of the cable itself.

The slope angle presented by sections of protected cable would be in the order of 5 to 9° 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.

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.

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.

This impact is therefore of negligible significance.

5.4.3 Mitigation

No mitigation is recommended.

5.4.4 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

6. Impact Assessment: Cumulative and In-Combination Effects

The effect of the three proposed wind farms and OfTI Transmission Cable alone has been described in the previous sections. A number of other developments will likely also be constructed during the lifetime of the three proposed wind farms, potentially introducing additional impacts that may combine with the effects of the wind farms, resulting in a greater potential magnitude, duration or extent of impact. This section considers the cumulative and in-combination effects that might foreseeably arise.

Cumulative impacts are those which might arise from multiple offshore wind farms in close proximity. In-combination impacts are those that might occur due to the offshore wind acting in-combination with other (non-windfarm) activities.

The following potential cumulative and in-combination impacts are considered:

- Interaction of sediment plumes;
- Changes to the tidal regime;
- Changes to the wave regime;
- Changes to the sediment transport regime; and
- Scour effects.

6.1 Potential Cumulative Impact: Interaction of sediment plumes

The source of this potential impact has already been discussed in the context of the three proposed wind farms alone in Section 3.1.

This section considers the potential cumulative impact of multiple and simultaneous sources of sediment release due to:

- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm foundation installation (drilling for pin piles or bed preparation for GBS);
- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm inter-array cable burial;
- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm transmission cable burial;
- Oil and gas foundation installation (drilling for pin piles or bed preparation for GBS); and
- SHETL cable burial.

6.1.1 Baseline conditions

Baseline conditions have previously been described in Sections 3.1.1 and 5.1.1 for the wind farm site and transmission cable route.

6.1.2 Impact assessment

Impact assessment has previously been provided for the individual sources of sediment release considered here. The results are summarised below.

- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm foundation installation (drilling for pin piles or bed preparation for GBS, Section 4.3):
    - 30 to 40 mg/l locally (50 to 100 m from the source) during operations;
    - 10 to 20 mg/l up to 1000 m downstream and up to 100 m wide during operations; and
    - <1 to 5 mg/l in other locations or at all locations after 1 hour following cessation of operations.
- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm inter-array and transmission cable burial (Sections 4.2 and 5.4):
    - Potentially high levels of SSC (order 10,000s to 100,000s of mg/l); but
    - Only locally to the route (order 10s of metres); and
    - Only a temporary impact (order of seconds to minutes).
- Oil and gas foundation installation (drilling for pin piles or bed preparation for GBS):
    - Assumed to be similar to Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm foundation installation.
- SHETL cable burial:
    - Assumed to be similar to Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm inter-array and transmission cable burial.

The maximum cumulative result of interaction between sediment plumes is an additive increase in SSC.

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 turbines 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 to the tidal axis, turbine foundations are located a minimum of 580 m (crosswind) or 812 m (downwind) apart so the downstream level of SSC in the sediment plume from the upstream source will have decreased to 20 mg/l or less. At most, this may cause the levels of SSC adjacent to the downstream source to increase from 30 to 40 mg/l, to 50 to 60 mg/l. The SSC level of the more disperse effects (1 to 5 mg/l) outside of the main plume during operations and in the area of plume following cessation of operations are unlikely to be changed as a result of in-combination or cumulative effects.

Foundation installation will 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 10s of metres from each other or from any other operation. Therefore, only the low-magnitude and dispersed effects from dredging or drilling activities (order of 1 to 5 mg/l) have the potential to combine with the higher-level effects of cable burial site (1000s to 10,000s of mg/l). Therefore, there is no potential for (measurable) interaction between cable burial and foundation installation activities.

The cumulative effects of plume interaction from a variety of sources are of a magnitude consistent with the natural range of variability (order 1,000 to 10,000 mg/l nearbed and order 10 to 100 mg/l 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.

The cumulative impact is therefore of minor significance.

6.1.3 Mitigation

No mitigation is recommended.

6.1.4 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

6.2 Potential Cumulative Impact: Sediment accumulation and change of sediment type at the seabed as a result of foundation installation activities

The source of this potential impact has already been discussed in the context of the three proposed wind farms in Section 3.2.

The previous Section 6.1 considers the potential cumulative impact of multiple and simultaneous sources of sediment release due to:

- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm foundation installation (drilling for pin piles or bed preparation for GBS);
- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm inter-array cable burial;
- Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm transmission cable burial;
- Oil and gas foundation installation (drilling for pin piles or bed preparation for GBS); and
- SHETL cable burial.

This section considers the thickness to which various sources of sediment release might accumulate.

6.2.1 Baseline conditions

Baseline conditions have previously been described in Sections 3.1.1 and 5.1.1 for the wind farm site and transmission cable route.

6.2.2 Impact assessment

The thickness of sediment accumulation in relation to inter-array and transmission cable burial was considered in Sections 3.3 and 5.1. These assessments show that although the thickness of accumulation can be significant (order of centimetres to metres), measurable effects are typically confined to within a small distance of the cable burial corridor and will therefore pose minimal potential to interact between routes.

In the event that new oil and gas infrastructure is installed that requires drilling or other ground preparation works, the scale of the operations are likely to be small in relation to that of the wind farm construction. The amount of disturbance from installation of a single large new platform might be considered equivalent to up to four WTG foundations. It is unlikely that more than a few new platforms will be installed in the near vicinity of the wind farms and not all at one time, allowing any effects to disperse. The additional effect of installing one new platform is therefore only around 1.2 % of the total sediment release from the Moray Firth Round 3 Zone (339 turbines) and 0.6 % of that from the Moray Firth Round 3 Zone and the Beatrice Offshore Wind Farm combined (616 turbines), and so represents only a minor potential contribution.

The major sources of relevance to the present study in this regard are from the installation of 616 foundations in the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm (drilling for pin piles or bed preparation for GBS).

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 2. 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.

Sensitive receptors
An accumulation of sediment 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 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.

The impact of the expected sediment accumulation will also be assessed separately by other EIA topics in relation to other sensitive receptors (e.g. benthic ecology, archaeology, navigation).

Seabed preparation for GBS

The sediment plume model was used to consider, for each of the three wind farm sites:

- An instantaneous release of sediment at all foundation locations (MORL development scenario T3-S5-M5 and BOWL 3.6 MW development scenario), corresponding to the total volume of sediment overspill when installing one foundation (according to the details of release described in previous Section 3.1).

The resulting spatial patterns of accumulation of fine material (silts and clays from ten foundation installations) are shown in Figure 26.

The results were analysed further and produced the same results as previously reported in Section 3.1. The maximum thickness of sediment accumulation remains as 1.4 mm, associated with the deposits from the three proposed wind farms. Additional deposits the development of the BOWL site are transported equally far south, but to a location west of the main MORL deposit. This occurs as the two sites are located side by side, rather than in line, in relation to the tidal axis.

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.

The cumulative impact is therefore of minor significance.

6.2.3 Mitigation

No mitigation is recommended.

6.2.4 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

6.3 Potential Cumulative and In-Combination Impact: Changes to the tidal regime

The source of this potential impact has already been discussed in the context of the three proposed wind farms alone in Section 4.1.

This section considers the potential cumulative impact on currents due to the simultaneous presence of:

- Moray Firth Round 3 Zone foundations;
- Beatrice Offshore Wind Farm foundations;
- European Offshore Wind Deployment Centre foundations;
- Forth and Tay wind farm foundations;
- New oil and gas infrastructure (Polly well) in the Beatrice oil field;
- SHETL cable hub; and
- Marine energy developments in the Pentland Firth and Orkney waters.

6.3.1 Baseline conditions

Baseline tidal conditions have previously been described in Section 4.1.1.

6.3.2 Impact assessment

It was previously demonstrated in 4.1 that the effect of the three proposed wind farms alone on tidal currents and water levels is largely confined to within the application site boundary and wholly within one tidal ellipse of the application site boundary. The following infrastructure types will interact with the tidal regime according to the same mechanisms and principals as the previous assessment and are also located (typically many) more than five tidal excursion distances from the three proposed wind farms, so posing no possibility of interacting in terms of effects on tidal currents:

- European Offshore Wind Deployment Centre wind farm foundations;
- Forth and Tay wind farm foundations; and
- Marine energy developments in the Pentland Firth and Orkney waters.

Therefore, no further assessment will be undertaken here with regard to the above developments.

The following infrastructure are potentially to be located within one tidal excursion but are characterised as isolated, relatively small (dimensions in the order of 1 to 10 m), nearbed obstacles:

- New oil and gas infrastructure (Polly well) in the Beatrice oil field; and
- SHETL cable hub

Based on the likely cross-sectional area (approximately equivalent to a full water depth monopile <1 m in diameter), these pose a much lower potential to interact with currents than any one of the 616 individual jacket (or GBS) foundations being assessed in the combined Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm, i.e. contributing much less than 0.1 % to any cumulative effect.

Therefore, no further assessment will be undertaken here with regard to the above developments.

The simultaneous presence of the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm foundations does have the potential to produce a cumulative impact on the tidal regime as flows interact with the structures. Any changes to the tidal regime may have a resultant impact on the sediment regime which is considered further in Section 6.5. The turbine and OSP foundations have the potential to impact on the following tidal characteristics:

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

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 impacts and associated significance of these changes to the tidal regime upon sediment transport and morphological receptors are discussed in Section 6.5.

Sensitive Receptors

There are no physical environmental receptors present within the wider study area that are directly sensitive to differences in the absolute water level or the speed or direction of currents 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). This potential impact is considered separately in Section 6.5.

The physical characteristics of designated habitats elsewhere in the Moray Firth (identified in Section 2.2) 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.

Water levels

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 Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm present, over a representative spring-neap tidal cycle.

A description of this receptor and the impacts resulting from the three proposed wind farms alone were described in Section 4.1. The predicted combined effect of the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm are the same as previously reported with the following differences:

- The maximum magnitude of effect from GBS foundations in any location and at any time during a typical spring-neap tidal cycle is a 2.4 mm difference in instantaneous tidal water levels (see Figure 21) , associated with a small effect on the phase of the tidal signal locally, i.e. not a measurable effect.

The pattern and maximum magnitude of effects are broadly similar to the case of the three proposed wind farms alone (considered in Section 4.1) 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.

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 predicted effect would not be measurable in practice.

The magnitude of the effect of the arrays on water levels 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.

This impact is therefore of negligible significance.

Currents

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.

A description of this receptor and the impacts resulting from the three proposed wind farms alone were described in Section 4.1. The predicted combined effect of the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm are the same as previously reported with the following differences:

- The spatial patterns of effect are different, as shown in Figure 22.
- The areas of effect associated with each site are visibly separate in the Figure, indicating that there is minimal potential for near-field interaction of direct effects on currents.
- Compared directly (i.e. due to the phasing difference), the maximum difference in instantaneous current speed is approximatel 0.03 m/s and only within a small area of the application site (differences in both sites are more typically 0.01 m/s or less). This difference is actually slightly smaller than for the MORL development alone, due to the source of the effect being distributed over a wider area.

The consequential impacts and associated significance of these changes to current speeds upon sediment transport and morphological receptors are discussed in Section 6.5.

Again, the pattern and maximum magnitude of effects are broadly similar to the case of the three proposed wind farms alone (considered in Section 4.1) 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.

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.

This impact is therefore of negligible significance.

6.3.3 Mitigation

No mitigation is recommended.

6.3.4 Residual impacts

Residual impacts are the same as the impacts reported in the 'Impact Assessment' section above.

6.4 Potential Cumulative and In-Combination Impact: Changes to the wave regime

The source of this potential impact has already been discussed in the context of the Moray Firth Round 3 Zone alone in Section 4.2.

This section considers the potential cumulative impact on waves due to the simultaneous presence of:

- Moray Firth Round 3 Zone foundations;
- Beatrice Offshore Wind Farm foundations;
- European Offshore Wind Deployment Centre wind farm foundations;
- Forth and Tay wind farm foundations;
- New oil and gas infrastructure (Polly well) in the Beatrice oil field;
- SHETL cable hub; and
- Marine energy developments in the Pentland Firth and Orkney waters.

6.4.1 Baseline conditions

Baseline wave conditions have previously been described in Section 4.2.1.

6.4.2 Impact assessment

It was previously demonstrated in Section 4.2 that the effect of the three proposed wind farms alone on waves is confined to areas of open sea in the lee of the wind farm outline (relative to the coming direction of the wave condition and taking account of wave spreading). The following infrastructure interact with waves according to the same mechanisms and principals as the previous assessmentbut are also in locations with no open sea fetch to the three wind farms and so pose no possibility of interacting in terms of effects on waves:

- European Offshore Wind Deployment Centre wind farm foundations;
- Forth and Tay wind farm foundations; and
- Marine energy developments in the Pentland Firth and Orkney waters.

Therefore, no further assessment will be undertaken here with regard to the above developments.

The following infrastructure might potentially be located with an open sea fetch to the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm, but are characterised as isolated, relatively small (dimensions in the order of 1 to 10 m), nearbed obstacles:

- New oil and gas infrastructure (Polly well) in the Beatrice oil field; and
- SHETL cable hub.

These physical obstructions are located near to the seabed and so waves will interact with these obstacles only as a small and localised variation in water depth. Firstly, this variation is within the range of depths found within and near to the application site. Secondly, the physical scale of the difference is much less than the length scale of a wave large enough to penetrate to and interact with the seabed (approximately 100 m wave length in 50 m water depth). Both of these reasons mean that the obstacle will be insufficient to cause wave breaking or refraction. Furthermore, these seabed mounted obstacles have no potential to interact directly with waves at or near to the water surface (i.e. no frictional, slamming or reflection effects).

Therefore, no further assessment will be undertaken here with regard to the above developments.

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

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

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.

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.

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.

Sensitive Receptor: Smith Bank

A description of this receptor and the impacts resulting from the three proposed wind farms alone were described in Section 4.2. The predicted combined effect of the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm are the same as previously reported with the following differences:

- The spatial patterns of effect are different - see Figure 23 to Figure 25; the Figures show that
- The maximum reduction in wave height within the site boundary due to GBS foundations varies between 0.40 and 1.52 m (6 to 21 % 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); and
- Reduction within the application site boundary is more typically around half of the maximum effect or less.

The consequential impacts and associated significance of these changes to the wave regime upon sediment transport and morphological receptors are discussed in Section 6.5.

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

Differences in wave climate from GBS nor Jacket schemes will not impact directly upon the form or function of Smith Bank.

This impact is therefore of negligible significance.

Sensitive Receptor: Other Designated Coastal Locations

A description of this receptor and the impacts resulting from the Beatrice Offshore Wind Farm alone were described in Section 4.2. The predicted combined effect of the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm are the same as previously reported with the following differences:

- The maximum magnitude of effect of GBS foundations on wave height for groups of designated sites are:
    - East Caithness Cliffs SAC: 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 <0.1 m (1 % of the incident wave condition) for other directions (29.6 % of the time).
    - Moray Firth SAC and Open Coastal Sites: 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 <0.1 m (up to 2 % of the incident wave condition) for other directions (46 % of the time).
- Inner Moray Firth and Enclosed Water Bodies: <0.05 m (<1 % of the incident wave condition, i.e. no measurable effect) for all wave coming directions.

The effects of the Moray Firth Round 3 Zone and Beatrice Offshore 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 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.

This impact is therefore of negligible significance.

Sensitive Receptor: Recreational Surfing Venues
A description of this receptor and the impacts resulting from the three proposed wind farms alone were described in Section 4.2.

The predicted cumulative effect of the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm Jackets were found to have no effect (>0.01 m wave height or >0.1 s wave period) at any location. The results of the GBS scheme are shown in Table 23.

In summary, the effect of the array on waves in both the near-field and the far-field is within the natural range of variability and would not be measurable in practice at the surfing venues. These site specific effects are also consistent with the more regional description of effects in relation to other near and far-field receptors.

The cumulative effects of the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm on waves at the surfing venues identified are of a very small magnitude relative to the range of naturally occurring variability and in the context of the particular measures of sensitivity for this receptor.

This impact is therefore of negligible significance.

6.4.3 Mitigation

No mitigation is recommended.

6.4.4 Residual impacts

Residual impacts are the same as the impacts reported in the 'Impact Assessment' section above.

Table 23. Difference in baseline wave conditions at surfing venues in the Moray Firth study area as a cumulative result of the Moray Firth Round 3 Zone (development scenario T3-S5-M5) and Beatrice Offshore Wind Farm (3.6MW) GBS schemes.

Surfers Against Sewage (2009) Description	Hs (m)	Tp (s)	Fraserburgh	Lossiemouth	Banff Beach	Sandend	Boyndie Bay	Inverallochy	Ackergill	Sinclairs Bay	Keiss	Freswick Bay	Skirza	Spey Bay	Cullen Bay	Sunnyside Bay	Pennan	Wisemans	Phingask	West Point
Small waves	1	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Annual mean wave			–	- 0.04 m -0.1s	- 0.01 m 0.0s	- 0.01 m 0.0s	–	–	–	–	- 0.01 m 0.0s	- 0.01 m 0.0s	- 0.01 m 0.0s	- 0.03 m -0.1s	- 0.02 m 0.0s	- 0.02 m 0.0s	- 0.01 m 0.0s	–	–	–
	2	10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	3	12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	4	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Large "classic" wave	4	16	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1:1 extreme wave height			–	-0.14	-0.06	-0.06	-0.03	–	–	-0.01	-0.02	-0.01	-0.01	-0.02	-0.09	-0.09	–	-0.01	–	-0.01

Note: ' – ' indicates no change.

6.5 Potential Cumulative and In-Combination Impact: Changes to the Sediment Transport Regime

The source of this potential impact has already been discussed in the context of the three proposed wind farms alone in Section 4.3.

This section considers the potential cumulative impact on patterns of sediment transport due to the simultaneous presence of:

- Moray Firth Round 3 Zone foundations; and
- Beatrice Offshore Wind Farm foundations.

The influence of other developments was scoped out in Sections 6.3.2 and 6.4.2 as they have little or no potential to affect currents and waves in conjunction with the Moray Firth Round 3 Zone and/or Beatrice Offshore Wind Farm.

6.5.1 Baseline conditions

Baseline sediment transport conditions and morphology have previously been described in Section 4.3.1.

6.5.2 Impact assessment

It has been demonstrated in the previous sections (6.3.2 and 6.4.2) that the following developments have no potential to significantly affect currents and waves (respectively), and therefore patterns of sediment transport, in combination with the three proposed wind farms:

- European Offshore Wind Deployment Centre wind farm foundations;
- Forth and Tay wind farm foundations;
- New oil and gas infrastructure (Polly well) in the Beatrice oil field;
- SHETL cable hub; and
- Marine energy developments in the Pentland Firth and Orkney waters.

Therefore, no further assessment will be undertaken here with regard to the above developments.

Sensitive Receptor: Smith Bank
If has been shown in previous sections 6.3.2 and 6.4.2that the combined Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm will have no significant impact upon tidal currents or waves, respectively. 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).

Other sections of this report consider the potential for the construction of the three proposed wind farms to affect the character or abundance of surface sediments (see Sections 3.2, 4.4, 4.5) and this information is used here as an analogy for the likely impact of the Beatrice Offshore Wind Farm. On this basis, 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 planned developments.

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

This impact is therefore of negligible significance.

Sensitive Receptor: Designated coastal habitats
It was demonstrated above that there will be no significant effect on sediment transport rates through the application sites as a result of the presence of the wind farm. The main effects on tidal currents and waves are generally confined to the application site extents and will therefore be of an even lower magnitude elsewhere. Therefore, there will therefore be no corresponding effect upon the rate of sediment supply to other parts of the Moray Firth.

The effect of the wind farm array on wave height, period and direction at the location of designated coastal habitats has been considered in Section 4.2 and was found to be of negligible significance both in absolute terms and in the context of natural variability. There will therefore be no corresponding effect upon the rates or directions of nearshore sediment transport at these locations.

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

This impact is therefore of negligible significance.

6.5.3 Mitigation

No mitigation is recommended.

6.5.4 Residual impacts

Residual impacts will be the same as the impacts reported in the 'Impact Assessment' section above.

6.6 Potential Cumulative and In-Combination Impact: Scour effects

The source of this potential impact has already been discussed in the context of the three proposed wind farms alone in Section 4.4.

This section considers the potential cumulative impact on scour effects due to the simultaneous presence of:

- Moray Firth Round 3 Zone foundations;
- Beatrice Offshore Wind Farm foundations;
- New oil and gas infrastructure (Polly well) in the Beatrice oil field; and
- SHETL cable hub.

Consideration is also given to the potential for cumulative scour effects from exposed inter-array and transmission cables in or from the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm sites.

6.6.1 Baseline conditions

Scour features of the type being considered here are not present in the baseline environment as a naturally occurring feature. Details have been provided in previous sections for the baseline tidal (4.1.1), wave (4.2.1), sedimentary (4.3.1) and morphological (3.2.1) environments.

6.6.2 Impact assessment

The additional effect of new oil and gas infrastructure (Polly well) in the Beatrice oil field and the SHETL cable hub cannot be explicitly predicted without further details regarding their shape and dimensions. However, it is reasonable to assume that the scale of scour effects from these installations will be of the same order (or smaller) as that of a single large GBS (i.e. < 0.15 % of the effect of the combined Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm). The additional effect of these installations is therefore not included in the following assessment.

Appendix A provides further detail on the scour assessment summarised in this section.

An assessment of scour effects relating to the foundation turbines for the three proposed wind farms alone was previously presented in Section 4.4. This section considers the additional cumulative impact of the foundations within the adjacent Beatrice Offshore Wind Farm.

The Moray Firth Round 3 Zone GBS foundations are assumed to have a base diameter of 65 m, but the number of turbines will vary depending upon the power rating. For the purposes of this assessment, it is conservatively assumed that all foundations in the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm site are of the same power rating (3.6MW) and that the Moray Firth Round 3 Zone foundations are confined to the eastern part of the Zone 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 rating (i.e. greatest number of foundations) are installed in both application sites.

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 18. Total effect values are provided in Table 24 for the Moray Firth Round 3 Zone alone and in Table 25 for the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm sites combined.

	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	
	Lowest Rated Option 50m (3.6 MW)	**Highest Rated Option 65m (7 MW)**	**Lowest Rated Option 50m (3.6 MW)**	**Highest Rated Option 65m (7 MW)**
Number of foundations	277	142	277	142
Footprint on seabed of all foundations (m^2)	543,888	471,200	7,832	4,015
Proportion of site area (%)	*0.414*	*0.359*	*0.006*	*0.003*
Footprint on seabed of all foundations + scour (m^2)	1,351,103	1,170,533	92,712	47,527
Proportion of site area (%)	*1.028*	*0.891*	*0.071*	*0.036*

Table 24. Total footprint of the different foundation types with and without scour: 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	
	Lowest Rated Options	**Highest Rated Options**	**Lowest Rated Options**	**Highest Rated Options**
Number of foundations	616	380	616	380
Footprint on seabed of all foundations (m^2)	1,209,513	1,074,425	17,417	10,744
Proportion of total site area (%)	*0.282*	*0.251*	*0.004*	*0.003*
Footprint on seabed of all foundations + scour (m^2)	3,004,619	2,669,038	206,175	127,186
Proportion of total site area (%)	*0.701*	*0.623*	*0.048*	*0.030*

Table 25. Cumulative footprint of different foundation types with and without scour: Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm

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 or water depths to be exceeded. The effects of scour are limited to only a small proportion of the area of the application sites and therefore an even smaller proportion of the area of Smith Bank.

This impact is therefore of minor significance.

Consideration of the scour effects relating to exposure of scour protection associated with inter-array and transmission cables was previously provided in Sections 4.5 and 5.4, respectively. The assessments show that the scour effect of either type of cable infrastructure is very localised (order of metres). Cables are not normally located in such close proximity and so there is therefore no potential for interaction between scour effects. Where cables are exposed within the extent of the foundation scour pit (e.g. at the j-tube exit points), scour effects may be additive in terms of depth, but not in terms of extent as the cable scour effects will be contained within the footprint of the foundation scour pit.

This impact is therefore of negligible significance.

6.6.3 Mitigation

The above assessments have been based on a 'worst-case' scenario that no scour protection is provided, at least for a sufficiently long time for scour to develop. As a matter of good engineering practice, the development of scour will likely be monitored and the project's detailed design will consider whether scour protection can reasonably be provided to further reduce any unacceptable predicted or actual impacts. 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 above). The design of the scour protection will likely take into account the transition from the scour protection to the natural seabed and the edges can potentially be profiled in some way to reduce secondary scouring (associated with the presence of the scour protection itself). The dimensions of secondary scour will be much smaller than that described in relation to the scour around an unprotected structure.

6.6.4 Residual impacts

Monitoring will not prevent the development of scour (unless scour protection is consequentially applied) and so the maximum potential impacts are as described in the 'Impact Assessment' section above.

Secondary scour might develop in association with and scour protection materials used. The extent and volume of secondary scour will depend on the design and scale of protection used but will be of a lesser order of magnitude than that described in the 'Impact Assessment' section above.

Where scour protection is used, the impact will be of negligible significance.

7. Summary of Potential Impacts

Table 26. Summary of the Project Impact Assessment

Effect	Receptor	Pre-mitigation Effect	Mitigation	Post-Mitigation Effect
Construction/Decommissioning				
Increase in suspended sediment concentrations as a result of foundation installation activities	Smith Bank	Minor Significance	None	Minor Significance
Accumulation of sediment and change of sediment type at the seabed as a result of foundation installation activities	Smith Bank	Minor Significance	None	Minor Significance
Increase in suspended sediment concentrations as a result of inter-array cable installation activities	Smith Bank	Minor Significance	None	Minor Significance
Indentations left on the seabed by jack-up vessels and large anchors	Smith Bank	Negligible Significance	None	Negligible Significance
Operation				
Changes to the tidal regime due to the presence of the turbine foundations	Smith Bank	Negligible Significance	None	Negligible Significance
	Designated Coastal Habitats	Negligible Significance	None	Negligible Significance
	Stratification Fronts	Negligible Significance	None	Negligible Significance
Changes to the wave regime due to the presence of the turbine foundations	Smith Bank	Negligible Significance	None	Negligible Significance
	Designated Coastal Habitats	Negligible Significance	None	Negligible Significance
	Recreational Surfing Venues	Negligible Significance	None	Negligible Significance
Changes to the sediment transport regime and geomorphology, due to the presence of the turbine	Smith Bank	Negligible Significance	None	Negligible Significance
	Designated Coastal Habitats	Negligible Significance	None	Negligible Significance
Scour effects due to the presence of the turbine foundations	Smith Bank	Minor Significance	Scour protection	Negligible Significance
Scour effects due to the exposure of inter-array cables and cable protection measures	Smith Bank	Negligible Significance	Scour protection	Negligible Significance

Table 27. Summary of the Offshore Transmission Infrastructure Impact Assessment

Effect	Receptor	Pre-mitigation Effect	Mitigation	Post-Mitigation Effect
Construction/Decommissioning				
Increase in suspended sediment concentrations as a result of export cable installation activities	Smith Bank & cable corridor	Minor Significance	None	Minor Significance
Increase in suspended sediment concentrations as a result of OSP installation activities	Smith Bank	Minor Significance	None	Minor Significance
Disturbance of coastal morphology at the landfall site	Fraserburgh Landfall	Negligible Significance	None	Negligible Significance
Operation				
Scour effects due to exposure of transmission cables and cable protection measures	Smith Bank & cable corridor	Negligible Significance	None	Negligible Significance

Table 28. Summary of the Cumulative Impact Assessment

Effect	MORL Total Project	BOWL (Wind Farm and associated transmission infrastructure)	WDA	Sensitivities for Telford, Stevenson and MacColl, and OfTI	Mitigation
Construction/Decommissioning					
Interaction of sediment plumes	Minor Significance	Minor Significance	No significant additive effect	Not sensitive	Not required
Sediment accumulation and change of sediment type at the seabed	Minor Significance	Minor Significance	No significant additive effect	Not sensitive	Not required
Operation					
Changes to the tidal regime	Negligible Significance	Negligible Significance	No significant additive effect	Not sensitive	Not required
Changes to the wave regime	Negligible Significance	Negligible Significance	No significant additive effect	Not sensitive	Not required
Changes to the Sediment Transport Regime	Negligible Significance	Negligible Significance	No significant additive effect	Not sensitive	Not required
Scour Effects	Minor Significance	Minor Significance	No significant additive effect	Not sensitive	Scour protection

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Appendix A – Assessment of Foundation Scour Potential

A.1 Aim of the Assessment

The purpose of this assessment is to quantify the estimated dimensions of scour and therefore the area of seabed that will altered during the operational phase of the wind farm as a result of the footprint of:

- The wind turbine generator (WTG) and Offshore Substation Platform (OSP) foundations; and
- Sediment scour that may develop adjacent to WTG and OSP foundations (in the absence of any scour protection).

This assessment is undertaken as a desktop exercise, considering the realistic combinations of foundation types, sizes and layouts, with respect to scour. Scour dimensions are evaluated using standard empirical relationships from the literature (as referenced in the following sections), summary engineering design information (from the developers) and the presently available understanding of the baseline metocean and sedimentary environments (ABPmer, 2012). The findings of the present study are also consistent with the evidence base, including industry engineering guidance (e.g. DNV, 2004), and specific research undertaken in relation to scour around offshore wind farm foundations (e.g. HR Wallingford et al., 2008; ABPmer et al., 2010) supported by in-situ observations of scour.

Change to the seabed area in the foundation's footprint (including scour) may be considered as a modification to habitat. The seabed area directly affected by scour may be modified from the baseline (pre-development) or ambient state in several ways, including:

- A different (coarser) surface sediment grain size distribution may develop due to winnowing of finer material by the more energetic flow within the scour pit;
- A different surface character will be present if scour protection (e.g. rip-rap or frond matting) is used;
- Seabed slopes may be locally steeper in the scour pit; and
- Flow speed / turbulence will be locally elevated, on average.

The magnitude of any effect will vary depending upon the foundation type, the local baseline oceanographic and sedimentary environments and the type of scour protection implemented (if needed). In some cases, the modified sediment character within a scour pit may not be so different from the surrounding seabed; however, effects relating to bed slope and elevated flow speed and (near-field) turbulence are still likely to apply. As such, depending upon the sensitivities of the particular ecological receptor, not all scouring effects necessarily correspond to a 'loss' in habitat. No further direct assessment is offered within this document as to the potential impact on sensitive ecological receptors.

A.2 Introduction to Scour

The term scour refers here to the development of pits, troughs or other depressions in the seabed sediments around the base of turbine foundations. Scour is the result of net sediment removal over time due to the complex three-dimensional interaction between the foundation and ambient flows (currents and/or waves). Such interactions result in locally accelerated time mean flow and locally elevated turbulence levels that enhance sediment transport potential in the area of effect. The resulting dimensions of the scour features and their rate of development are, generally, dependent upon the characteristics of the:

- Obstacle (dimensions, shape and orientation);
- Ambient flow (depth, magnitude, orientation and variation including tidal currents, waves, or combined conditions); and
- Seabed sediment (geotextural and geotechnical properties).

Based on the existing literature and evidence base, an equilibrium depth and pattern of scour can be empirically approximated for given combinations of these parameters. Natural variability in the above parameters means that the predicted equilibrium scour condition may also vary over time on, for example, spring-neap, seasonal or annual timescales. The time required for the equilibrium scour condition to initially develop is also dependant on these parameters and may vary from hours to years.

Scour assessment for EIA purposes is considered here for three foundation types: conical gravity base structures (GBS); jackets on pin piles; and a semi-submersible option for OSPs.

The potential concerns under consideration include the seabed area that may become modified from its natural state (potentially impacting sensitive receptors through habitat alteration) and the volume and rate of additional sediment resuspension, as a result of scour.

The assessment presented here is not intended for use in detailed engineering design; however, similar methodologies to those recommended for the design of offshore wind farm foundations (e.g. DNV, 2004) have been used where available and appropriate.

A.3 Assumptions

The following preliminary scour assessment for the three proposed wind farms reports the predicted equilibrium scour depth. It assumes that there are no limits to the scour development by time or the nature of the sedimentary or metocean environments. As such, the results of this study are considered to be conservative and provide an (likely over-) estimation of the maximum potential scour depth. Several factors (discussed in Section A.7) may lead to naturally reduce the equilibrium scour depth, with a corresponding reduction in the area and volumes of effect.

This study makes the basic assumption that the seabed sediments are composed of uniform non-cohesive sediment. This is consistent with the baseline understanding of the Moray Firth in the vicinity of the wind farms (e.g. ABPmer, 2012). Project specific surveys (EMU, 2011) indicate that seabed sediments upon the banks comprise medium to well-sorted medium sands (typically 200 to 400 µm diameter), slightly gravelly sands or gravelly sands that are present in variable thickness across the sites (these surficial sediments are absent or thinner in the shallower parts of the sites but up to 30 m over the underlying glacial till at other locations). Seabed sediments were assessed to be mobile in response to the naturally present wave regime, but not to the tidal regime, except perhaps infrequently during tidal ranges greater than the mean spring condition. Water depths within the array vary from 35 to 60 m and are therefore adopted for all of the structure types being considered.

Scheme, foundation and other details are consistent with the preliminary project design information made available at the time of this assessment by the developers (MORL, 2011, including information provided by BOWL). With regards to the present study, the generalised foundation types are broadly similar between the two wind farm developments. Differences in foundation dimensions are represented in the range of options tested here (the jacket on GBS plinth is considered to have a scour potential equivalent to or less than that of the GBS and the jacket on suction caissons is considered to have a scour potential equivalent to or less than that of the jacket on pin piles). Other differences in the design details are not considered to significantly affect the potential scour risk for EIA purposes.

Reported observations of scour under steady current conditions (e.g. in rivers) generally show that the upstream slope of the depression is typically equal to the angle of internal friction for the exposed sediment (typically 32° from horizontal in sands); the downstream slope is typically less steep. In reversing (tidal) current conditions, both slopes will develop under alternating upstream and downstream forcing and so will tend towards the less steep or an intermediate condition. For the purposes of the present study, the angle of internal friction will be used as the characteristic slope angle.

A.4 Equilibrium Scour Depth, Extent and Volume

In the present study, the maximum equilibrium scour depth (S_e) is defined as the depth of the scour pit adjacent to the structure, below the mean ambient or original seabed level. The value of S_e is typically proportional to the diameter of the structure and so is commonly expressed in units of structure diameter (D).

Scour depth decreases with distance from the edge of the foundation. The scour extent (S_{extent}) is defined as the radial distance from the edge of the structure (and the point of maximum scour depth) to the edge of the scour pit (where the bed level is again equal to the mean ambient or original seabed level). This is calculated on the basis of a linear slope at the angle of internal friction for the sediment, i.e.:

$$S_{\text{extent}} = \frac{S_e}{\tan 32^\circ} \approx S_e \times 1.6 \qquad \text{(Eq. 2.1)}$$

The scour footprint ($S_{footprint}$) is defined as the seabed area affected by scour, excluding the foundation's footprint, i.e.:

$$S_{\text{footprint}} = \pi\left(\frac{S_{extent}}{2}\right)^2 - \pi\left(\frac{D}{2}\right)^2 \qquad \text{(Eq. 2.2)}$$

The scour pit volume is calculated as the volume of an inverted truncated cone described by Equations 2.1 and 2.2 above, accounting for the presence of the foundation but excluding its volume.

A.5 Scour Assessment: Gravity Bases Structures

The outline design of the proposed gravity base foundation is shown in Figure A.1. The foundation is characterised as a round base plate upon which sits a circular cross-section cone, tapering upwards to a monopile-like section in the middle or upper water column. Three WTG GBS base diameters (50, 60 and 65 m) are considered in the present study, representative of the various WTG GBS designs being considered by both the Moray Round 3 Zone and Beatrice Offshore Wind Farm. For the purposes of this EIA, the Moray Round 3 Zone is considering only a 65 m WTG GBS as a worst case scenario.

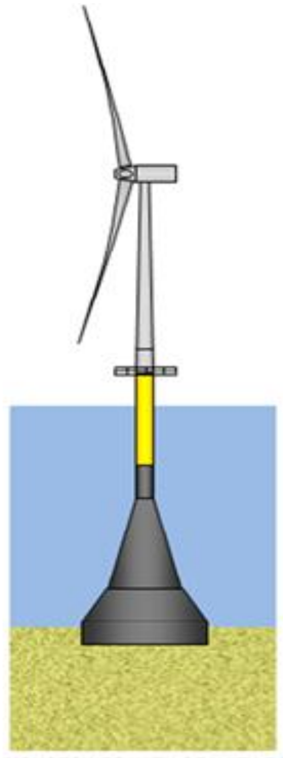

Figure A.1. Outline Design of the Proposed Gravity Base Foundation

The evidence base for scour associated with GBS installations is relatively limited in comparison to that for monopiles and typically refers to oil and gas platforms which have a wide range of shapes and designs. Post-construction monitoring data from the Thornton Bank offshore wind farm (the only site to use GBS foundations so far) is not yet forthcoming in the public domain; however, these GBS structures were installed in conjunction with scour protection measures and so will likely not experience scour. Attempts to produce empirical relationships are complicated by this diversity of 'gravity base' structures.

The pattern and extent of scouring and the location of the point of maximum scouring may also vary depending upon the gravity base's relative size and shape. For the purposes of the present assessment, scour is assumed to be equally present at the predicted depth around the whole perimeter of the GBS, decreasing in depth with distance from the base edge to the ambient bed level at the angle of internal friction for the sediment (32°).

A.5.1 Under steady currents

Relationships for scour associated with a conical top gravity base for currents alone or waves alone are not readily available from the literature. However, Whitehouse (2004) provides relationships for a 'girder top' GBS, predicting equilibrium scour depth due to currents alone of

$$S_e = 0.18D \qquad \text{(Eq. 2.3)}$$

(where D is the base diameter of the GBS). This would yield values of S_e = 9.0 m, 10.8 m and 11.7 m for the 50 m, 60 m and 65 m gravity bases respectively. Whitehouse (2004) concluded that the scour depth was controlled in part by the profile and slope of the conical section of the foundation, which may vary depending upon the final design chosen for the developments.

A.5.2 Under waves and combined wave-current forcing

Relationships for scour associated with a conical top gravity base for waves alone are also not readily available from the literature. However, Whitehouse (2004) also provides a relationship for a 'girder top' GBS, predicting an equilibrium scour depth in response to waves alone of

$$S_e = 0.04D \qquad \text{(Eq. 2.4)}$$

This yields values of S_e = 2.0 m, 2.4 m and 2.6 m for the 50 m, 60 m and 65 m gravity bases, respectively.

Empirical results from physical model testing by Whitehouse (2004) suggest that the maximum scour depth around a conical top gravity base (broadly similar to that proposed here) under combined wave-current conditions will be

$$S_e = 0.064D \qquad \text{(Eq. 2.5)}$$

This yields maximum scour depths of S_e = 3.2 m, 3.8 m and 4.2 m for the 50 m, 60 m and 65 m gravity bases, respectively. This is considered to be a very worst-case scenario and the actual scour depth achieved is likely to be reduced by either the installation of scour protection or the erosion resistant nature of the underlying geology.

A.6 Scour Assessment: Jacket Structures

The outline design of the proposed jacket foundation for WTGs is shown in Figure A.2. Above the seabed the jacket comprises a lattice of vertical primary members and diagonal cross-member bracing, typically 2 m and 1 m in diameter, respectively. It is assumed that any near bed horizontal cross-member bracing is located sufficiently high above the seabed (following the development of global scour) to not cause significant further local scour. The jacket frames supporting wind turbines will have a nominally square plan view cross-section with base dimensions of approximately 40 m, 60 m or 80 m, depending upon the rating of the turbine it is supporting. These are representative of the various WTG GBS designs being considered by both the Moray Round 3 Zone and Beatrice Offshore Wind Farm. For the purposes of this EIA, the Moray Round 3 Zone is considering only a 60 m WTG jacket as a worst case scenario.

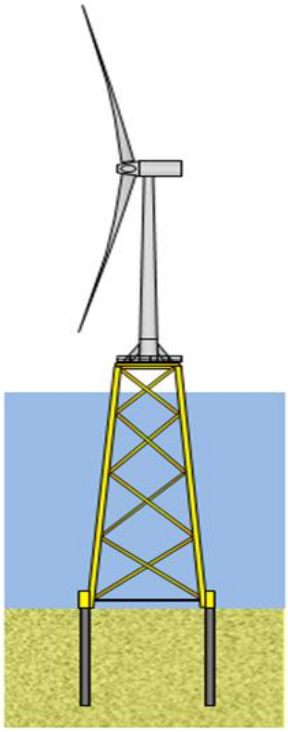

Figure A.2. Outline Design of the Proposed Jacket on Pin Pile Foundation

The jacket frames supporting OSPs will also have a nominally square plan view cross-section with base dimensions of approximately 130 m. This is conservatively representative of the various WTG GBS designs being considered by both the Moray Round 3 Zone and Beatrice Offshore Wind Farm.

Pin piled WTG and OSP options are anchored to the seabed at the end of each primary member by a circular pile, maximum 3 m in diameter and driven up to 60 m into the sediment. The suction caisson option for OSPs anchors the jacket to the seabed at the end of each primary member by a suction caisson (an inverted bucket drawn into the sediment by suction) 20 m in diameter. The suction caissons are essentially flush with the seabed following installation. As such, the suction caisson option provides a scour resistant surface at the seabed surrounding the upright member potentially responsible for scour. Hence, it is assumed that the potential for scour around suction caissons will be less than for the pin piled option and so only the latter is considered further here.

A jacket structure may result in the occurrence of both local and global scour. The local scour is the local response to individual structure members. Global scour refers to a region of shallower but potentially more extensive scour associated with a multi-member foundation resulting from the:

- Change in flow velocity through the gaps between members of the structure; and
- turbulence shed by the entire structure.

Global scour does not imply the presence of continuous scour at the scale of the wind farm array.

A.6.1 Under steady currents

Under currents alone, the equilibrium scour depth around the vertical members of the structure base can be assessed using the same methods as for monopiles, unless significant interaction between individual members occurs. The potential for such interaction is discussed below.

Compared to other more complex foundation types, scour around upright slender monopile structures in steady currents is relatively well understood in the literature and is supported by an empirical evidence base from the laboratory and from the field. Breusers et al. (1977) presented a simple expression for scour depth around monopiles under live-bed scour (i.e. scour occurring in a dynamic sediment environment). This was extended by Sumer et al. (1992) who assessed the statistics of the original data to show that:

$$\frac{S_e}{D} = 1.3 \pm \sigma_{S_e/D} \qquad \text{(Eq. 2.6)}$$

Where $\sigma_{Se/D}$ is the standard deviation of observed S_e/D. Based on the experimental data, □ S_e/D is taken to be 0.7, hence, 95 % of observed scour falls in the range $0 < S_e/D < 2.7$. Based on the central value S_e = 1.3 D (as recommended in DNV, 2004), the maximum equilibrium depth of scour for a 3 m diameter pile end significantly exposed proud of the seabed is estimated to be 3.9 m. Should the 2 m diameter vertical member be the primary cause of scour, the scour depth will be proportionally reduced to 2.6 m.

In the case of currents, inter-member interaction has been shown to be a factor when the gap to pile diameter ratio (G/D) is less than 3. In this case limited experiments by Gormsen and Larson (1984) have shown that the scour depth might increase by between 5 and 15 %. However, in the case of the present study the gap ratio for members at the base of this jacket structure is much greater than 3, and so no significant in-combination effect is expected.

Empirical relationships also presented in Sumer and Fredsøe (2002) indicate that global scour (measured from the initial sediment surface to the new sediment surface surrounding local scour holes) for an array of piles similar to a jacket (2x2) can be approximated as 0.4D (i.e. approximately 1.2 m based on a 3 m corner pile diameter or 0.8 m based on a 2 m primary member diameter).

Together, the predicted maximum scour depth at the corner piles (2.6 to 3.9 m) and global scour (0.8 to 1.2 m) is conservatively consistent with evidence from the field reported in Whitehouse (1998), summarising another report that scour depths of between 0.6 and 3.6 m were observed below jacket structures in the Gulf of Mexico (although these were potentially constrained from the maximum possible scour depth by environmental factors and it was not clear whether this was a total depth, including both local and global scour).

A.6.2 Under waves and combined wave-current forcing

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

$$KC = \frac{U_{0m}T}{D} \quad \text{(Eq. 2.7)}$$

Where U_{0m} is the peak orbital velocity at the seabed and T is the corresponding wave period. Sumer and Fredsøe (2001) found that for $KC < 6$, wave action is insufficient to cause significant scour in both wave alone and combined wave-current scenarios. Values of the KC parameter were calculated for a 1.6 m diameter jacket member or pin pile from the extreme wave conditions for the Moray Firth sites (originally reported in ABPmer, 2012).

Table A.1. Extreme omni-directional wave conditions considered

Return Period (years)	Significant Wave Height (m)	Peak Wave Period (s)
10:1	6.7	8.8
1:1	8.0	9.6
1:10	8.9	10.1
1:50	9.2	10.3

The value of U0m for given (offshore or deep water) wave conditions depends upon the local water depth, which varies from 35 to 60 m within the site; the effects of shoaling and wave breaking have been ignored in the present study (a conservative assumption). Typical values of KC in the deepest parts of the Moray Firth application sites (50+ m) remain below the critical value of 6 under all of the wave conditions shown in Table A.1. However, in the shallowest parts of the site (35 m), the 1 in 10 year return period storm and greater may result in a small additional contribution to scour.

The depth of wave induced S_e can be estimated using the following empirical relationship from Sumer et al. (1992)

$$\frac{S_e}{D} = 1.3\left(1 - e^{-0.03(KC-6)}\right) \qquad \text{for KC} > 6 \qquad \text{(Eq. 2.8)}$$

The resulting equilibrium scour depth is only <0.2 m during the largest wave events and much smaller for others. As such, little or no significant additional scour is predicted to result from waves, either alone or in combination with currents.

A.7 Factors Affecting Equilibrium Scour Depth

The consolidated till surface at approximately 0.5 to 2 m below the sandy seabed surface is described as layered sandy silty clays of variable density and hardness, and therefore is likely to be generally cohesive, consolidated and largely more resistant to erosion than non-cohesive (sandy) sediments. The presence of gravel in the upper sandy layers will also likely lead to bed armouring in the scour pit that will restrict the overall depth or rate of scour development. The depth of scour will likely be limited to the depth of this geological horizon locally, or at least the rate of scour development will be markedly reduced.

The need for scour protection is being considered in conjunction with all foundation types. This will likely be considered locally on the basis of the foundation design (including safety tolerances) and the local surface seabed sediment type (which may be variably more or less susceptible to scour across the Zone). Where scour protection is installed, it is likely that the development of scour associated with the main structure being protected will be minimal. However, the scour protection material itself may constitute a change of seabed type, and may result in a relative change in seabed height (likely above the ambient level), in the area of effect. A smaller depth and extent of (secondary) scour may arise at the edges of the scour protection due to flow interaction with the materials used.

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

- Frequency and magnitude of ambient sediment transport;
- Ratio of structure diameter to water depth;
- Ratio of structure diameter to peak flow speed;
- Ratio of structure diameter to sediment grain size; and
- Sediment grain size, gradation and geotechnical soil properties.

In particular, the relatively benign nature of the tidal regime within the Moray Firth, which limits both the frequency and magnitude of sediment transport, actually maximises the scour that can potentially develop (i.e. corresponding to that provided by the relationships used here), as the scour hole is not simultaneously being (partially) in-filled by ambient sediment transport.

The above factors have been considered in the context of the Moray Firth application sites and were not found to significantly affect the predicted values for EIA purposes. As exemplified above, the effect of these factors where they do apply is to reduce the depth, extent and volume of the predicted scour, hence providing a less conservative estimate.

A.8 Time for Scour to Develop Around the Foundation Options

Using empirical relationships from Whitehouse (1998) and making the assumption of a mobile uniform non-cohesive sediment substrate, the time required for the majority of scour pit development around all foundations is estimated to be within the order of 6 to12 hours under flow conditions sufficient to induce scour. (Near) symmetrical scour will only develop following sufficient exposure to both flood and ebb tidal directions. Waves typically do not cause rapid initial scour directly but can increase the rate of initial scour development.

A.9 Summary of Results

Based on the analysis undertaken above for the three foundation types, Table A.2 summarizes the key results of the first-order scour assessment contained in the preceding sections. Results conservatively assume maximum equilibrium scour depths are symmetrically present around the perimeter of the structure or jacket members in a uniform and frequently mobile sedimentary environment. Derivative calculations of scour extent, footprint and volume assume an angle of internal friction = 32°. Scour extent is measured from the structure's edge. Scour footprint excludes the footprint of the structure. Scour pit volumes for gravity base and jacket on gravity base foundations are calculated as the volume of an inverted truncated cone, minus the structure volume; scour pit volume for the jacket foundations are similarly calculated but as the sum of that predicted for each the corner piles.

Values for single foundations are scaled up in Table A.3 by the anticipated total number in the three proposed wind farms to summarise the total seabed area directly affected by the each foundation type, with and without the presence of scour. Equivalent values for the Beatrice Offshore Wind Farm are given in Table A.4 (assuming all turbines are of the same rating and that the maximum permitted number of turbines are installed in the eastern part of the Zone only). Combined values for the Moray Firth Round 3 Zone and Beatrice Offshore Wind Farm together are shown in Table A.5.

Tables A.3 to A.5 show that scour can significantly contribute to the total footprint of the impact of foundations on the seabed within the site boundary. However, the area of effect as a proportion of the wind farm site(s) as a whole remains relatively small and is a much smaller proportion again of all the available seabed area of this type in the regional area.

Table A.2. 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	**60m**	**65m**	**40 m**	**60 m**	**80 m**
Equilibrium Scour Depth (m)						
Steady current	9.0	10.8	11.7	2.6	2.6	2.6
Waves	2.0	2.4	2.6	*Insufficient to cause scour*		
Waves and current	3.2	3.8	4.2	2.6	2.6	2.6
Global scour	0.0	0.0	0.0	0.8	0.8	0.8
Scour extent from foundation* (m)	14.4	17.3	18.7	4.2	4.2	4.2
Scour footprint excluding foundation* (m^2)	2,914	4,196	4,925	306	306	306
Structure footprint (m^2)	*1,963*	*2,827*	*3,318*	28	28	28
Scour volume (m^3)	12,136	20,971	26,663	11,107	22,435	37,783
Of which local scour	*12,136*	*20,971*	*26,663*	*324*	*324*	*324*
Of which global scour	*0*	*0*	*0*	*10,783*	*22,110*	*37,459*
* Based upon the scour depth for steady currents. Footprint and volume values per foundation						

Table A.3. 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		**Tubular Jacket and Pin Piles**	
	Lowest Rated Option 65m (Development Scenarios 4 to 7)	**Highest Rated Option 65m (3 sites @ 7 MW)**	**Lowest Rated Option 50m (3.6 MW)**	**Highest Rated Option 65m (7 MW)**
Number of foundations	339	214	339	214
Footprint on seabed of all foundations (m^2)	665,625	605,071	9,585	6,051
Proportion of site area (%)	*0.224*	*0.204*	*0.003*	*0.002*
Footprint on seabed of all foundations + scour (m^2)	1,653,516	1,503,090	113,463	71,626
Proportion of site area (%)	*0.557*	*0.506*	*0.038*	*0.024*

Table A.4. 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	
	Lowest Rated Option 50m (3.6 MW)	Highest Rated Option 65m (7 MW)	Lowest Rated Option 50m (3.6 MW)	Highest Rated Option 65m (7 MW)
Number of foundations	277	142	277	142
Footprint on seabed of all foundations (m^2)	543,888	471,200	7,832	4,015
Proportion of site area (%)	*0.414*	*0.359*	*0.006*	*0.003*
Footprint on seabed of all foundations + scour (m^2)	1,351,103	1,170,533	92,712	47,527
Proportion of site area (%)	*1.028*	*0.891*	*0.071*	*0.036*

Table A.5. Total footprint of the different foundation types with and without scour: Moray Firth Round 3 Zone and 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	
	Lowest Rated Options	Highest Rated Options	Lowest Rated Options	Highest Rated Options
Number of foundations	616	380	616	380
Footprint on seabed of all foundations (m^2)	1,209,513	1,074,425	17,417	10,744
Proportion of total site area (%)	*0.282*	*0.251*	*0.004*	*0.003*
Footprint on seabed of all foundations + scour (m^2)	3,004,619	2,669,038	206,175	127,186
Proportion of total site area (%)	*0.701*	*0.623*	*0.048*	*0.030*

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Appendix B – Cable Landfall Impact Assessment

B.1 Introduction

The proposed landfall is located adjacent to the town of Fraserburgh at the south western edge of the Moray Firth (Figure B.1).

This assessment considers two different potential construction methods for the cable, namely:

- Open cut trenching; and
- Horizontal Directional Drilling (HDD).

Prior to detailed design work the full details of each construction method are not known. Therefore the assessment has been completed by applying professional judgment to the likely form of each method as it would be applied at this location.

Each of the proposed construction methods will be evaluated in terms of their potential impacts on the landfall site and the local hydrodynamic and sedimentary regimes. The assessment will consider impacts associated with both the construction and a nominal 50 year operational lifespan.

Having assessed the potential impacts of the cable construction on the natural environment, the risk of future damage to the cable through beach erosion and rising sea levels will also be considered.

This appreciation of the extent of disturbance of natural processes will inform the design of any cable laying works and will consider what mitigation measures may need to be adopted.

B.2 Baseline Characterisation – General Information

The coastline at the landfall site is generally characterised as a shallow gradient sandy beach backed by mature vegetated sandy dunes (see Figures B.1 & B.2). The site is subject to special protection or designation (SSSI, SAC, SPA, RAMSAR, etc).

B.2.1 Dune Processes and Maintenance

Dunes at the back of coastal sandy beaches are normally maintained by the aeolian transport of dry sand from the beach itself. Sand is deposited within the dune system and stabilized by vegetation and the generally lower wind speeds present. Further net landward aeolian transport will cause gradual rollback of the dunes. Erosion will also occur at the seaward foot of the dunes where they are exposed to wave action, up to the point exposed at the highest tides. Removal of sediment volume from this location may destabilize this slope of the dune, leading to avalanching or slumping of sediment, depositing it also into the zone of erosion. This process will continue until a stable slope angle is achieved or the dune retreats beyond or above the zone of erosion. The stability of the dunes and the position of the most seaward dune crest is therefore a net result of the balance between the rates of accretion and erosion.

B.2.2 Sediment Type and Thickness

The beach material in the vicinity of the landfall site is predominantly sandy and so it is likely that the main body of sediments immediately offshore is also predominantly sand of a similar type. In locations near to the cable landfall site, areas of bedrock are visibly exposed in the nearshore, especially around headlands. This suggests that, regionally, the nearshore, beach and dunes are a sandy veneer on a rocky platform. The thickness of the sand veneer is not known in detail but is likely to vary both spatially and temporally due to variations in the relative elevation of the rock horizon and in the distribution of the overlying sand in response to storms and seasonal and other cycles. Measurements of sediment thickness (where they can be practicably made) in the dynamic nearshore and inter-tidal areas will only represent a 'snapshot' in time and will become rapidly out-dated.

As such, should sediment erosion occur either locally or regionally, lowering will be limited to the level of the rock horizon. Apart from limits with regards to water depth, slope stability and the total volumes of sediment available, there is theoretically no limit to the potential thickness to which sediment can accrete.

B.2.3 Sediment Transport

On the beach and nearshore, the highest instantaneous rates of sediment transport will be associated with alongshore transport in the intertidal zone due to occasionally strong wave action. Unless interrupted, this transport will naturally tend to be spatially uniform and balance out over long time periods, having little visible impact on local beach morphology.

Large volumes of sediment volumes can also be transported across-shore (onshore/offshore) by the net effects of a seasonally varying wave climate. The net result of this transport will have a more tangible effect on beach morphology. In coastal processes theory and in practice, the volume and distribution of sediment on an exposed sandy beach and its nearshore zone will vary on seasonal timescales. More energetic wave action during winter months will tend to draw sediment off the beach, steepening it and forming nearshore and offshore bars. The nature, magnitude and rate of the beach response to high energy wave events is generally in proportion to the magnitude of the forcing and so may vary on hourly, daily, inter-annual or decadal timescales. The related processes and features can be dynamic on time scales as short as hours and length scales as short as metres during a single storm event, even responding to the difference in water levels between high and low water periods.

During the more quiescent summer months, sediment will instead be gradually returned to the beach by net shorewards wave induced transport, causing beach widening and offshore bars to lose volume and become less distinct. The response time is longer in this case as the process relies on persistent low energy wave action.

B.3 Baseline Characterisation - Fraserburgh

B.3.1 General Description

This general description has been developed on the basis of ground level and aerial images available from the area (see Figures B.1 & B.2), more detailed descriptions of the beach morphology and processes in Ritchie *et al.* (1979), and more regional scale sediment transport considerations from Ramsay and Brampton (2000a) and Ritchie and Mather (1984).

Fraserburgh Bay is generally characterised as a shallow gradient, broad sandy beach up to 100m wide at low tide) backed by mature vegetated sandy dunes, probably underlain by boulder clay and glacial moraine deposits. The bay is bounded by Fraserburgh port to the east and Cairnbulg Point headland to the west. North of the landfall site are commercial developments protected by rubble mound breakwaters and a port protected by extensive breakwater structures. The dunes in the hinterland of the landfall area in the west of the bay are variable in height (crests typically in the order of 5 m above beach level) and are managed with various developments and footpaths visible (as shown in Figures B.2 to B.5). In the central and eastern parts of the bay (and still within the wider landfall area being considered), dune heights increase to 15m or more and are less visibly developed with less dense networks of footpaths. There is evidence of vegetation management in some areas near to the largest dunes.

North of the landfall site are commercial developments, built on a previously exposed rocky headland and presently protected by rubble mound breakwaters. Further north is a commercial port protected by extensive shear breakwater structures.

Fraserburgh Bay is open to northerly and north westerly sectors but has coastline orientations from north to south and east to west. In the area of the landfall site (on the western side of the bay) the coastline is aligned generally north west to south east. The otherwise rocky coastline in this part of Outer Moray Firth coastline is punctuated by several semi-independent beach units (such as Fraserburgh Bay) within which sediment circulates, but does not regularly exchange with or along the adjacent coastlines. As a result, regional net longshore sediment transport in this cell (3a) is considered to be minimal.

B.3.3 Dune, intertidal and nearshore sedimentary environments

See Section B.2 for general information about the hinterland dunes, beach sediment type and sediment transport.

Specific to this cable landfall site, areas of bedrock are visibly exposed in the nearshore to the western side of the landfall area, adjacent to the rubble mound breakwater protecting commercial developments in Fraserburgh, and around Cairnbulg Point.

The beach in Fraserburgh Bay is visibly narrower at its western end and broader at its eastern end. This would normally suggest that the balance of net transport favours eastwards transport. However, given that the bay is a largely sealed unit with regards to sediment transport, the local orientation of the beach is likely in equilibrium with the dominant wave regime and the sand already present is probably only being re-circulated on a more local basis. Sediment will still experience seasonal cross shore transport but rates of net longshore transport will be quite small.

No evidence was found to suggest that the underlying rocky platform is normally extensively exposed in the nearshore environment in the central parts of the bay and landfall site. It is also unlikely that the underlying rocky platform is normally exposed in the intertidal zone or in the dunes.

The dunes in the hinterland of the landfall area in the west of the bay are relatively lower in height due to previous sand extraction works (now discontinued and variably vegetated). Crest elevation in this area is typically in the order of 5 m above beach level) and are clearly actively managed with various developments (including a golf course), roads and footpaths visible (as shown in Figures B.2 to B.5). In the central and eastern parts of the bay (and still within the wider landfall area being considered), main dune heights increase to 10 or even 15m or more in places and are less visibly developed with less dense networks of footpaths. There is evidence of vegetation management in some areas near to the largest dunes. The inner dunes were also subject to previous sand extraction works (also now discontinued and variably vegetated).

B.3.4 Historic Shoreline Evolution

Repeated aerial photograph surveys (December 2004 and June 2009) are available from Google Earth for the landfall site area (Figures B.3 to B.5). The position of the vegetated dune crests at the back of the beach were identified (also shown in the figures) and compared in order to estimate the rate of dune retreat in this period. Measurements of distance were made using the Google Earth spatial measurement tools.

A direct comparison of the location of permanent footpaths (the esplanade, close to the beach in the centre of the identified potential landfall area) and the coastal defence structures (rubble mound breakwaters) showed that the accuracy of the analysis is in the region of 1 to 2m.

The analysis shows that the vegetated dune crest has retreated between 6 and 8 m in the vicinity of the smaller dunes to the north west of the landfall area. The larger dunes to the south east of the landfall area have retreated a greater distance, between 10 and 15 m. Based on the time interval between the two surveys (4.5 years) this corresponds to rates of retreat in the order of 1.3 to 1.8 m/yr and 2.2 to 3.3 m/yr, respectively (±0.4 m).

It is noted that this analysis is based on a relatively short time interval and so may be skewed by the relative frequency and magnitude of infrequent but extreme events in this period. Despite being frequently used as a recreational area, the longshore uniformity of the measured retreat suggests that it is the result of natural processes and not anthropogenic influences.

B.3.5 Approximation of Beach Closure Depth

The beach profile at a given site is subject to sometimes quite extreme variations (in addition to long term evolutionary trends) in response to wave action as sediment from the upper shore is 'drawn down' the face of the beach. Vertical variations are greatest in the nearshore zone with the envelope of change narrowing in an offshore direction. This zonation has been related to the annual wave climate by Hallermeier (1981), who described the so called 'beach closure depth' as the seaward limit of extreme bottom changes for open coast sandy beaches. The closure depth is defined as:

$H_c = 2.28H_e - 68.5\ (H_e^2/gT_e^2)$

Where

H_e = Annual extreme wave height (10 in 1 year condition) (m)
T_e = Corresponding wave period (s)

Given the generally wide, sandy intertidal and offshore morphology of both MORL landfall locations, the Hallermeier (1981) method was considered generally appropriate for estimating beach closure depth.

Values of H_e and T_e have been derived as 5.31 m and 12.5 s respectively for a location immediately offshore of the cable landfall (in around 15 to 20 m water depth) using the numerical wave model. Using these values in the above equation gives a beach closure depth of 10.9 m. The vertical datum for the beach closure depth is assumed to be the Lowest Astronomical Tide (LAT).

B.5 Description of Methods and Assessment of Potential Impacts of Cable Installation

The methods and potential impacts for both open trenching and HDD are described in more detail below.

B.5.1 Open Cut Trenching

This technique involves mechanically excavating a trench through the beach and hinterland to the jointing bay. The cable is placed in the trench, which is then backfilled. Open cut trenching can be a fast, economical means of installing cables but the technique poses some difficult engineering challenges in a tidal environment to keep the trench open during tidal inundation. Open cut trenching is invasive and therefore also has the potential to temporarily alter the character of the beach and any hinterland dunes during the installation process.

Excavating a trench across the nearshore and intertidal zone has the potential to impact upon local morphology and sedimentary processes, including the relative bed level, seabed mobility and local longshore sediment transport. Trench excavation would be completed (potentially requiring ongoing excavations to maintain the trench opening and depth during subsequent tidal cycles) before the cable is installed and the trench backfilled. It is possible that the excavation will include both the removal of sand and cutting of rock in places to locate the cable below the minimum expected bed level. Given that operations will likely be undertaken during relatively calm conditions (when longshore transport rates are minimal) and the short duration of activities (expected to be no more than a few days), the only expected impact on coastal processes is likely to be a temporary and localised increase in suspended sediment concentration and the temporary presence of either a trench depression or furrow in the beach. With or without backfilling, a trench in sand will be quickly incorporated back into the natural environment within at most a few tidal inundations. No wider or longer term effect is expected.

The potential for damage to the existing intertidal and subtidal beach features is proportional to the duration of the installation operation. The trench will be backfilled immediately after the cable is laid and the beach locally re-profiled accordingly. The trenching operation is unlikely to last longer than a few days. Consequently, the potential for damage to intertidal and subtidal features, assuming burial depth is reached, is considered to be negligible.

The potential impacts that might arise should the cable become exposed post-burial is described in the following section (B.5.2).

Excavating a trench across any hinterland dunes present also has the potential to impact upon local morphology and sedimentary processes. Cutting a trench through dry sand will require a significant width and depth of disturbance, proportional to the planned burial depth. Where the route transects the crest or flanks of a dune, this will likely result in a displacement of sediment by avalanching, which may take significant time to recover (proportional to the local rates of net sediment accumulation). Similar procedures in the saddles (low points) between dunes will not cause the same effect as the dry sand will have little or no structural memory. Where the route transects areas of stabilising vegetation, the vegetation will likely be removed or disturbed by the operation, reducing its capacity to stabilise the dune itself. Similar procedures in areas of no vegetation will not have any further negative impact. Ideally therefore, the chosen route through the dunes should target low lying areas, preferably without extensive or mature vegetation, e.g. existing footpaths and access routes. Replanting of any damaged vegetation following burial would mitigate many of the remaining residual effect.

During its operational phase, the cable will be buried. As there will be no surface evidence of the cable either on the beach or in the intertidal zone, there will be no further impacts during the operational lifetime of the scheme. The depth of burial will be designed to prevent cable exposure of the cable during this time.

B.5.2 Horizontal Directional Drilling

HDD permits the installation of a cable underneath the beach without disturbing the surface sediments. A small diameter pilot hole is drilled to a predetermined path from a landbased drilling point. The pilot string is drilled a short distance before the washover pipe is inserted. Alternate pilot string and drilling operations are then carried out until the exit point is reached. Considerable control is possible over the drilled route allowing the avoidance of sensitive areas.

The potential impacts of this cable installation method on coastal processes are limited. There will be no anticipated changes to waves, currents, seabed mobility or sediment transport, other than slightly elevated levels of suspended sediment at the drill exit site. Any sediments released into the water column will be of a small volume and quickly redistributed to trace levels across the intertidal area. In order to ensure the least amount of disturbance, the HDD will be started on land and extended out seawards towards (but not necessarily as far as) the beach closure depth where active beach processes are of a lower magnitude and less important in controlling onshore beach morphology. This will reduce impacts on the local hydrodynamic or sedimentary regime associated with the operational lifespan of the cabling method.

This method of construction will have no direct impact on the beach and dunes as the cable will pass under them. The HDD will commence adjacent to the onshore jointing bay and the cable will emerge seawards of the main active part of the beach. On the basis of the depth of beach closure calculations, the seabed material may be actively mobile with regards seasonal cross shore transport out to the 11 mLAT depth contour (with activity decreasing in proportion to the depth). It is not however necessary for the exit point to be located beyond the depth of closure, provided that the cable is buried to the depth of closure using other means, to a suitable depth to avoid surface exposure. The potential impacts that might arise should the cable become exposed is described in the following section (B.5.2).

The only potential impacts that may then arise, relate to the exit point and to the transportation of plant/equipment across the beach and intertidal zone if this is required (though this may not be necessary). Any damage to the beach will be both actively and naturally repaired following construction and as such, any impacts arising from the construction will be both temporary and localised, as the drilling operation will be completed within a relatively short time and recovery rates are expected to be fast.

B.5.2 Other Generic Impacts

The planned cable route will approach the landfall site perpendicular to the shore and therefore also perpendicular to the main directions of longshore sediment transport. Should the cable become exposed, e.g. due to seasonal bed lowering, the cable diameter of the cable is small (order less than 0.3 m) and the length exposed will not likely be great, so that the barrier presented by it will not likely affect the total transport rates along the beach. However, where cables are initially or partially exposed, scour may occur, growing and maintaining an open depression within which the cable may tend to remain exposed, which is undesirable for many reasons (e.g. Wavehubwavehub export cables becoming exposed on Hayle Beach, Cornwall due to seabed lowering in November 2011, See Figure B.6, [http://www.bbc.co.uk/news/uk-england-cornwall-15540281]).

Provided that the cable is adequately buried, its exposure of the cable in this manner will not arise. Should the cable become exposed irrespective of design, the impact on the physical environment will likely be in the form of a local scour pit (order of metres to each side of the exposed section length). This is unlikely to have any impacts on regional scale coastal process or morphology but may have some local impacts on immediately adjacent dunes.

B.5.3 Potential Damage to the Cable Landfall as a Result of Coastal Erosion and Seabed Mobility

In addition to the potential impacts of the cable installation on the natural environment and on the designated features, it is also necessary to consider whether the evolving coast could cause damage to the cable either in the short term or during the 50 year operational period. This assessment will also provide information as to a suitable location for any onshore infrastructure that will not necessitate the construction of hard defences at any point in the future.

Based on the assessments of coastal processes and historic shoreline evolution, it is evident that the proposed landfall site is eroding coastlines with an average shoreline recession rate of approximately 3 m/yr or less at Fraserburgh. The main risks to the landfall site are:

- Reduced sediment supply;
- Accelerated sea level rise; and
- Increased wave attack.

Assuming that the beach and dunes will continue to roll back slowly in response to storm events and sea level rise at similar average rates to those above, the total landward recession over the proposed 50 year scheme lifetime is extrapolated to be around 50 m or less at Fraserburgh. However, this does not take into account the effects of extreme waves or changes to longshore transport processes and assumes that the frontage continues to remain undefended. Consequently, when selecting a suitable location for the jointing bay, an appropriate degree of conservatism should be added to the predictions of profile retreat. It is suggested that any onshore infrastructure should be sited at least 50 m further inshore than the values given from the present day coastline (i.e. 100 m for Fraserburgh), to allow for any increases in the current recession rate.

B.6 Conclusions and Recommendations

The assessments carried out are based on the information available at the time of the study. It is recognised that the data history for the specific proposed landfall sites is limited (e.g. in relation to wave records, number of beach profiles, etc.). However all interpretations have adopted a conservative stance and have been correlated to other available information (site observations etc) to ensure that the results and conclusions are valid and that these inherent uncertainties do not compromise any subsequent recommendations. The following site specific recommendations are offered.

The following recommendations should be applied to the design of cable landfall operations and infrastructure at the Fraserburgh landfall site.

- The design of an open trenching operation should account for the beach closure depth at, approximately, 11 mLAT, aiming to achieve sufficient burial in this area to avoid subsequent exposure due to naturally occurring seabed level changes (in the order of several meters). The design burial depth should be achieved below the summer seabed level (which is lower than the winter level) in the lower intertidal and subtidal areas, but below the winter seabed level (which is lower than the summer level) in upper intertidal areas;.

- The design of the HDD should account for the beach closure depth at approximately 11 mLAT, aiming to achieve burial in this area, either by the HDD or other means (i.e. other sub-tidal burial methods);).

- Any onshore infrastructure (jointing bays, etc) should be sited at least 100 m behind the present day coastline; and.

- The route chosen through the hinterland dunes should be considerate sensitive (where possible) to the existing morphology. Ideally the route should maximise the use of low lying areas and existing footpaths and un-vegetated areas.

B.6.3 Monitoring

A suitable programme of pre and post installation monitoring is recommended at the site. This monitoring might include:

- A pre- and post-installation survey to ensure that the beach has remained undisturbed or can be re-profiled correctly following any disturbance;
- Summer and winter profiles at the landfall site;
- Biannual site visit to undertake a visual assessment of beach levels;
- Seabed assessment in the nearshore zone to monitor potential scour around the cable entry / exit point.

In conclusion, provided that the mitigation and monitoring presented above are implemented, the HVDC cables and associated onshore infrastructure can be installed without significant damage to the designated features and remain throughout the proposed operating period without necessitating any remedial coastal defence works.

B.7 References

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Figure B.1. Regional details of the cable landfall area (in grey) at Fraserburgh

Figure B.2. Local detail of the cable landfall area (in grey) at Fraserburgh

Figure B.3. Comparison of aerial images showing relative coastline positions (whole of Fraserburgh landfall area).

Figure B.4. Comparison of aerial images showing relative coastline positions (western part of Fraserburgh landfall area).

Figure B.5. Comparison of aerial images showing relative coastline positions (eastern part of Fraserburgh landfall area).

Figure B.6. Wavehub transmission cable exposure on Hayle Beach, Cornwall, November, 2011. From [http://www.bbc.co.uk/news/uk-england-cornwall-15540281]

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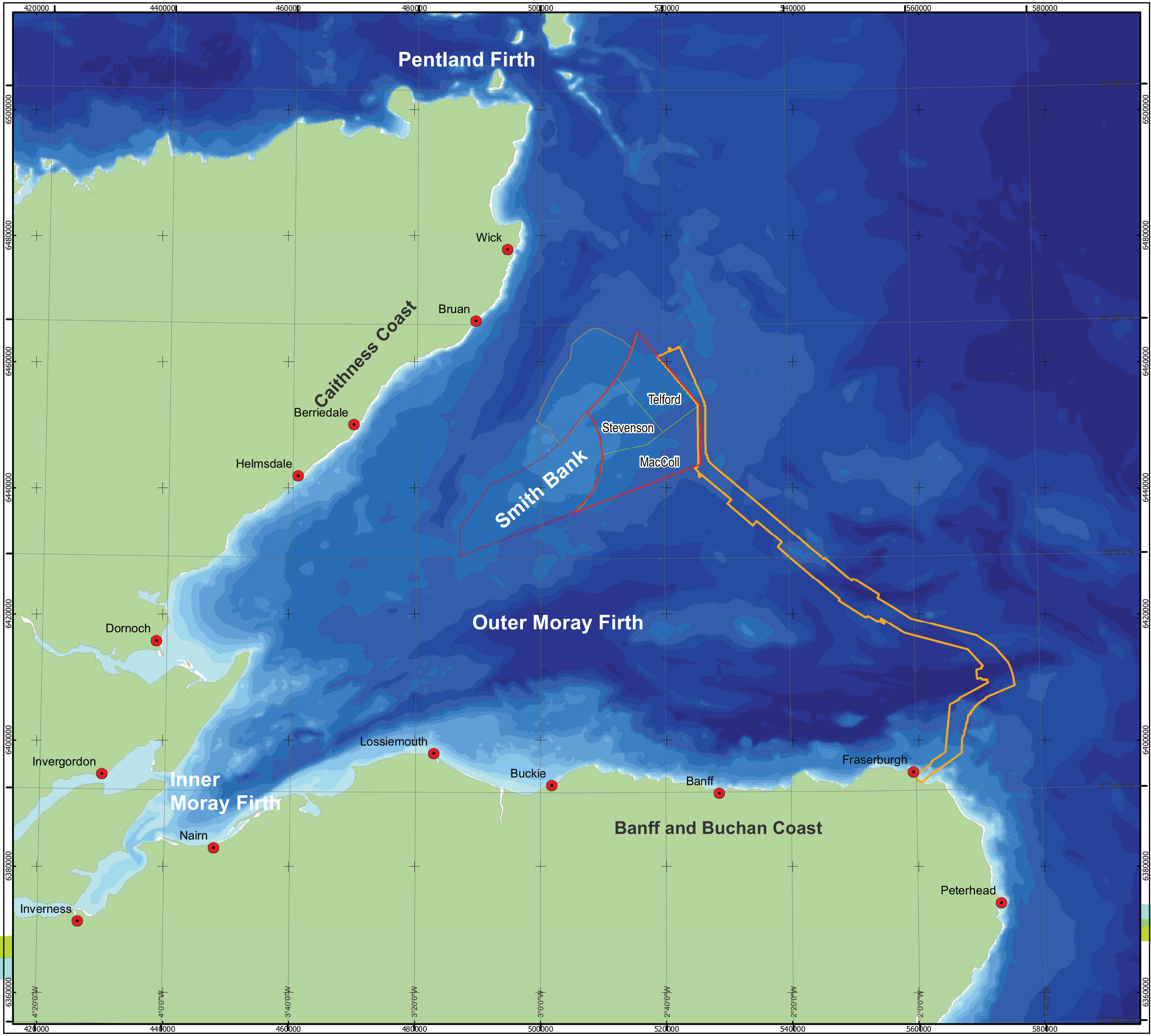

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KEY

- MORL EDA
- MORL WDA
- Beatrice Offshore Wind Farm
- OFTO Transmission Cable
- Site Boundaries

m MSL

- < -100
- -99 - -80
- -79 - -70
- -69 - -60
- -59 - -50
- -49 - -40
- -39 - -30
- -29 - -25
- -24 - -20
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Horizontal Scale: 1:575,000 A3 Chart

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Geodetic Parameters: WGS84 UTM Zone 30N

Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 24/05/2012 Revision: A

REF: 8460001-PPW0201-ABP-MAP-001

Fig 1 - The Study Area

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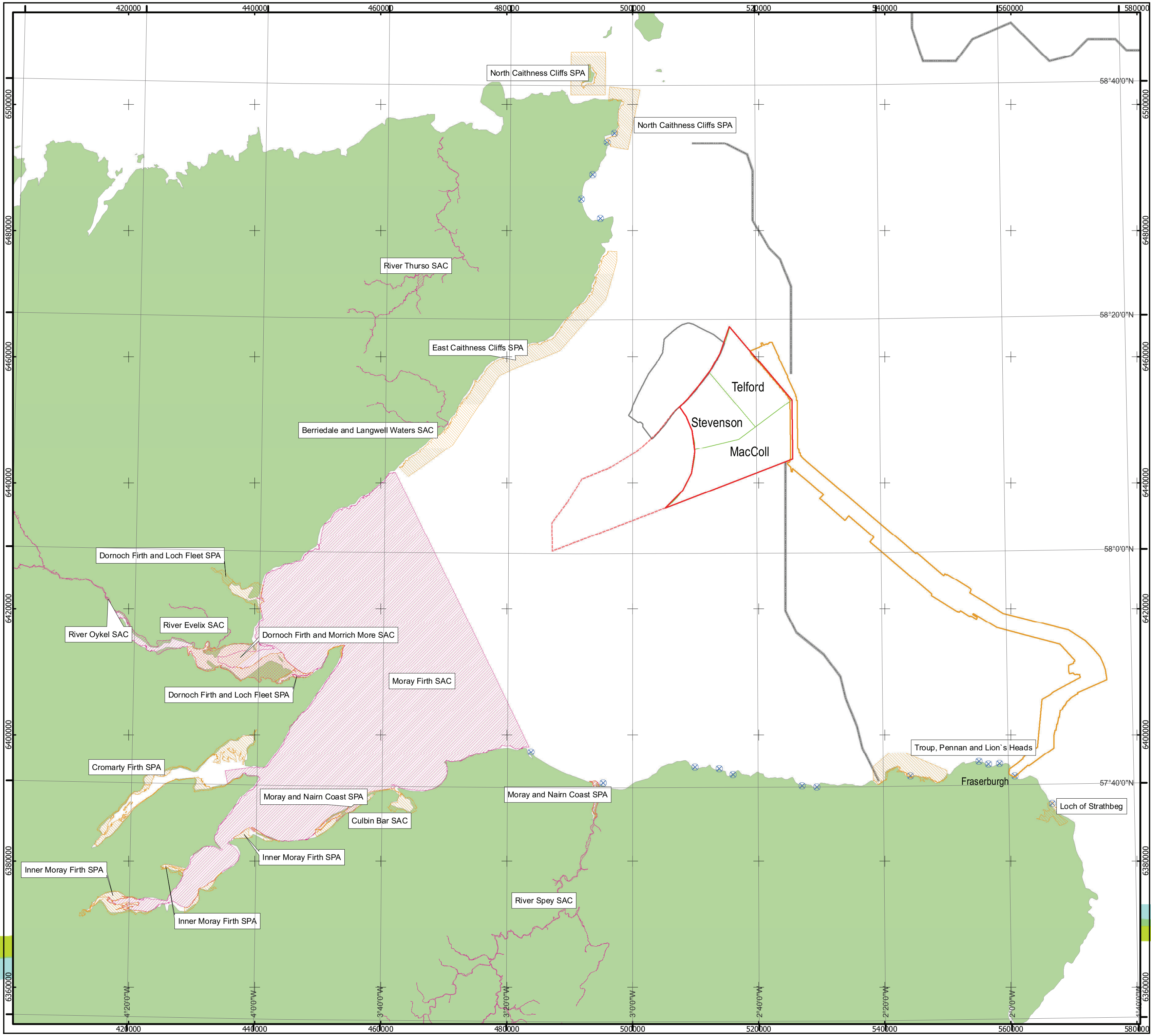

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KEY

- MORL EDA
- MORL WDA
- Beatrice Offshore Wind Farm
- OFTO Transmission Cable
- Site Boundaries
- SPA Sites
- SAC Sites
- Surfing Locations
- Fronts

Horizontal Scale: 1:575,000 A3 Chart

0 15,000 30,000 Metres

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Geodetic Parameters: WGS84 UTM Zone 30N

Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 07/06/2012 Revision: A

REF: 8460001-PPW0201-ABP-MAP-002

Fig 2 - Identified Physical and Coastal Process Receptors

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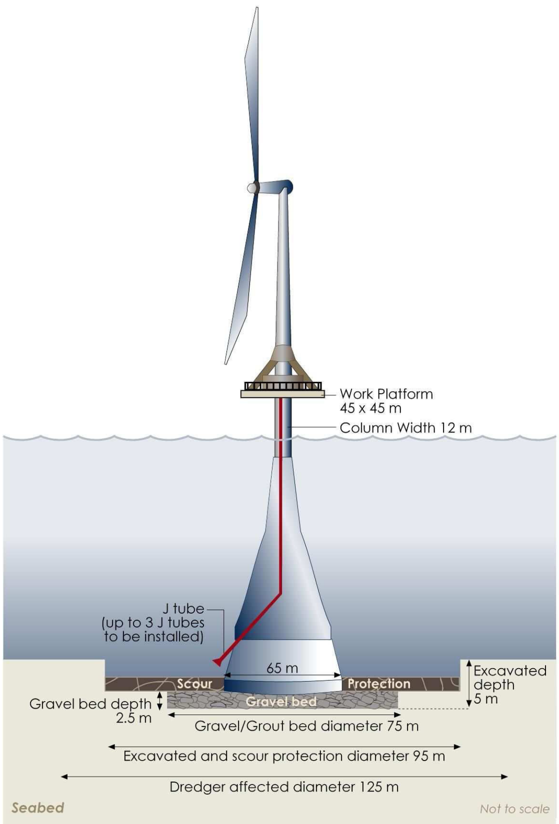
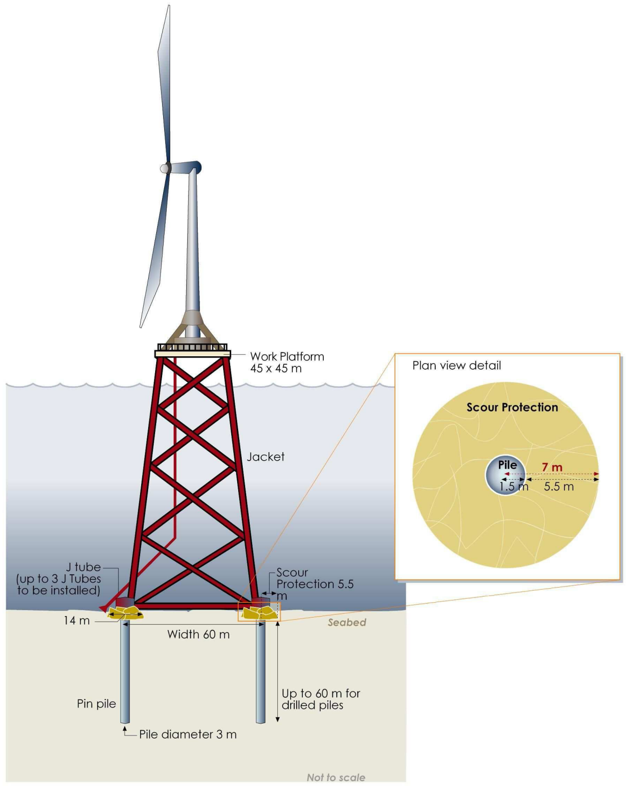
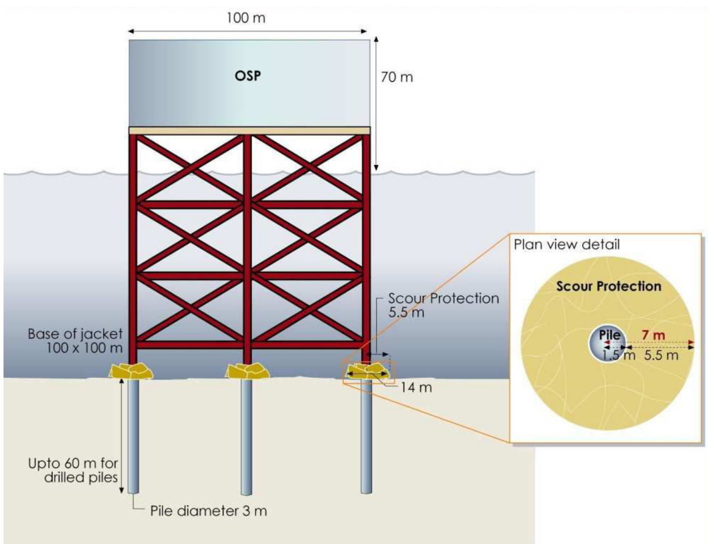
WTG Gravity Base Structure



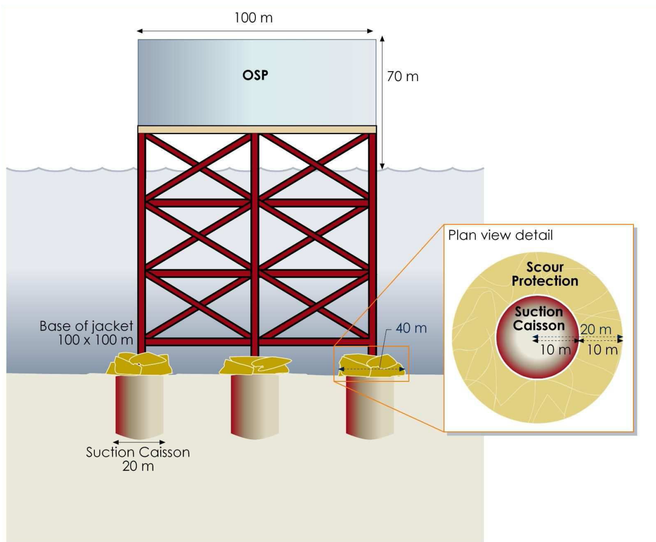
WTG Pinned Jacket



OSP Pinned Jacket



OSP Jacket on Suction Caissons



edp renewables REPSOL
Moray Offshore Renewables Ltd

Produced: DOL
Reviewed: CLH
Approved: WSC

A4
Chart

Revision: | Date: 01/06/12

REF: 8460001-PPW0201-ABP-MAP-003

Fig 3. Schematic Descriptions of the WTG and OSP Foundation Types

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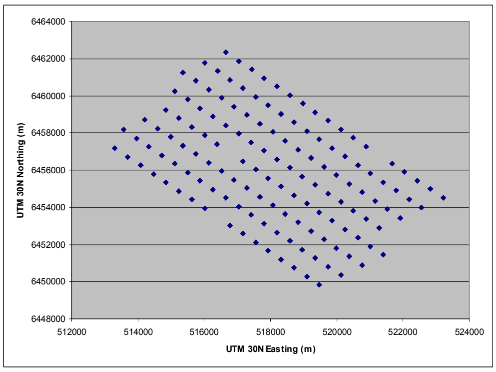
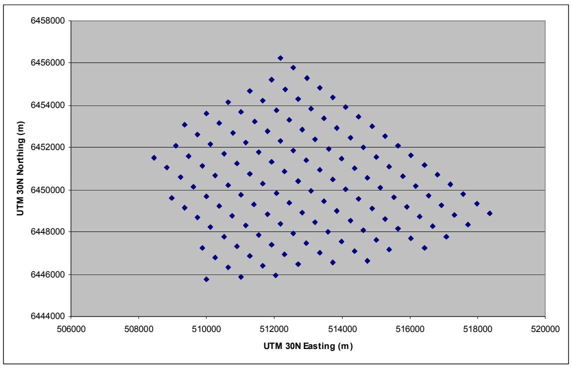
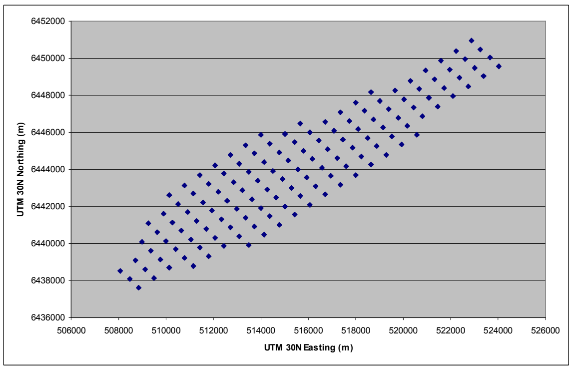
T3



S3



M3



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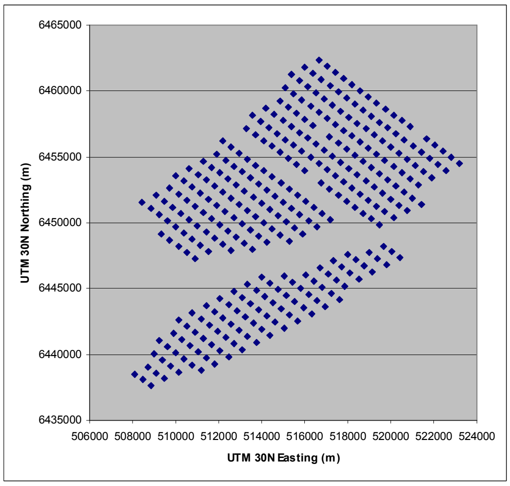

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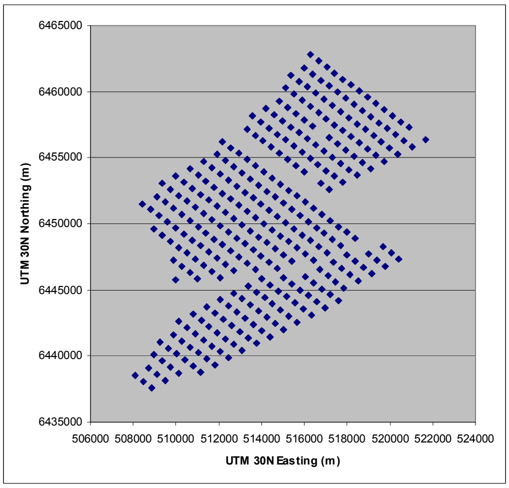

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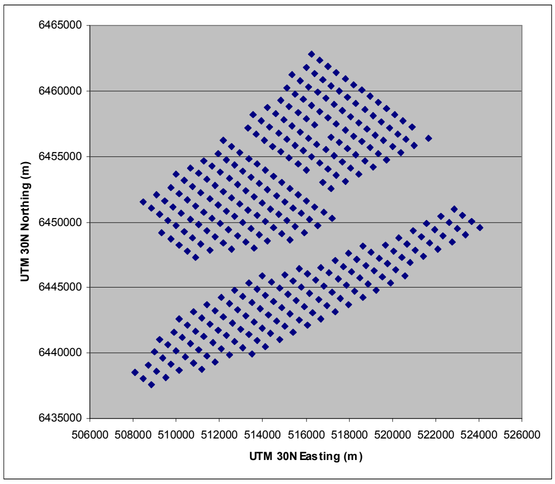

renewables REPSOL

Moray Offshore Renewables Ltd

Produced: DOL
Reviewed: CLH
Approved: WSC

A4
Chart

Revision:

Date: 01/06/12

REF: 8460001-PPW0201-ABP-MAP-004

Fig 4. Indicative Turbine Layouts

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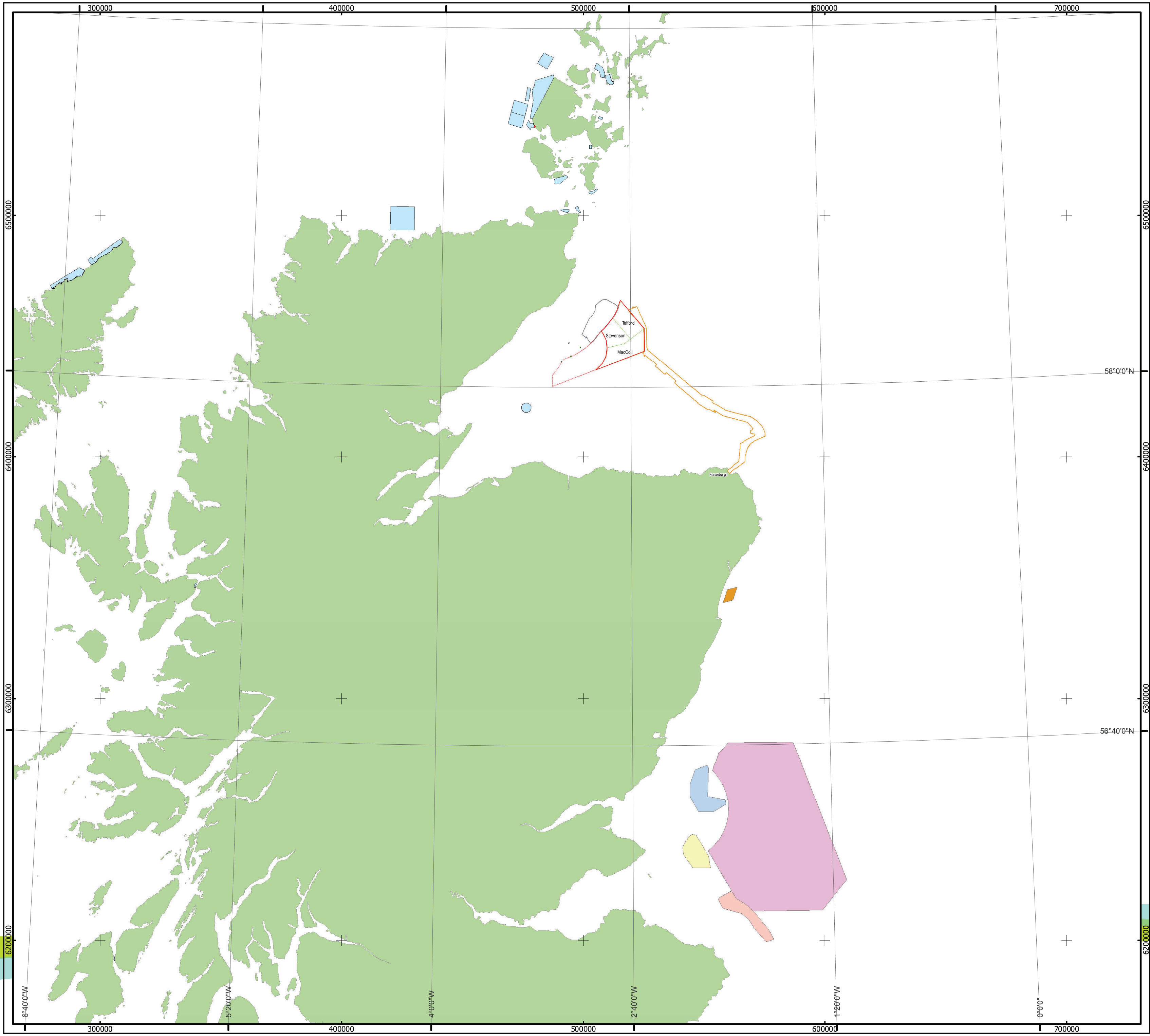

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KEY

- Jacky Platform
- Beatrice Platforms
- Beatrice Demonstrator Turbines
- MORL EDA
- MORL WDA
- Beatrice Offshore Wind Farm
- OFTO Transmission Cable
- Site Boundaries
- EMEC Tidal Power Test Facility
- EMEC Wave Power Test Facility
- TCE Lease Areas for Tide & Wave
- Beatrice Hydrocarbon Field
- Jacky Hydrocarbon Field
- European Offshore Wind Development Centre
- Firth of Forth R3 Zone
- Forth Array OWF
- Inch Cape OWF
- Neart na Gaoithe OWF

Horizontal Scale: 1:1,500,000 A3 Chart

0 37,500 75,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

Produced: MCE
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Fig 5 - Location of Cumulative and In-Combination Developments

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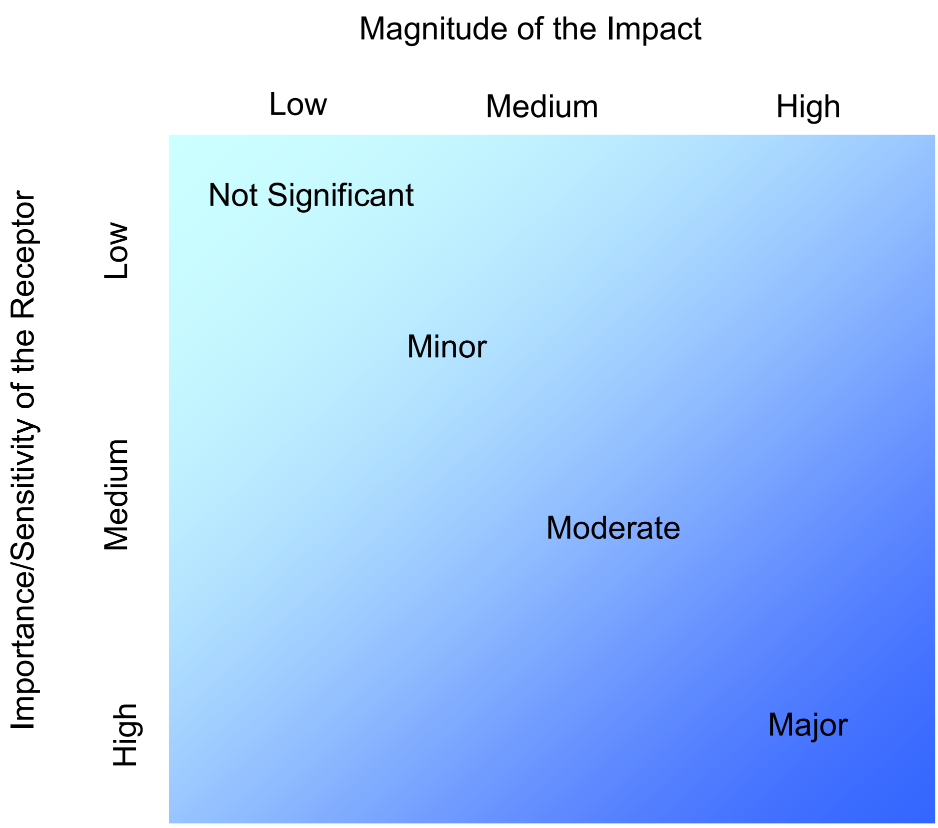


renewables REPSOL

Moray Offshore Renewables Ltd

Produced: DOL
Reviewed: CLH
Approved: WSC

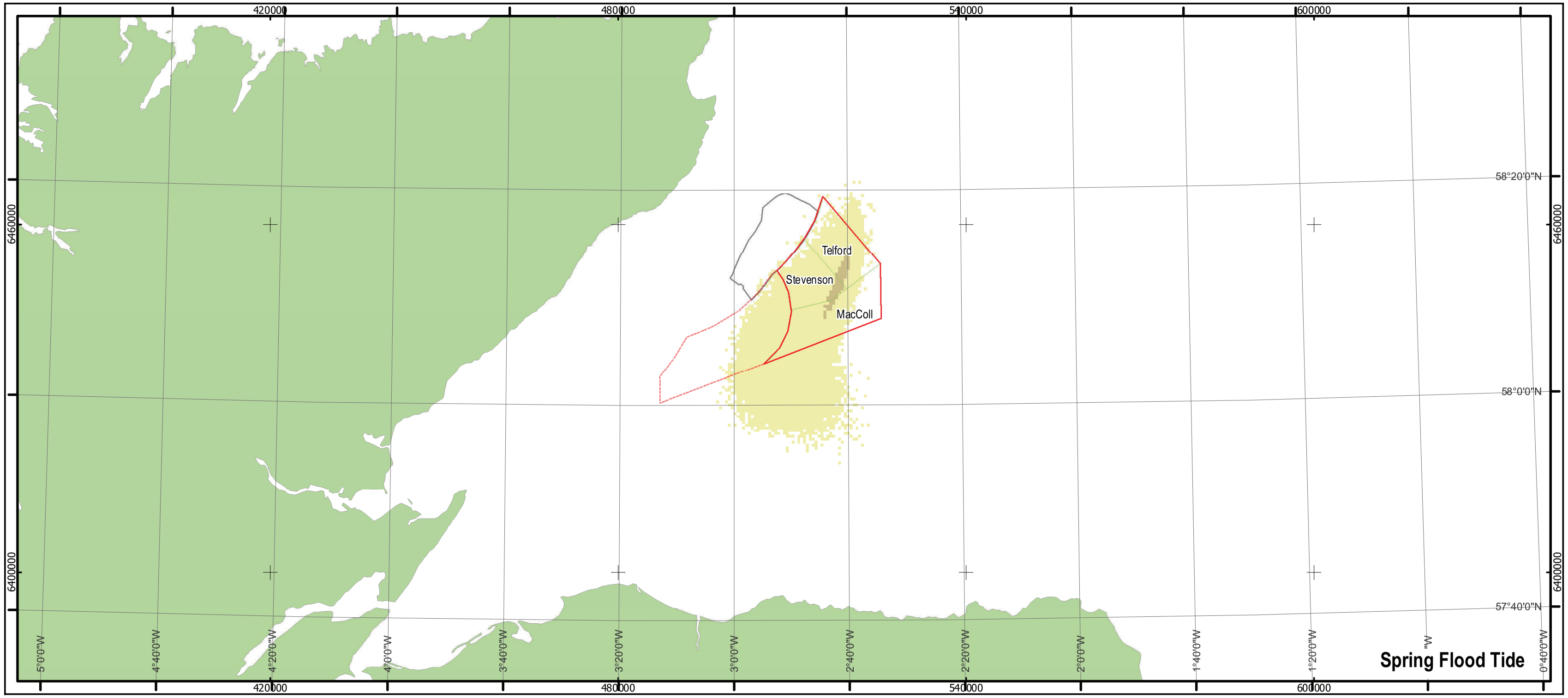
A4
Chart

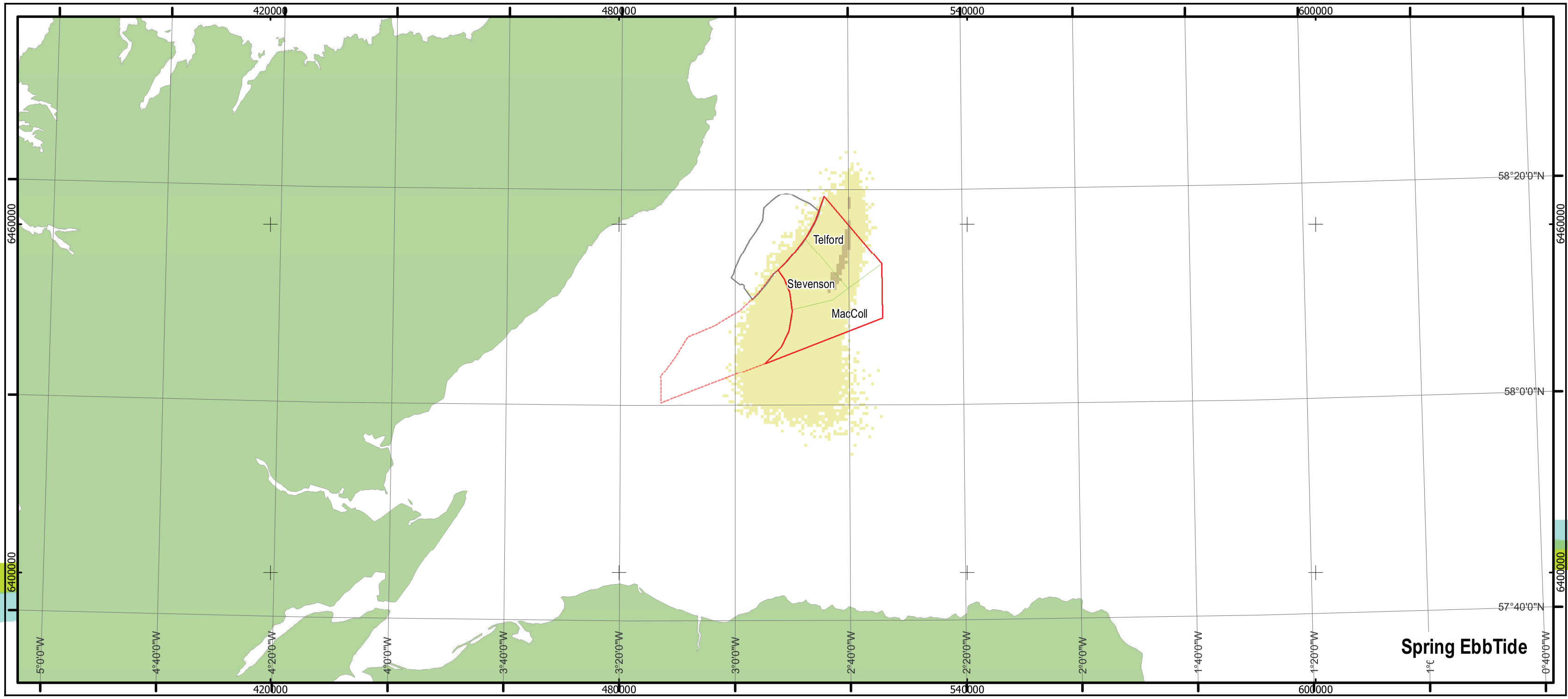
Revision: | Date: 01/06/12

REF: 8460001-PPW0201-ABP-MAP-006

Fig 6. Significance Matrix

Moray Offshore Renewables Ltd





Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries
- Beatrice Offshore Wind Farm

SSC - mg/L

- < 1
- 1.1 - 2
- 2.1 - 4
- 4.1 - 6
- 6.1 - 8

Horizontal Scale: 1:850,000 A3 Chart

0 22,500 45,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

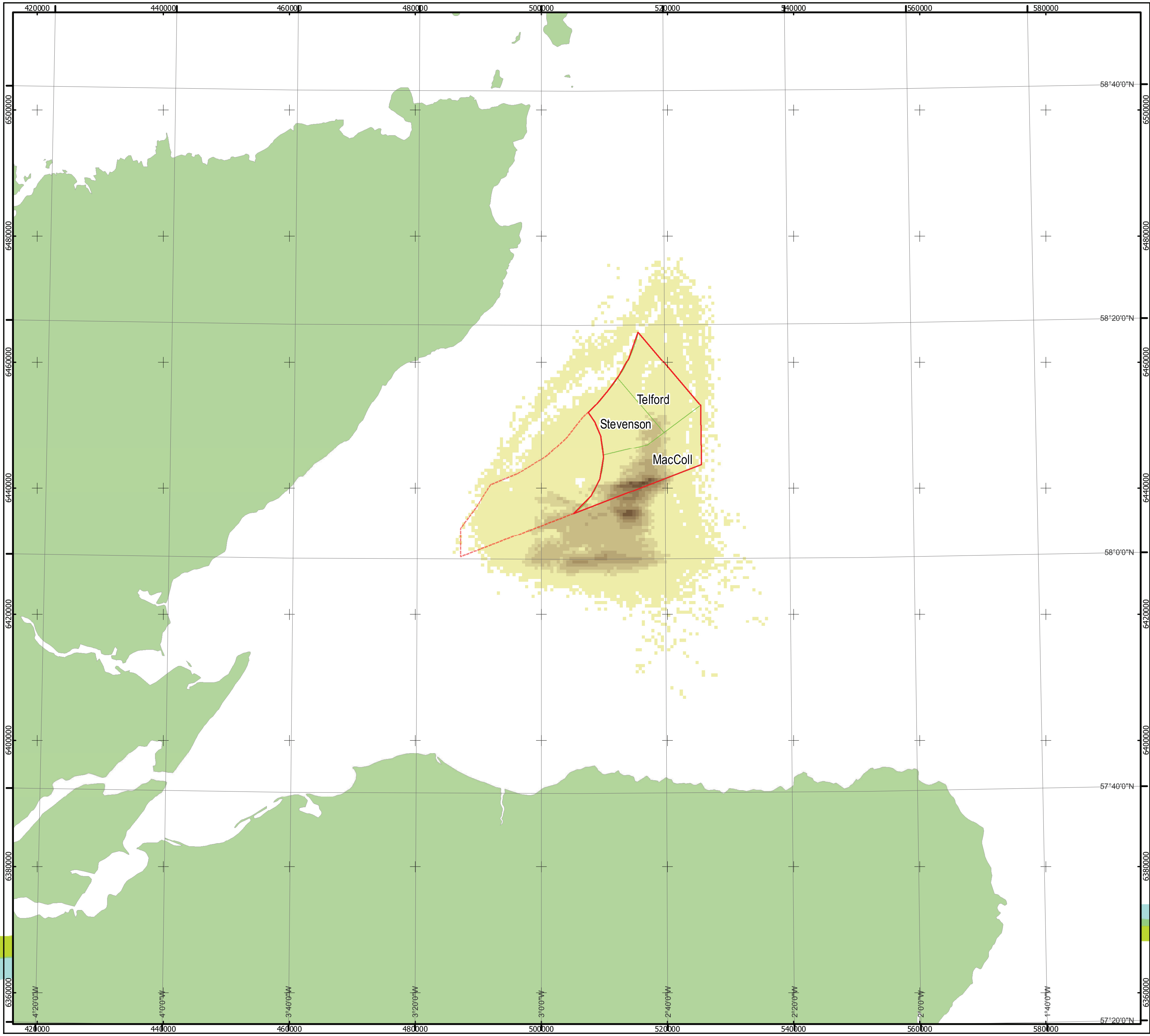
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 04/05/2012 Revision: A

REF: 8460001-PPW0201-ABP-MAP-007

Fig 7 - Typical Sediment Plume Resulting from Dredging Overspill (Tenth Foundation in Sequence)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

Maximum Deposition Thickness (mm)

- < 0.01
- 0.01 - 0.02
- 0.03 - 0.05
- 0.06 - 0.1
- 0.11 - 0.2
- 0.21 - 0.3
- 0.31 - 0.4
- 0.41 - 0.5
- 0.51 - 0.6

Dredging Overspill During Bed Preparation for 10 GBS

Horizontal Scale: 1:575,000 A3 Chart

0 15,000 30,000 Metres

N

Geodetic Parameters: WGS84 UTM Zone 30N

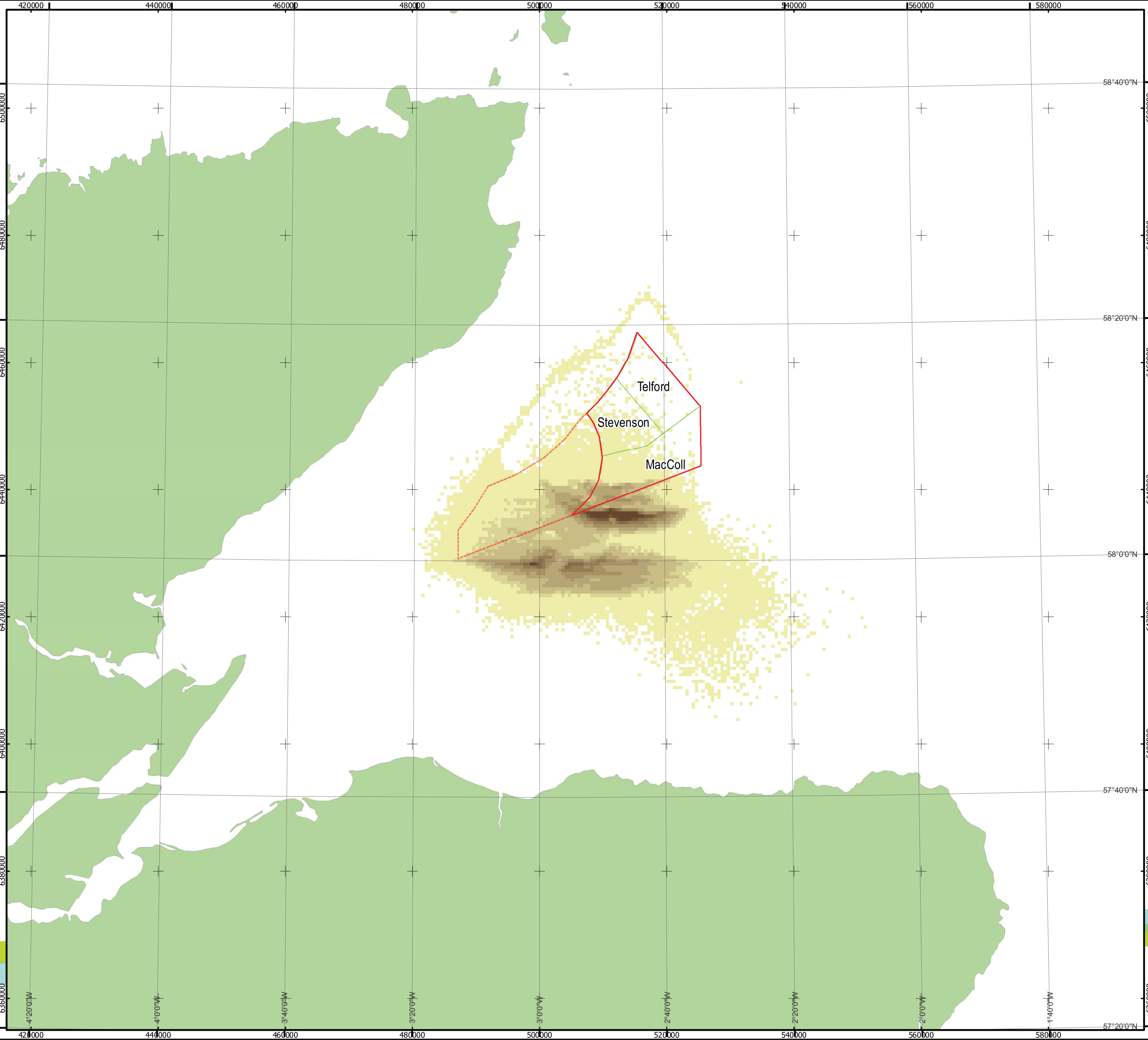
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 23/11/2011 Revision: A

REF: 8460001-PPW0201-ABP-MAP-008

Fig 8 - Maximum Deposition Thickness of Fine Sediments

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY
- MORL EDA
- MORL WDA
- Site Boundaries

Maximum Deposition Thickness (mm)
- < 0.01
- 0.01 - 0.02
- 0.03 - 0.05
- 0.06 - 0.1
- 0.11 - 0.2
- 0.21 - 0.3
- 0.31 - 0.4
- 0.41 - 0.5
- 0.51 - 0.6

Dredging Overspill During Bed Preparation for 339 GBS, T3_S5_M5

Horizontal Scale: 1:575,000 A3 Chart

0 15,000 30,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

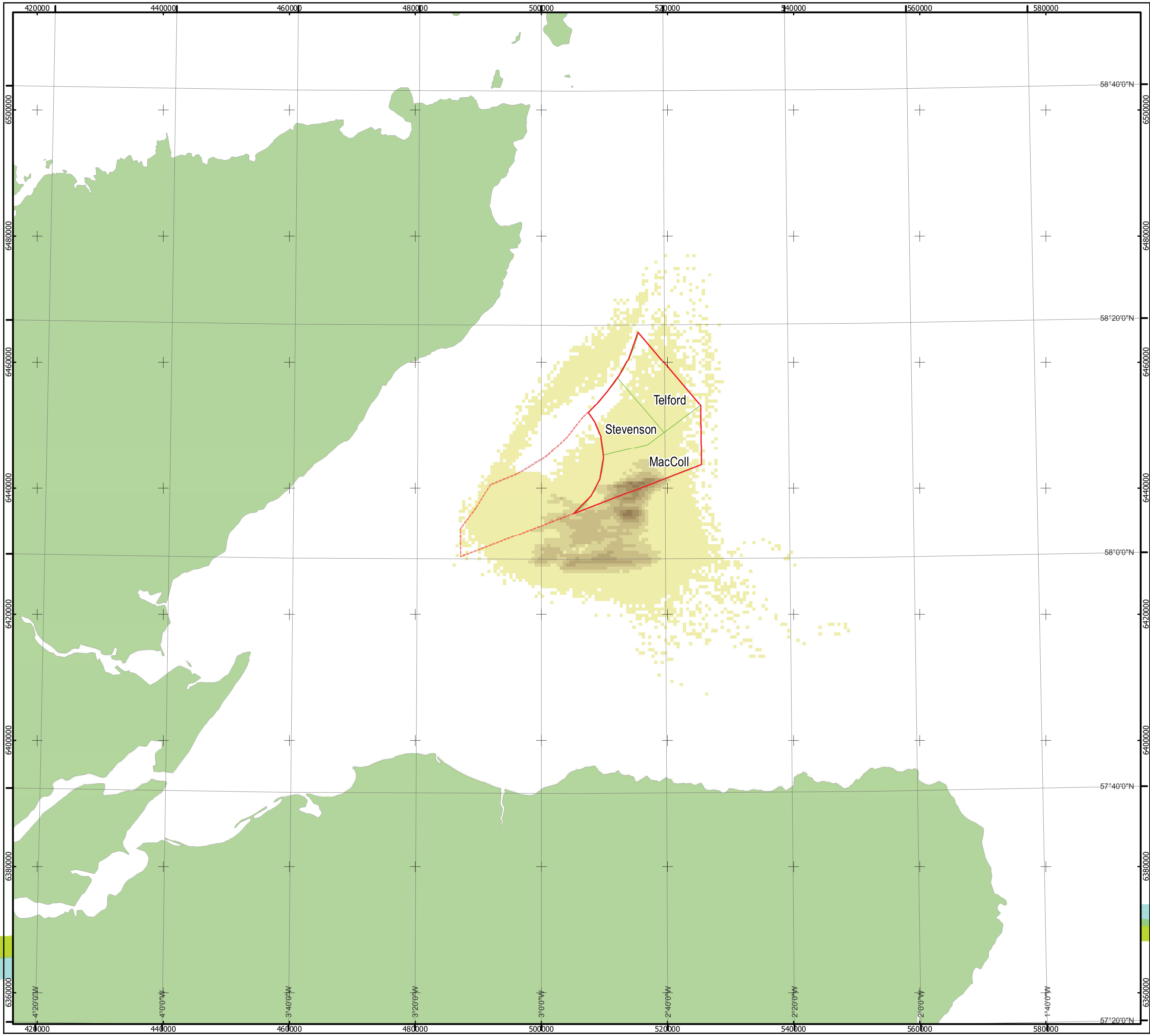
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 04/05/2012 Revision: A

REF: 8460001-PPW0201-ABP-MAP-009

Fig 9 - Maximum Deposition Thickness of Fine Sediments

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

Maximum Deposition Thickness (mm)

- < 0.01
- 0.01 - 0.02
- 0.03 - 0.05
- 0.06 - 0.1
- 0.11 - 0.2
- 0.21 - 0.3
- 0.31 - 0.4
- 0.41 - 0.5
- 0.51 - 0.6

Drill Arisings From Installation of 10 Pinned Jacket Foundations, T3_S5_M5

Horizontal Scale: 1:575,000 A3 Chart

0 15,000 30,000 Metres

N

Geodetic Parameters: WGS84 UTM Zone 30N

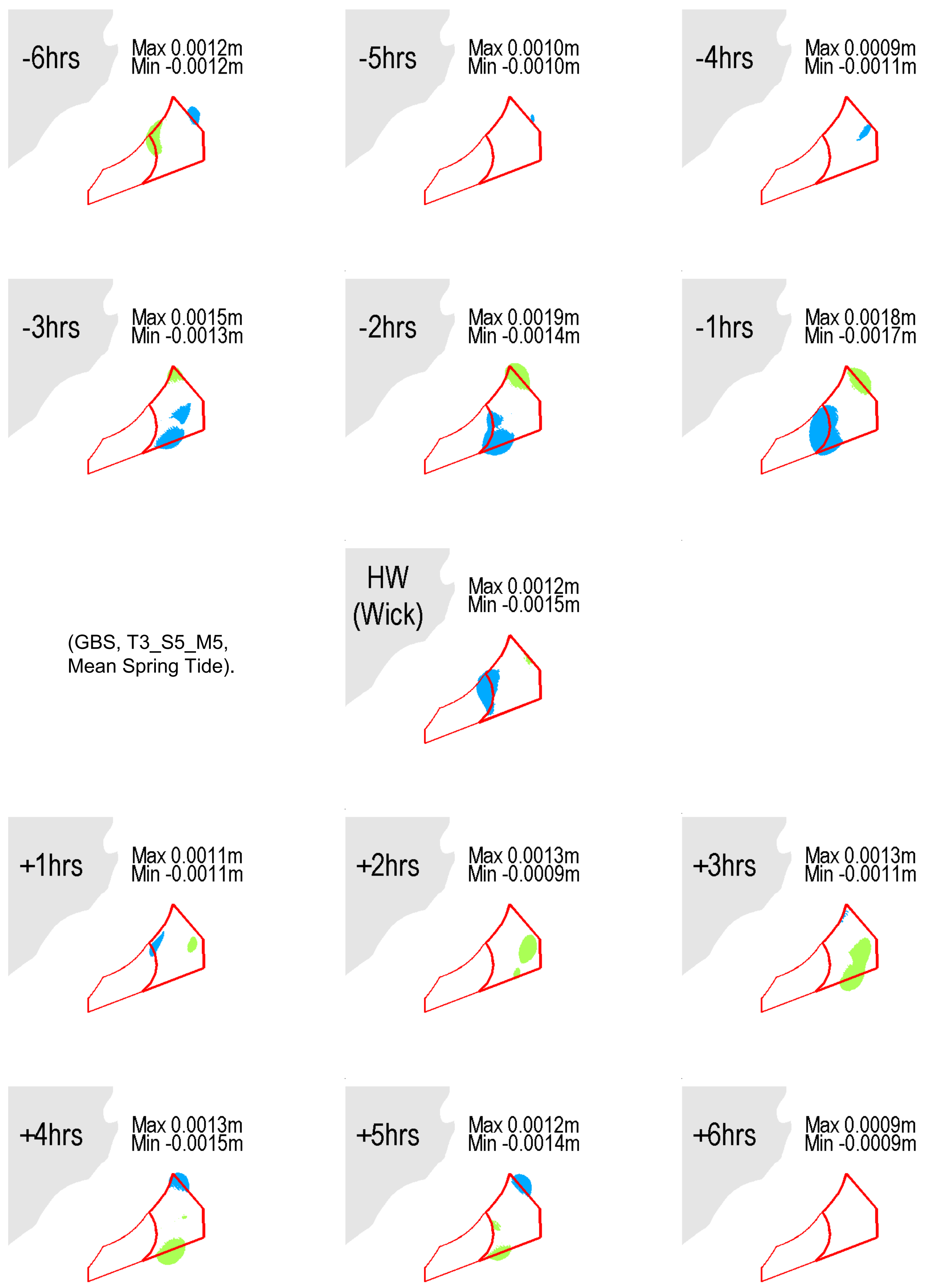
Produced: MCE
Reviewed:NMW
Approved: DOL

Date: 07/06/2012 Revision: A

REF: 8460001-PPW0201-ABP-MAP-010

Fig 10 - Maximum Deposition Thickness of Fine Sediments

Moray Offshore Renewables Ltd



Water level difference (m)

+0.005
+0.004
+0.003
+0.002
+0.001
0.000
-0.001
-0.002
-0.003
-0.004
-0.005

(Differences <0.001m are excluded as white)

Site outline

Corresponding effects on neap tides and for jackets at all times are <0.001m

edp renewables REPSOL

Moray Offshore Renewables Ltd

Produced: DOL
Reviewed: CLH
Approved: WSC

A4 Chart

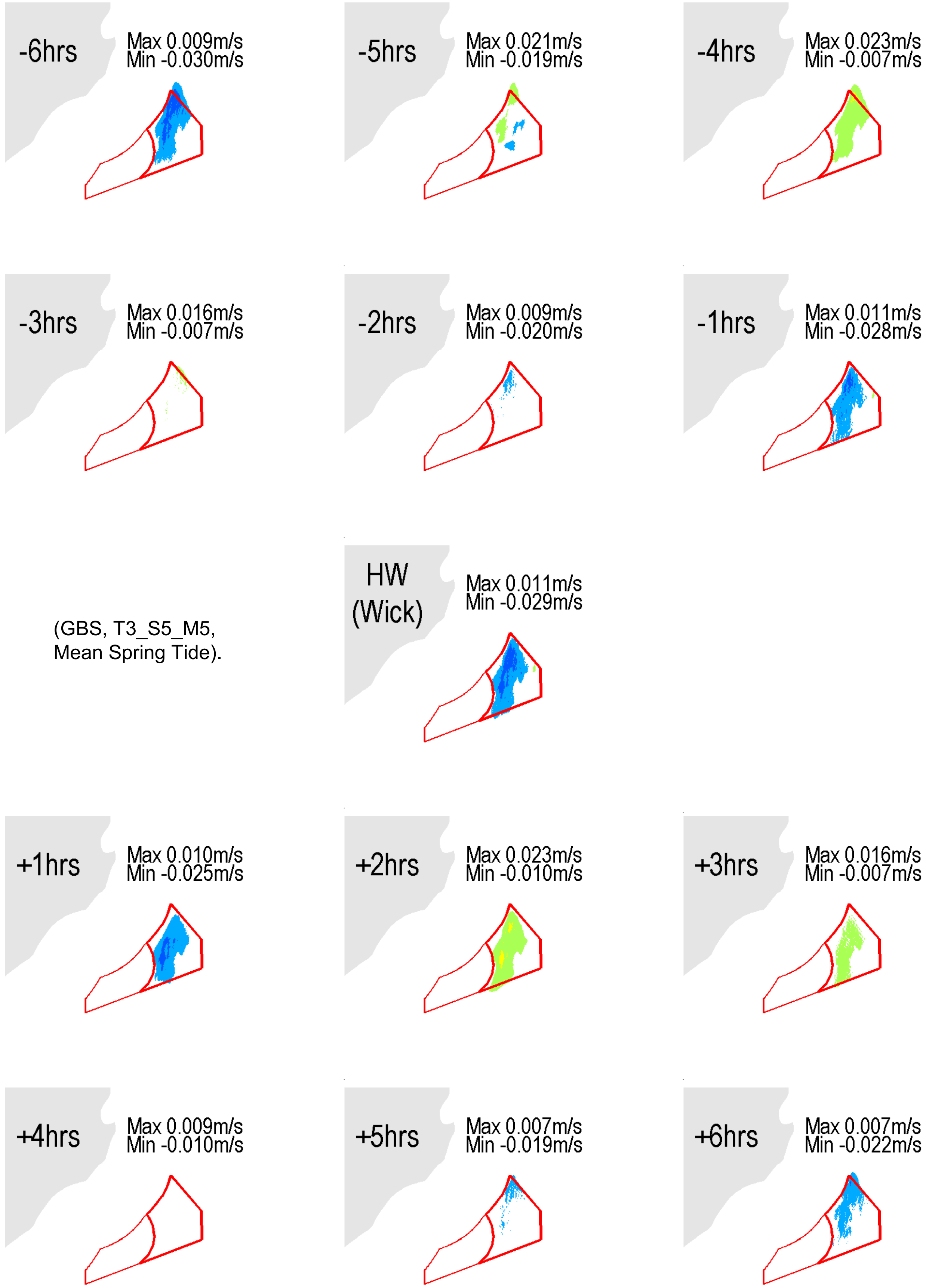
Revision:

Date: 01/06/12

REF: 8460001-PPW0201-ABP-MAP-011

Fig 11. Effect of the Project on Tidal Water Levels.

Moray Offshore Renewables Ltd



+0.05
+0.04
+0.03
+0.02
+0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05

Current speed difference (m/s)

(Differences <0.01m/s are excluded as white)

MORL EDA Outline

R3 Zone Outline

Corresponding effects on neap tides and for jackets at all times are <0.01m/s

renewables REPSOL

Moray Offshore Renewables Ltd

Produced: DOL
Reviewed: CLH
Approved: WSC

A4 Chart

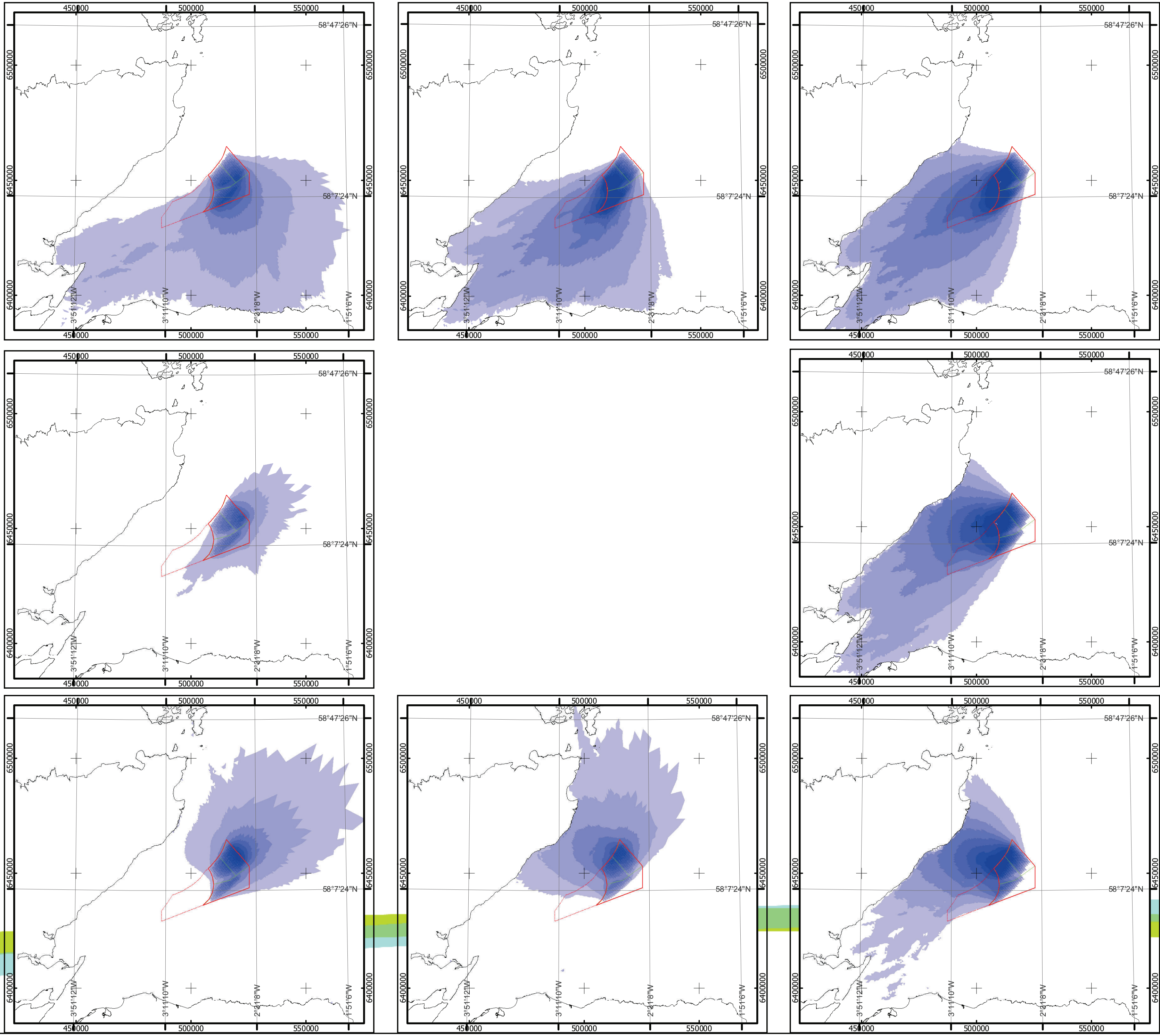
Revision:

Date: 01/06/12

REF: 8460001-PPW0201-ABP-MAP-012

Fig 12. Effect of the Project on Tidal Current Speed.

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

MORL EDA
MORL WDA
Site Boundaries
T3mw S5mw M5mw West
Difference

Above -0.05
-0.10 - -0.05
-0.20 - -0.10
-0.30 - -0.20
-0.40 - -0.30
-0.50 - -0.40
-0.60 - -0.50
-0.70 - -0.60
Below -0.70

Horizontal Scale: 1:1,600,000 A3 Chart
0 40,000 80,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

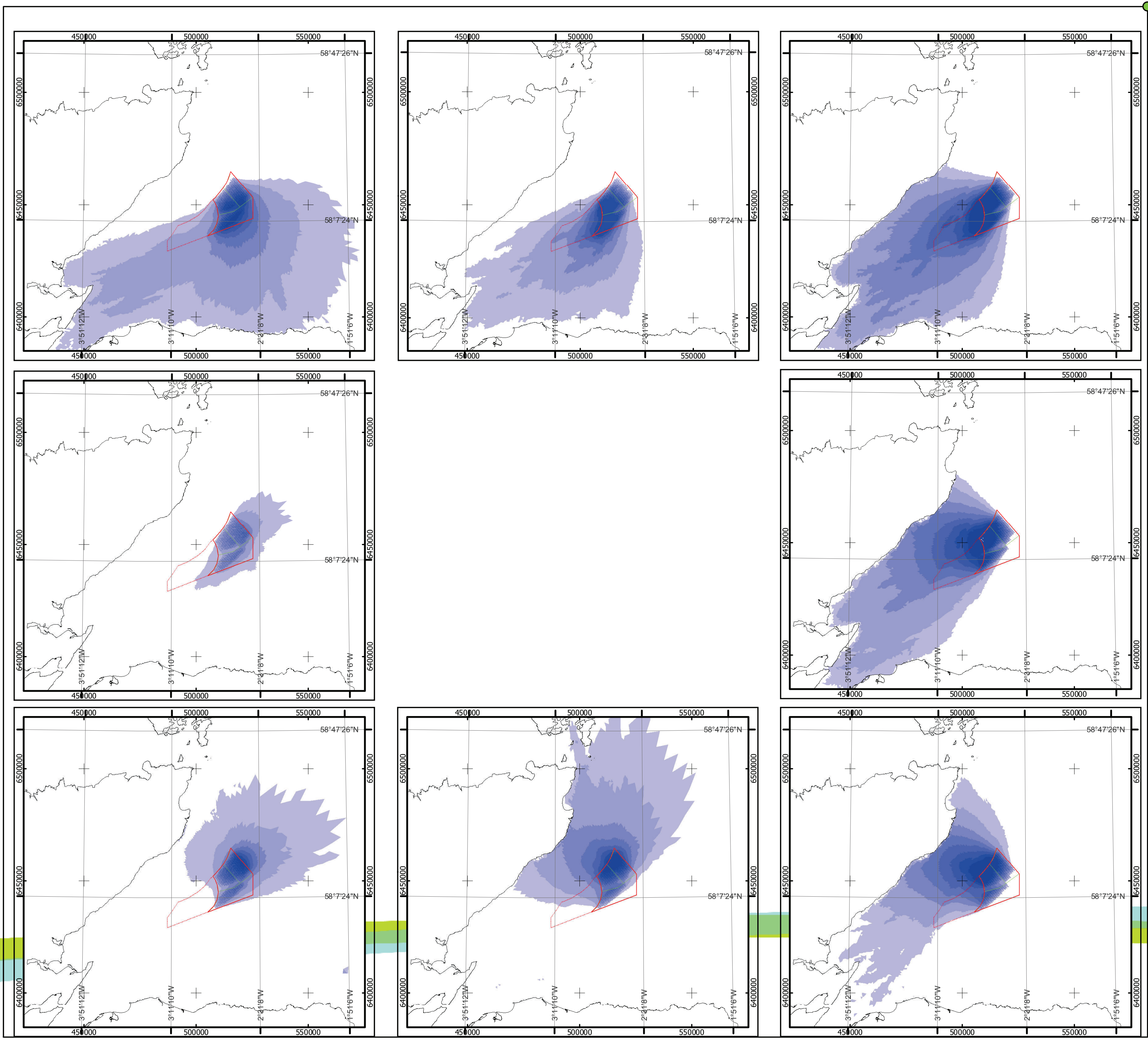
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 08/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-013

Fig 13 - Effect of the Project on Wave Height (GBS, T3_S5_M5, 1in1yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

T3mw S5mw M5mw West

Difference

- -0.09 - -0.05
- -0.19 - -0.10
- -0.29 - -0.20
- -0.39 - -0.30
- -0.49 - -0.40
- -0.59 - -0.50
- -0.69 - -0.60
- -1.99 - -0.70
- -1.30 - -2.00

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

N

Geodetic Parameters: WGS84 UTM Zone 30N

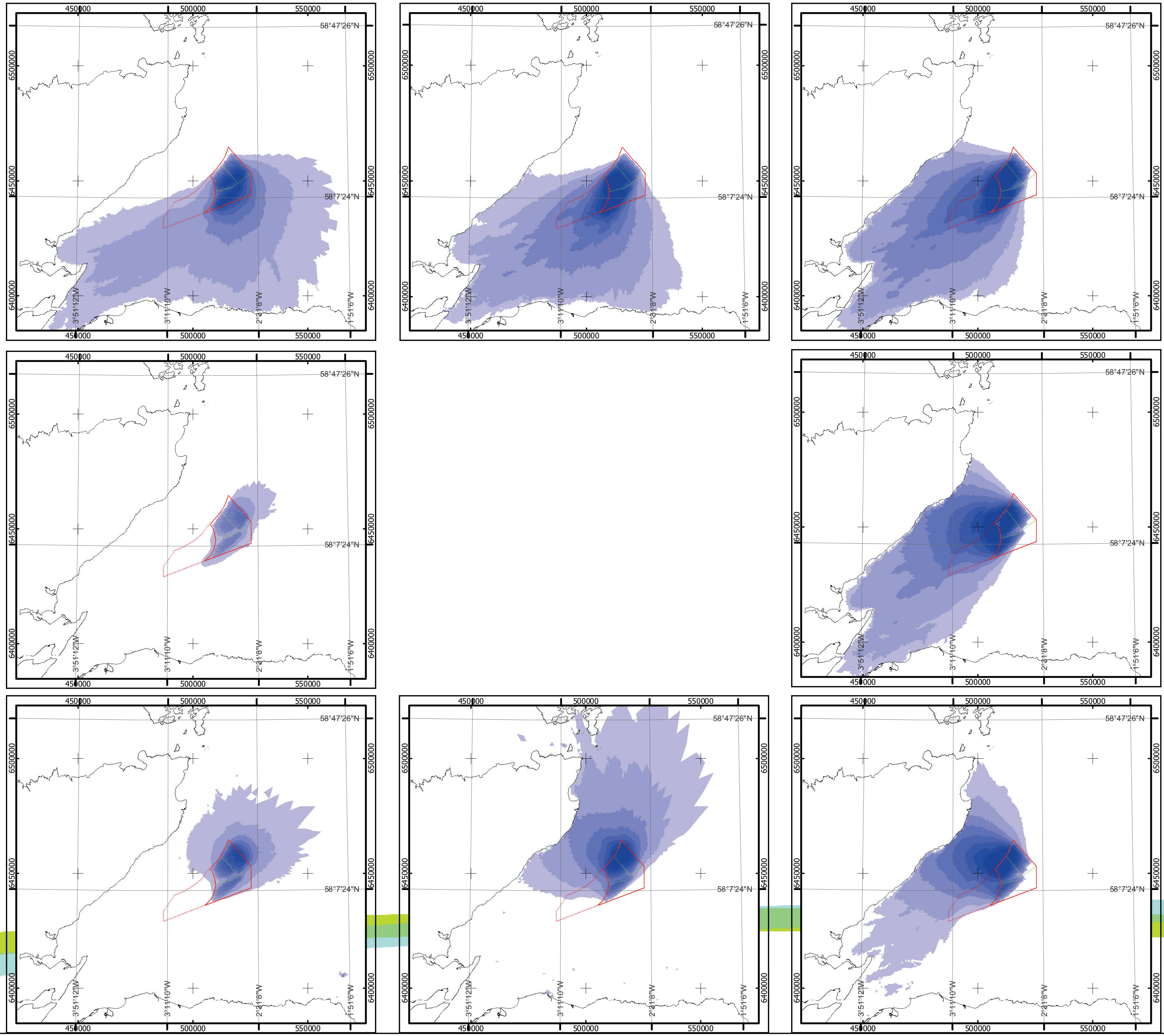
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 08/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-014

Fig 14 - Effect of the Project on Wave Height (GBS, T3_S5_M5, 1in10yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

T3mw S5mw M5mw West

Difference

- Above -0.05
- -0.10 - -0.05
- -0.20 - -0.10
- -0.30 - -0.20
- -0.40 - -0.30
- -0.50 - -0.40
- -0.60 - -0.50
- -0.70 - -0.60
- Below -0.70

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

N

Geodetic Parameters: WGS84 UTM Zone 30N

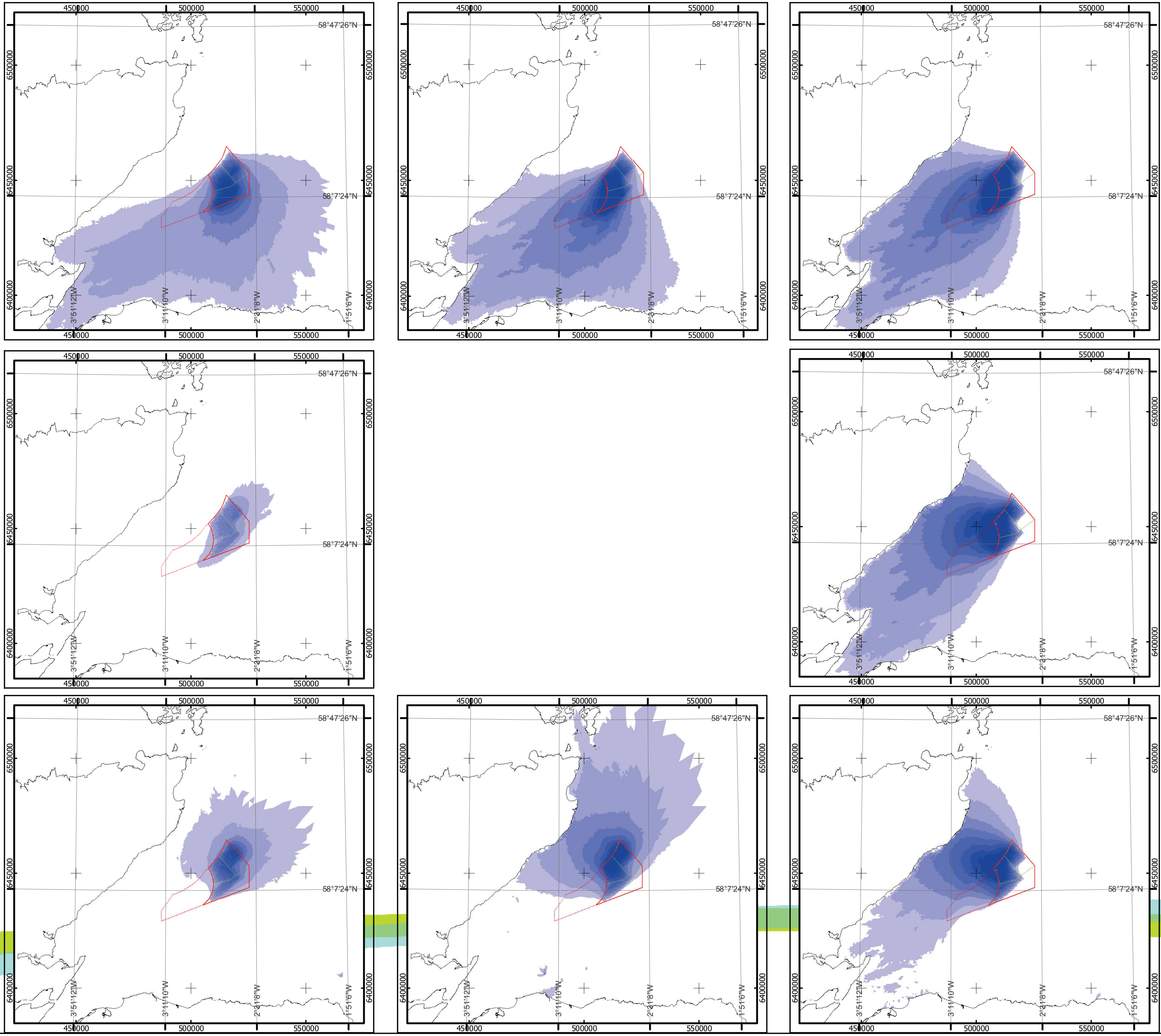
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 08/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-015

Fig 15 - Effect of the Project on Wave Height (GBS, T3_S5_M5, 1in50yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

T5mw S3mw M5mw West

Difference

- -0.04 - 0.50
- -0.09 - -0.05
- -0.19 - -0.10
- -0.29 - -0.20
- -0.39 - -0.30
- -0.49 - -0.40
- -0.59 - -0.50
- -0.69 - -0.60
- -1.99 - -0.70
- -1.36 - -2.00

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Meters

N

Geodetic Parameters: WGS84 UTM Zone 30N

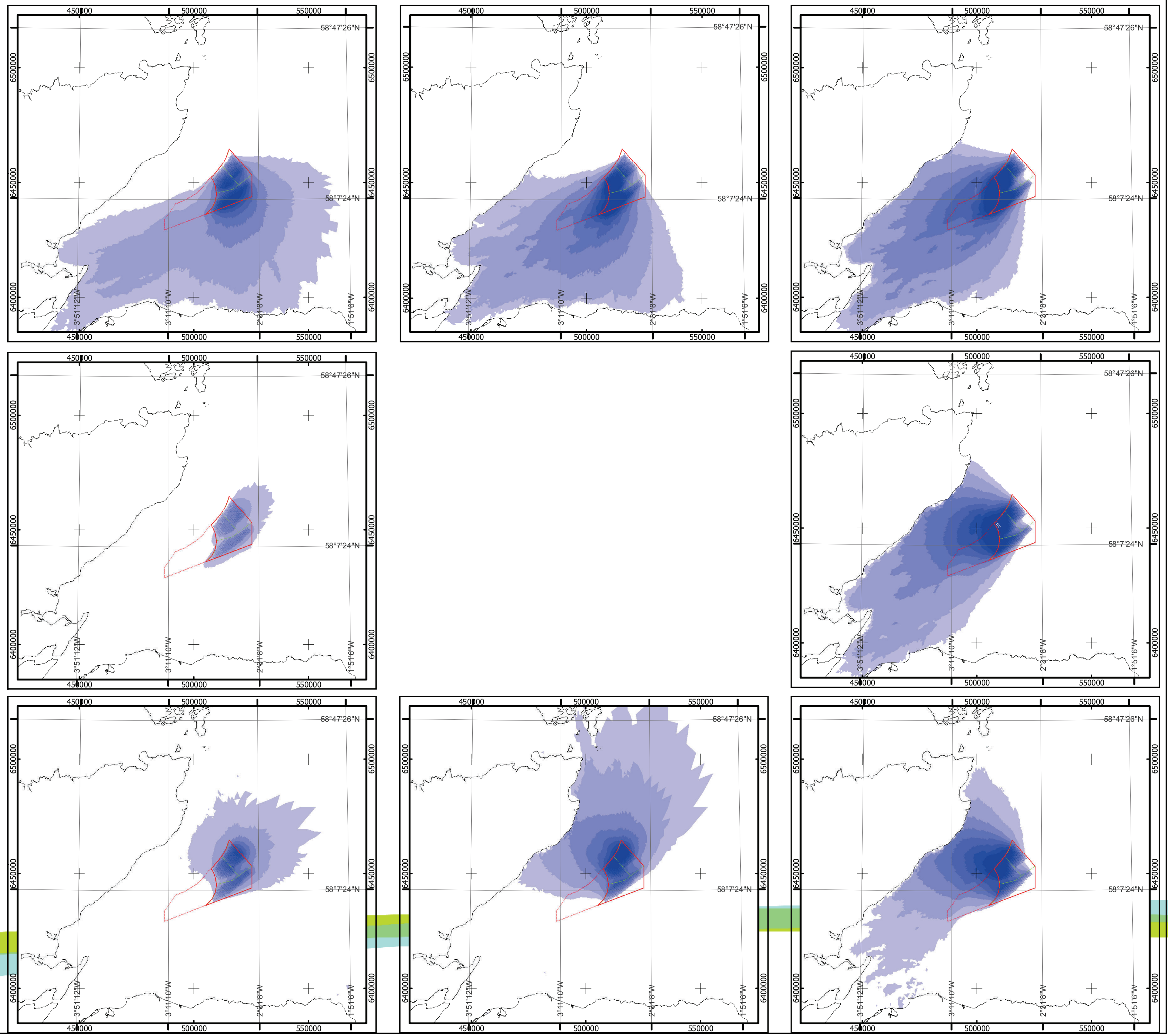
Produced: MCE
Reviewed: DRAFT
Approved: DRAFT

Date: 08/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-016

Fig 16 - Effect of the Project on Wave Height (GBS, T5_S3_M5, 1in50yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

T5mw S5mw M3mw West

Difference

- Above -0.05
- -0.10 - -0.05
- -0.20 - -0.10
- -0.30 - -0.20
- -0.40 - -0.30
- -0.50 - -0.40
- -0.60 - -0.50
- -0.70 - -0.60
- Below -0.70

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

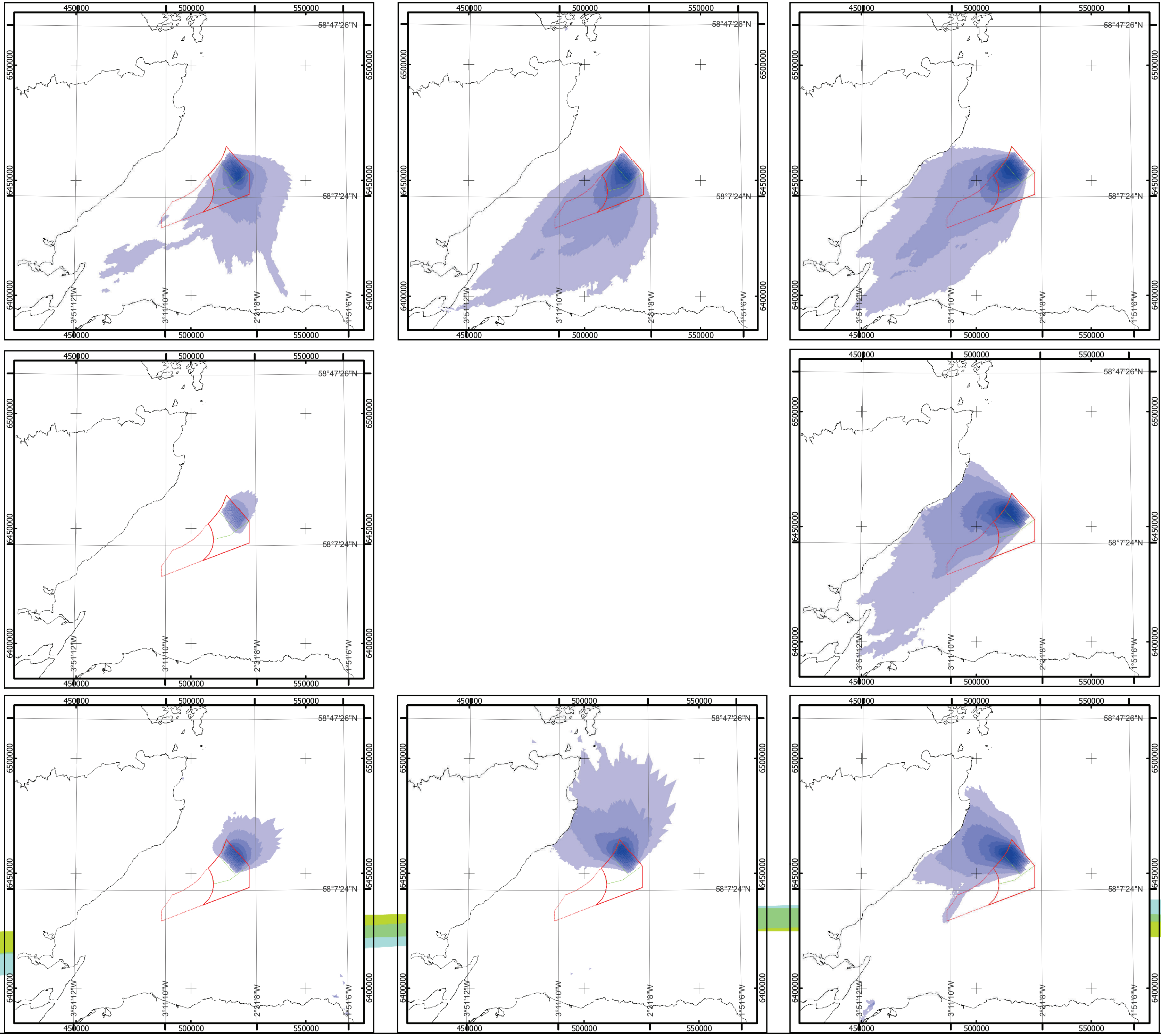
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 08/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-017

Fig 17 - Effect of the Project on Wave Height (GBS, T5_S5_M3, 1in50yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

T3mw Difference

- Above -0.05
- -0.10 - -0.05
- -0.20 - -0.10
- -0.30 - -0.20
- -0.40 - -0.30
- -0.50 - -0.40
- -0.60 - -0.50
- -0.70 - -0.60
- Below -0.70

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

N

Geodetic Parameters: WGS84 UTM Zone 30N

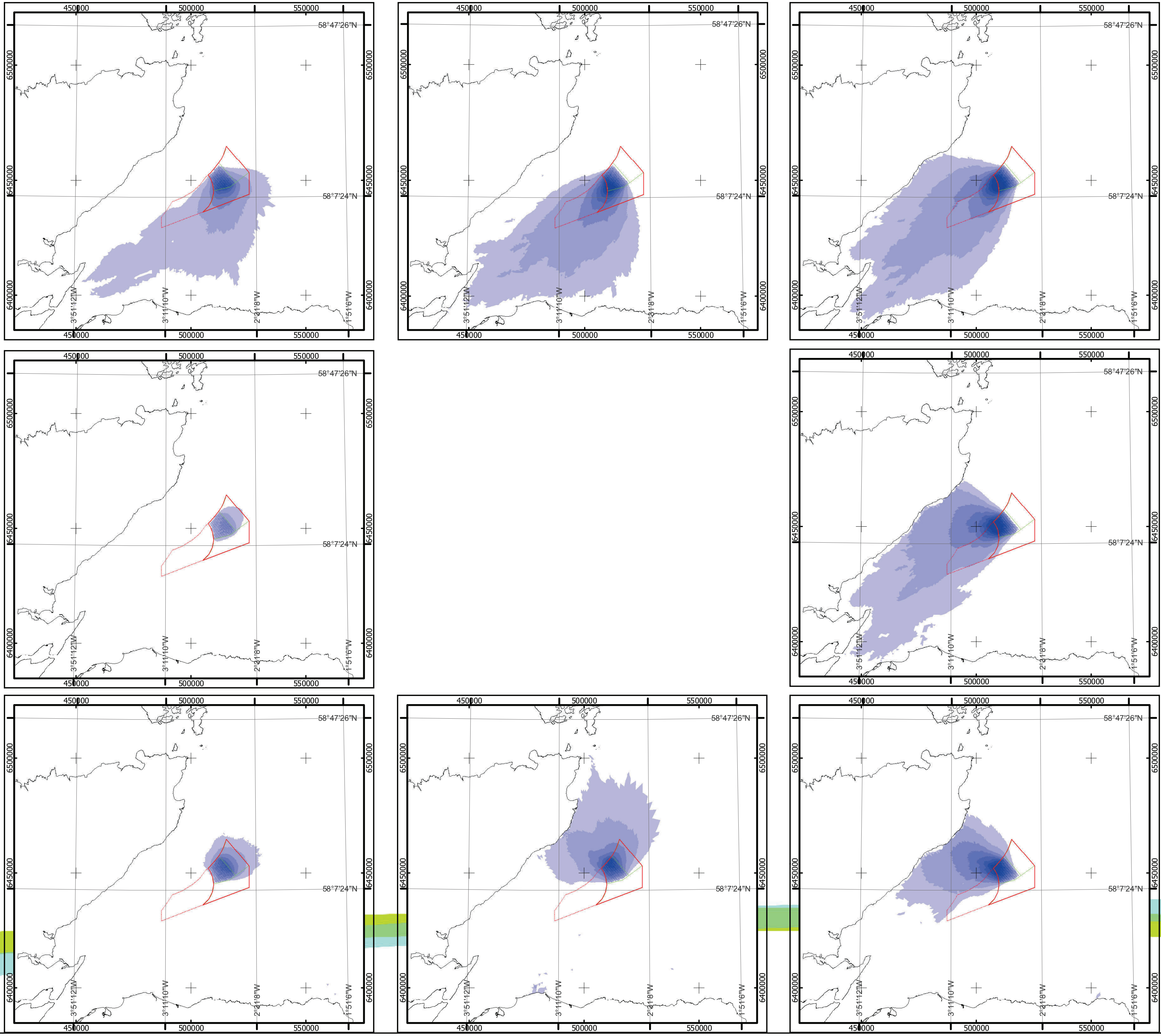
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 08/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-018

Fig 18 - Effect of one MORL Wind Farm on Wave Height (GBS, T3, 1in50yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

MORL EDA

MORL WDA

Site Boundaries

S3mw

Difference

Above -0.05

-0.10 - -0.05

-0.20 - -0.10

-0.30 - -0.20

-0.40 - -0.30

-0.50 - -0.40

-0.60 - -0.50

-0.70 - -0.60

Below -0.70

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

N

Geodetic Parameters: WGS84 UTM Zone 30N

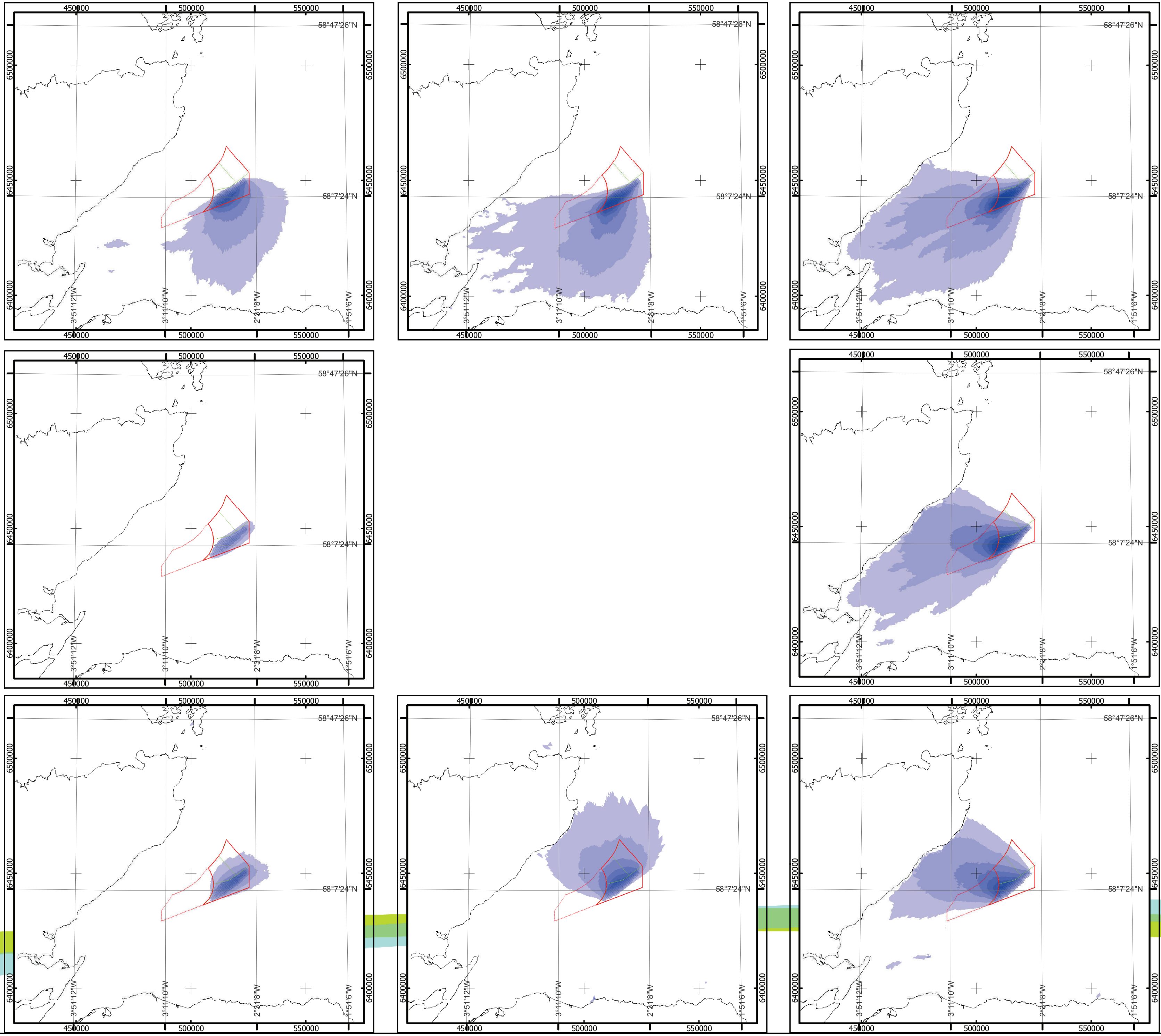
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 08/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-019

Fig 19 - Effect of one MORL Wind Farm on Wave Height (GBS, S3, 1in50yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Site Boundaries

M3mw

Difference

- Above -0.05
- -0.10 - -0.05
- -0.20 - -0.10
- -0.30 - -0.20
- -0.40 - -0.30
- -0.50 - -0.40
- -0.60 - -0.50
- -0.70 - -0.60
- Below -0.70

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

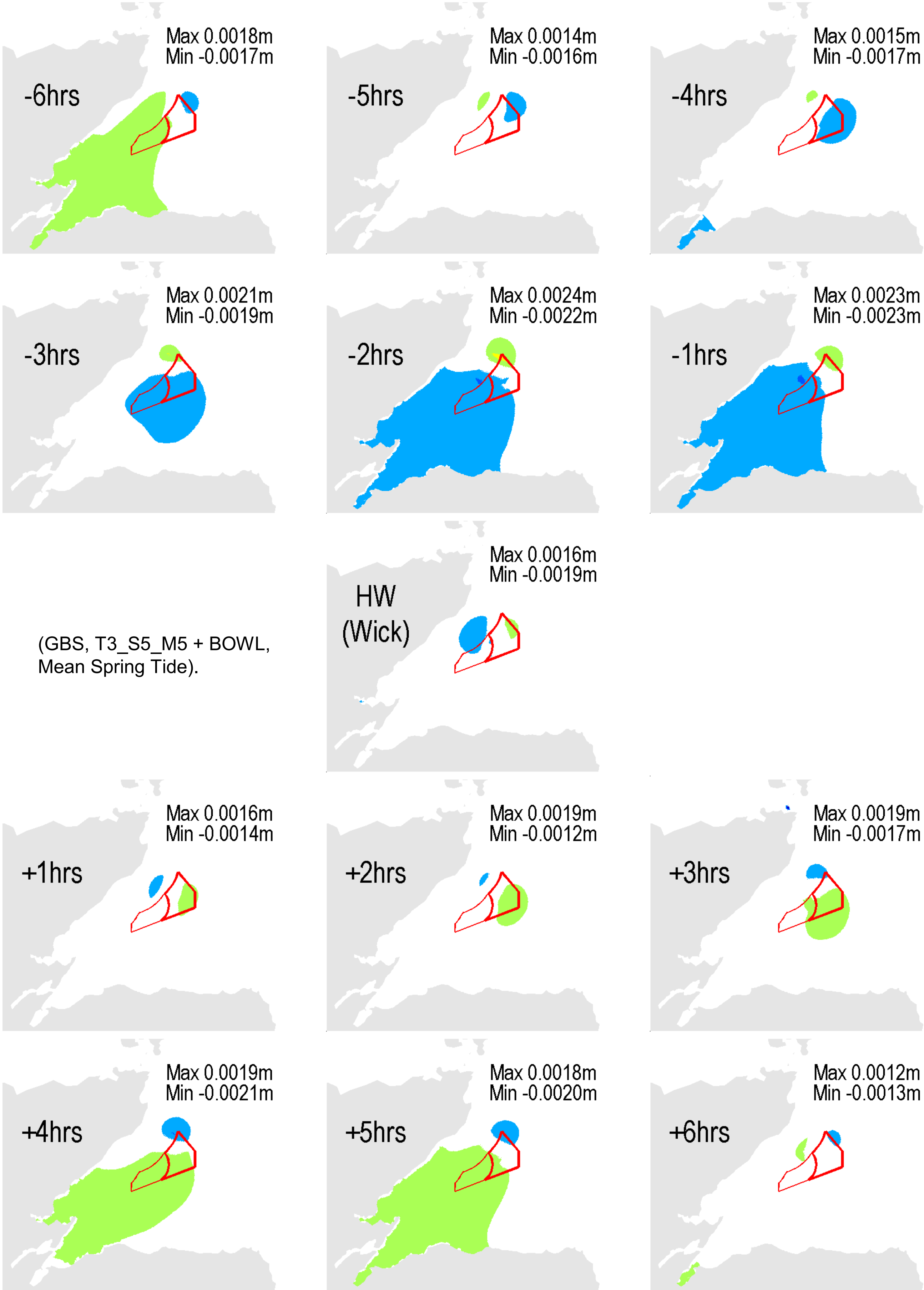
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 09/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-020

Fig 20 - Effect of one MORL Wind Farm on Wave Height (GBS, M3, 1in50yr)

Moray Offshore Renewables Ltd



Water level difference (m)

+0.005
+0.004
+0.003
+0.002
+0.001
0.000
-0.001
-0.002
-0.003
-0.004
-0.005

(Differences <0.001m are excluded as white)

Site outline

Corresponding effects on neap tides and for jackets at all times are <0.001m

edp renewables REPSOL

Moray Offshore Renewables Ltd

Produced: DOL
Reviewed: CLH
Approved: WSC

A4 Chart

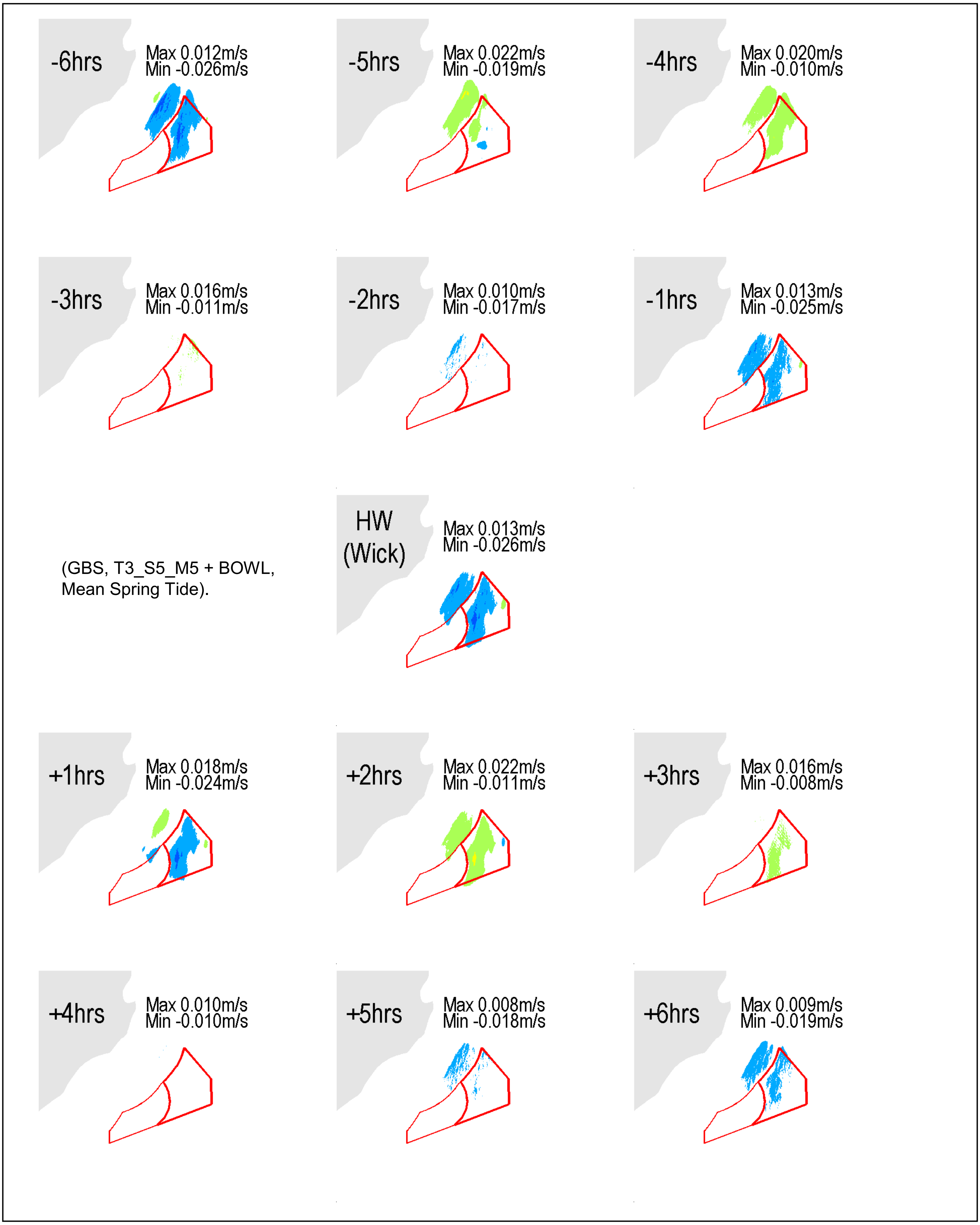
Revision:

Date: 01/06/12

REF: 8460001-PPW0201-ABP-MAP-00#

Fig 21. Combined Effect of the Project and BOWL Development on Tidal Water Levels

Moray Offshore Renewables Ltd



+0.05
+0.04
+0.03
+0.02
+0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05

Current speed difference (m/s)

(Differences <0.01m/s are excluded as white)

MORL EDA Outline

R3 Zone Outline

Corresponding effects on neap tides and for jackets at all times are <0.01m/s

edp renewables REPSOL

Moray Offshore Renewables Ltd

Produced: DOL
Reviewed: CLH
Approved: WSC

A4 Chart

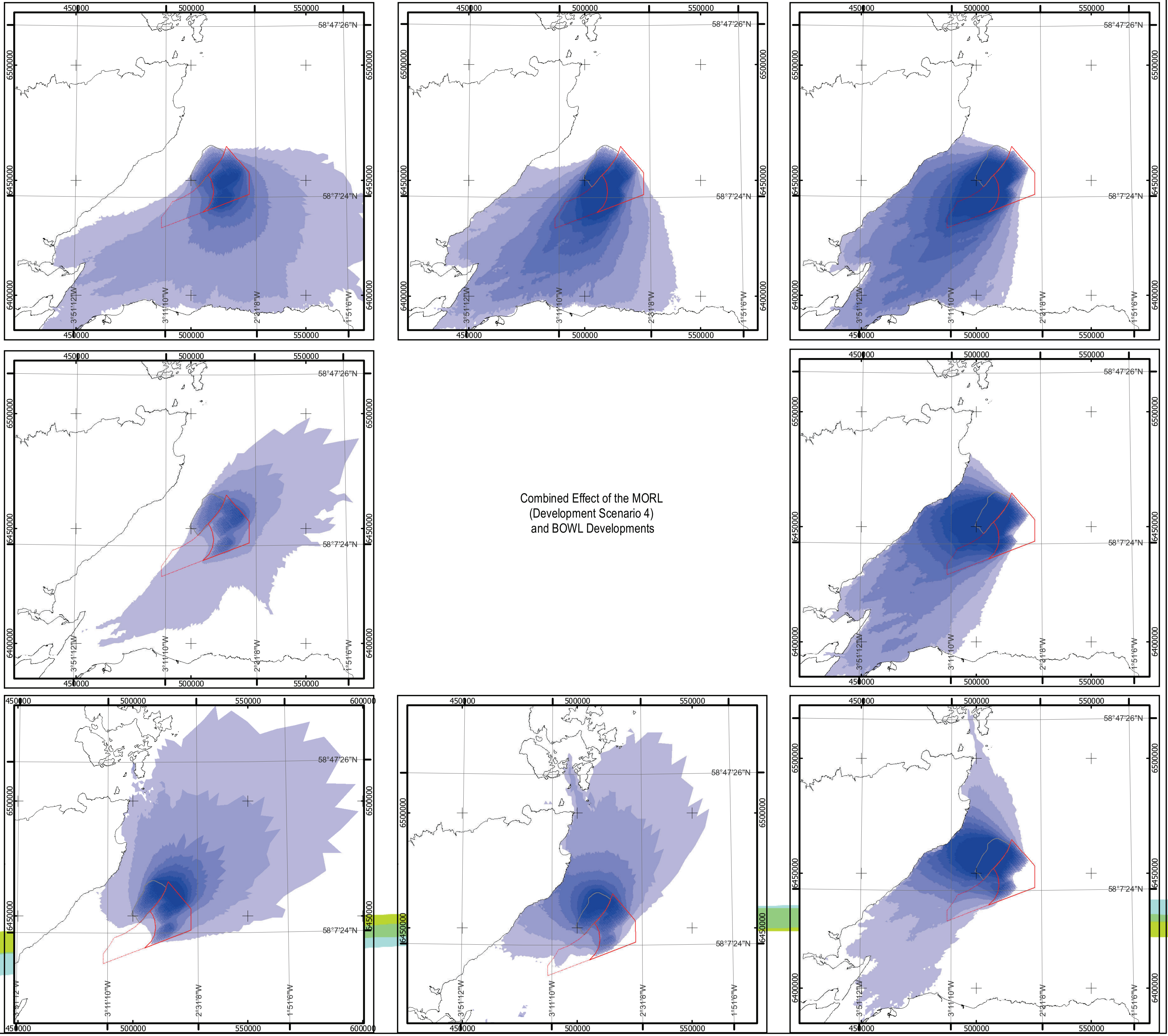
Revision:

Date: 01/06/12

REF: 8460001-PPW0201-ABP-MAP-022

Fig 22. Combined Effect of the Project and BOWL Development on Tidal Current Speeds.

Moray Offshore Renewables Ltd



Combined Effect of the MORL (Development Scenario 4) and BOWL Developments

Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Beatrice Offshore Wind Farm

Difference

- -0.04 - 0.50
- -0.09 - -0.05
- -0.19 - -0.10
- -0.29 - -0.20
- -0.39 - -0.30
- -0.49 - -0.40
- -0.59 - -0.50
- -0.69 - -0.60
- Below -0.70

616 GBS, T3_S5_M5 + BOWL 3.6MW

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

N

Geodetic Parameters: WGS84 UTM Zone 30N

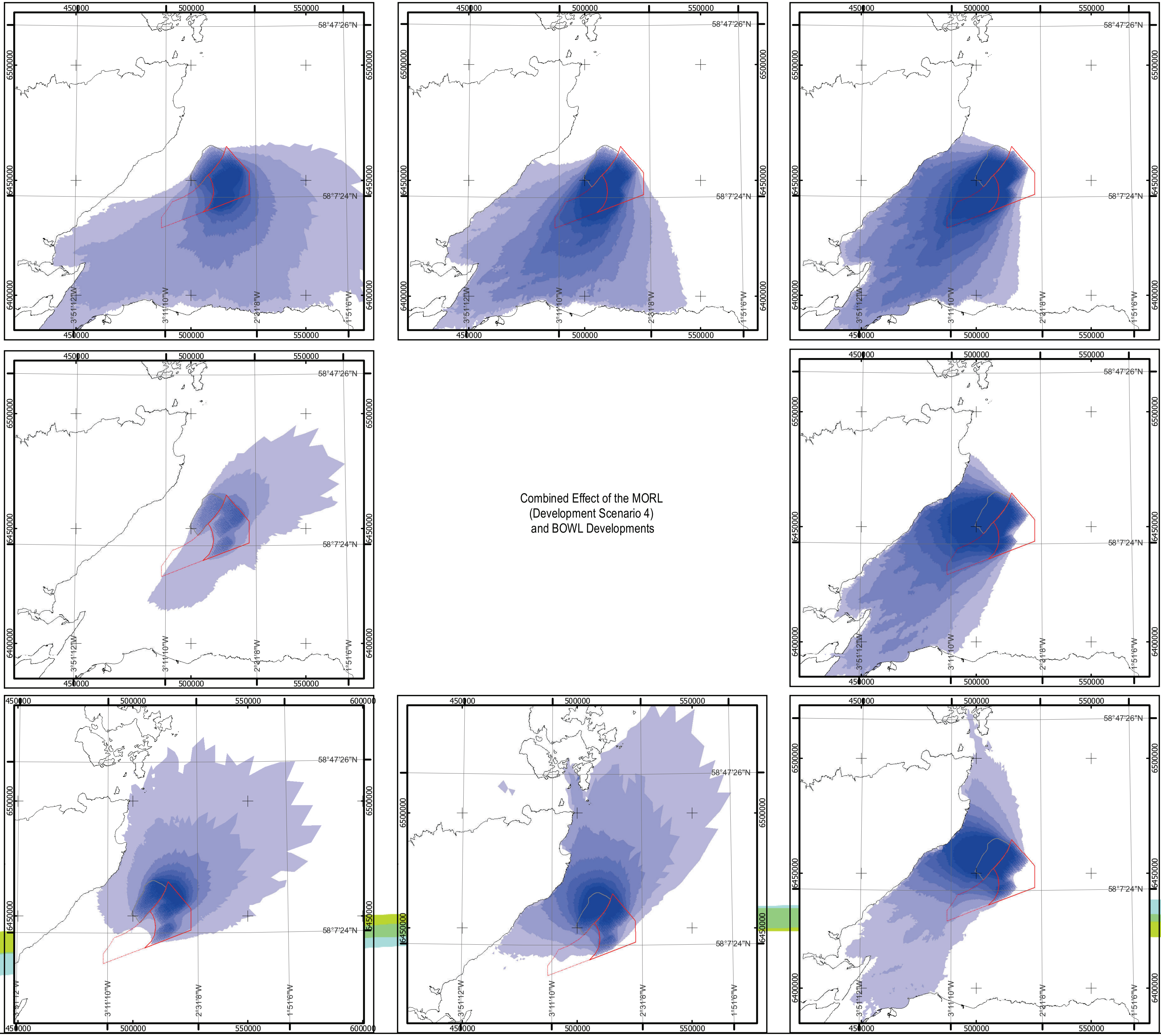
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 23/11/2011 Revision: A

REF: 8460001-PPW0201-ABP-MAP-023

Fig 23 - Cumulative Effect of the Project and BOWL Developments on Wave Height (1in1yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

MORL EDA

MORL WDA

Beatrice Offshore Wind Farm

Difference

-0.04 - 0.50

-0.09 - -0.05

-0.19 - -0.10

-0.29 - -0.20

-0.39 - -0.30

-0.49 - -0.40

-0.59 - -0.50

-0.69 - -0.60

-1.99 - -0.70

616 GBS, T3_S5_M5 + BOWL 3.6MW

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

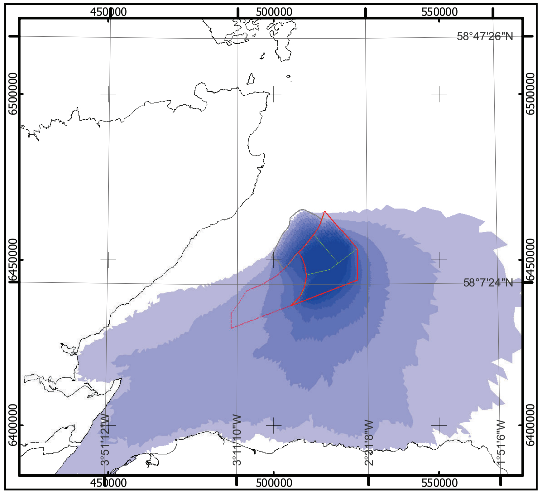
Produced: MCE
Reviewed: NMW
Approved: DOL

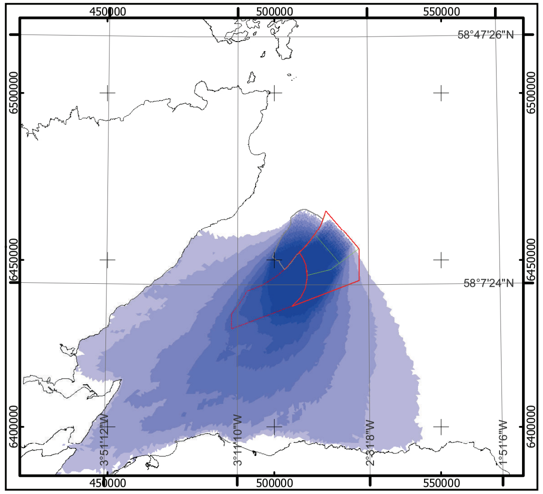
Date: 23/11/2011 Revision: A

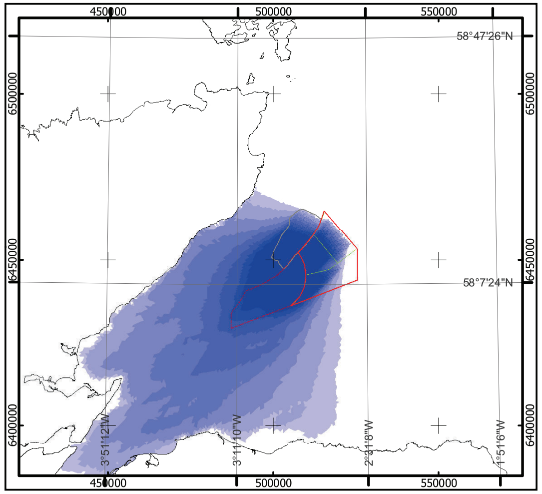
REF: 8460001-PPW0201-ABP-MAP-024

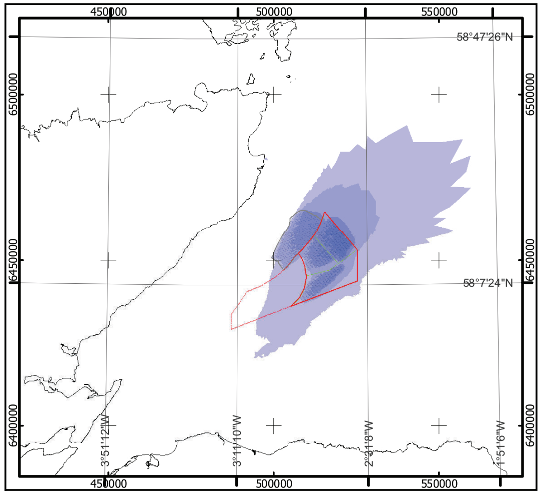
Fig 24 - Cumulative Effect of the Project and BOWL Developments on Wave Height (1in10yr)

Moray Offshore Renewables Ltd

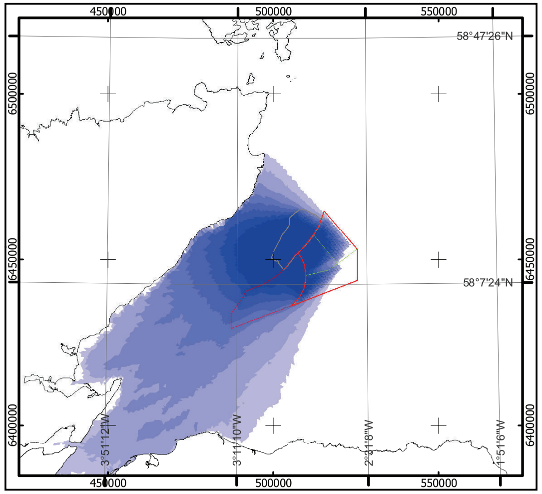


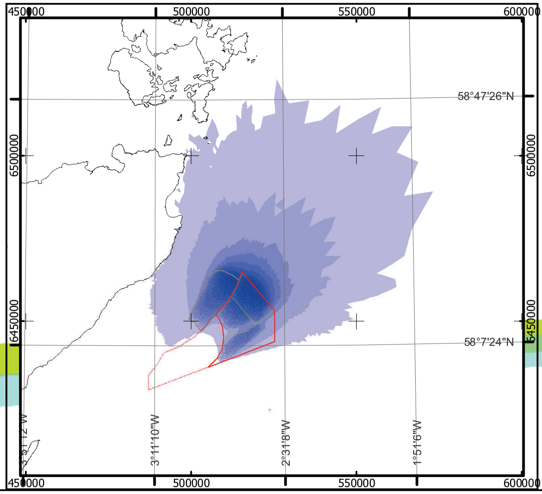


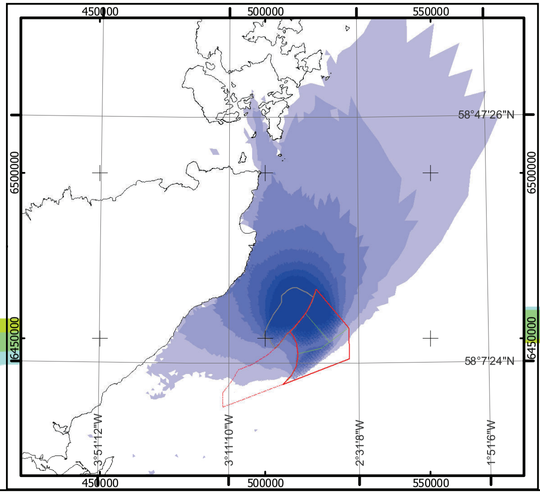


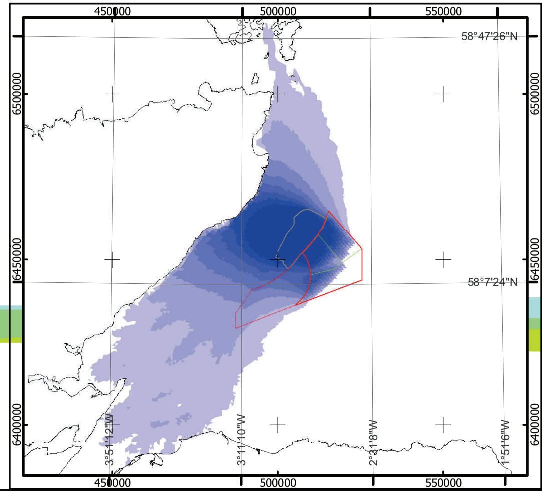


Effect of the MORL EDA on Wave Height (GBS, Development Scenario T3-S5-M5-BOWL, 1:50 Year Return Period)









Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Beatrice Offshore Wind Farm
- Site Boundaries

Difference

- -0.04 - 0.50
- -0.09 - -0.05
- -0.19 - -0.10
- -0.29 - -0.20
- -0.39 - -0.30
- -0.49 - -0.40
- -0.59 - -0.50
- -0.69 - -0.60
- Below -0.70

616 GBS, T3_S5_M5 + BOWL 3.6MW

Horizontal Scale: 1:1,600,000 A3 Chart

0 40,000 80,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

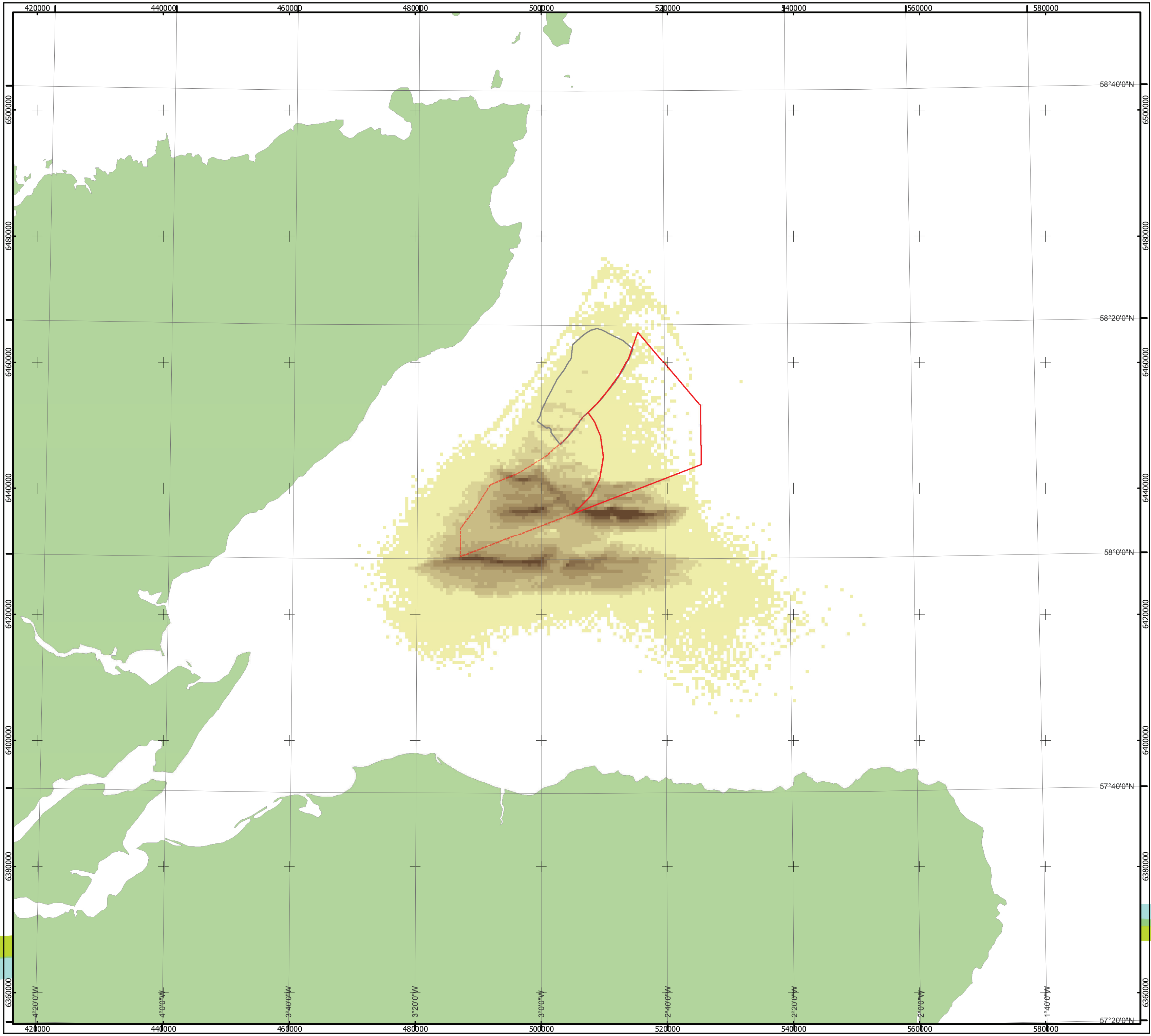
Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 17/05/2012 Revision: B

REF: 8460001-PPW0201-ABP-MAP-025

Fig 25 - Cumulative Effect of the Project and BOWL Developments on Wave Height (1in50yr)

Moray Offshore Renewables Ltd



Moray Offshore Renewables Ltd

KEY

- MORL EDA
- MORL WDA
- Beatrice Offshore Wind Farm

Maximum Deposition Thickness (mm)

- 0 - 0.01
- 0.02
- 0.03 - 0.05
- 0.06 - 0.1
- 0.11 - 0.2
- 0.21 - 0.3
- 0.31 - 0.4
- 0.41 - 0.5
- 0.51 - 0.6

Dredging Overspill During Bed Preparation for 616 GBS, T3_S5_M5 + BOWL 3.6MW

Horizontal Scale: 1:575,000 A3 Chart

0 15,000 30,000 Metres

Geodetic Parameters: WGS84 UTM Zone 30N

Produced: MCE
Reviewed: NMW
Approved: DOL

Date: 23/11/2011 Revision: A

REF: 8460001-PPW0201-ABP-MAP-026

Fig 26 - Maximum Cumulative Deposition Thickness of Fine Sediments

Moray Offshore Renewables Ltd