Appendix E1 – Physical Environment Consultation Documents

Seagreen Wind Energy

July 2012

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Royal HaskoningDHV
Enhancing Society Together

This appendix contains the following reports which were used during consultation with Marine Scotland in relation to the Physical Environment.

- Part I – Seagreen Position Paper: Coastal and Seabed Impact Assessment (November 2011); and

- Part II - Seagreen Position Paper Update: Further Evidence Base (June 2011)

Part I
Seagreen Position Paper:
Coastal and Seabed Impact Assessment
(November 2011)

DOCUMENT NO:

[A4MR/SEAG-Z-DEV240-SRP-052]

DOCUMENT TITLE:

Seagreen Position Paper: Coastal and Seabed Impact Assessment

PROJECT NAME:

Round 3 Zone 2
Firth of Forth
Offshore Wind Farm Development

RESTRICTED COMMERCIAL

A1	24/11/10	DRAFT FOR DISCUSSION	JC / NC	NB	JC
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1.0 BACKGROUND

Assessment of the tidal, wave and sediment regimes, and their influences on morphological change, are an essential part of the Environmental Impact Assessment (EIA) process associated with offshore wind farms.

Such assessments were undertaken during Round 1 and Round 2 schemes as 'Coastal Process Studies', but as schemes move towards deeper water in Round 3 so coastal processes become less relevant and sea bed processes more so.

The purpose of Coastal and Sea Bed Impact Assessment is to assess and, where necessary and practicable, mitigate the environmental impact of offshore wind farm developments on the marine environment. The studies consider both near-field effects (within the development site) and far-field effects (beyond the development site and across the wider regional sea bed and coastline). They also consider different phases of the lifecycle of the development, such as construction, operation and decommissioning.

The main impacts on the marine environment from an offshore wind farm development are associated with the turbine towers and foundations, offshore substations and foundations, inter-connecting and export cables, and the landfall at the shoreline.

2.0 BEST PRACTICE GUIDANCE

During Round 1 and Round 2 schemes, coastal process impact assessments were undertaken in accordance with best practice guidance from ETSU (2002) and CEFAS *et al.* (2004).

Since some of those schemes are now operational, post-project monitoring has been undertaken and reviewed to evaluate some of the environmental issues associated with those schemes.

This has been used to develop new best practice guidance for Round 3 schemes to reflect the lessons learned from Rounds 1 and 2 and the new challenges associated with developments in the deeper water environments. The resulting guidance (COWRIE, 2009) highlights five key areas, which have been screened below for their relevance (or otherwise) to the Firth of Forth Round3 Zone and their consideration in the Phase 1 EIA site:

Ref.	Issue	Screening	RELEVANT
1	Suspended sediment dispersion and deposition patterns resulting from foundation and cable installation or decommissioning	Potential to impact upon receptors sensitive to changes in burial depth, suspended sediment loads and textural changes in sedimentary habitats.	IN
2	Changes in coastal morphology due to cable landfall	While changes in coastal morphology due to landfall can not be discounted, 'mitigation by design' shall seek to reduce any potential impact to environmentally acceptable levels.	IN
3	Scour and scour protection	Potential to impact upon receptors sensitive to changes in burial depth, suspended sediment loads and textural changes in sedimentary habitats.	IN

Ref.	Issue	Screening	RELEVANT
4	Wave energy dissipation and focussing for sites close to shore (<5km)	Located >25km from the shoreline, therefore, wave energy dissipation and focussing for sites further offshore not considered to be an issue	OUT
5	Wave and current processes controlling very shallow sandbank morphology especially with less understood foundations types	The majority of the Phase 1 developments are located in an area of sea bed with no major sandbanks and in water depths of approximately 35-60m below LAT. However where isolated sandwaves are present they attain elevations of ~10m above the seabed, with overlaying water depths of approximately 40m.	OUT

3.0 KEY ISSUES FOR ASSESSMENT

Based on the above screening exercise the key issues for further assessment and study relate to:

1. Suspended Sediment Dispersion and Deposition Patterns Resulting From Foundation and Cable Installation or Decommissioning

2. Changes in Coastal Morphology due to Cable Landfall

3. Scour and Scour Protection

These issues are discussed briefly in terms of their relevance to Seagreen's Phase 1 developments and issues learned from Round 1 and Round 2 with key Best Practice Guidance set out in the following sub-sections.

3.1 Suspended Sediment Dispersion and Deposition Patterns Resulting From Foundation and Cable Installation or Decommissioning

Relevance: Receptors sensitive to changes in burial depth, suspended sediment loads and textural changes in sedimentary habitats.

Lessons Learned from R1/R2 and Best Practice Guidance:

- There is no research or evidence to define significant harm thresholds for species in UK Waters, therefore there is presently no purpose in undertaking plume modelling, except for public relations purposes where this is deemed of value (COWRIE, 2009)

- Jetting – since this installation technique results in suspended sediments remaining close to the sea bed, there is no identified concern

- Impacts are typically of temporary / short-duration and temporary / small in proportion to presence of turbines and towers

Seagreen Approach

Seagreen's approach to the assessment of suspended sediment dispersion and deposition patterns resulting from foundation and cable installation and decommissioning is set out in below.

- Analyse metocean data to define critical relationships between waves, tidal currents and suspended sediment concentrations
- Analyse geophysical, bathymetry and benthic sediment data to define the character of the sea bed sediments and topography
- Use a ranking system to assess the level of disturbance of the installation techniques proposed, similar to that presented in BERR guidance on Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry (2008)
- Develop a conceptual understanding of the key processes operating across the site, including the tidal streams and tidal excursion distances
- Identify critical receptors and their sensitivity to change(s)
- Use ecological expertise to interpret the significance of the impact caused by the level of disturbance on the particular sea bed characteristics, based upon conceptual understanding of the tidal excursion patterns and the sensitivity of the receptors.

Data to Inform Assessment:

- Met Office European Wave Model - 10 years wave data
- UK Hydrographic Office network of 'standard' and 'secondary' ports
- Existing 3rd party regionally modeling of tidal ellipses at twenty locations across the Zone
- Seagreen Metocean campaign (Zone and potential export cable route deployments) – Current and wave data and corresponding suspended sediment concentrations and sea bed sediment characterisation
- Geophysical survey Seagreen Phase 1: multibeam bathymetry, backscatter, side-scan sonar, sub-bottom profiling, magnetometer.
- Seagreen Phase 1 benthic survey – sediment particle size distributions and seabed photography at locations throughout the Phase 1 area

3.2 Changes in Coastal Morphology due to Cable Landfall

Relevance: Receptors sensitive to erosion or accretion including habitat and landscape.

Lessons Learned from R1/R2 and Best Practice Guidance:

- Expert opinion should suffice (COWRIE, 2009)

Seagreen Approach

Seagreen's approach to the assessment of changes to coastal morphology and cable landfall is set out in below. It is envisaged that the assessment of coastal landfall works shall not require detailed modelling but may be assessed via Expert Geomorphological Assessment.

- Historical Trend Analysis (HTA) to identify changes in shoreline position over recorded historic time
- Analysis of any available beach profile surveys to determine more contemporary changes
- Develop a conceptual understanding of the evolution of the shoreline, and the influence of waves, tides, currents, and structures
- Expert Geomorphological Assessment (EGA) to assess the impacts of landfall on the existing processes and future evolution of the shore.

Data to Inform Assessment:

- Coastal Cells in Scotland: Cell 1 – St Abb's Head to Fife Ness
- Coastal Cells in Scotland: Cell 2 – Fife Ness to Cairnbulg Point
- Sediment movements at Barry's Link
- Metocean survey results (Zone and potential export cable route locations)
- Geophysical survey of Export Cable Route and Landfall location

3.3 Scour and Scour Protection

Relevance: Seabed scour associated with cables and foundations and their impact upon receptors sensitive to the introduction of new substrate

Lessons Learned from R1/R2 and Best Practice Guidance:

- To date empirical approaches have been used to assess scour hole formation without need for numerical modelling of these scour-formation processes (although modelling of the fate of any scoured material has sometimes been undertaken). Since previous work has been mainly focused on mono-pile foundations, there may be the need for further research, including both numerical and physical modelling, in this area for R3. However, Seagreen feel that this is an issue for the industry as a whole and should not be the sole responsibility of a single developer.

Seagreen Approach:

Seagreen's approach to the assessment of scour and scour protection is to consider both 'global' sea bed scour (i.e. general erosion) and scour around turbine and substation foundations, using the methods set out below.

- Global sea bed scour (this has relevance to cable burial depths and the potential for free-spanning of cables)
  - Historical Trend Analysis (HTA) of seabed morphology based on available multibeam bathymetry data sets already made available to Seagreen by UK Hydrographic Office , including near complete coverage of the Firth of Forth Zone. This would enable sandwave and megaripple migration rates and spatial and temporal changes in seabed substrate type to be assessed over recent historic timescales.
  - Develop a conceptual understanding of the evolution of the sea bed, and the influence of waves, tides, currents, and sea bed features such as sandwaves and megaripples
  - Expert Geomorphological Assessment (EGA) to assess the impacts of sea bed changes on cables.

- Scour around foundations:
  - Desk-based review of existing empirical methods for assessing scour hole development around particular foundation types
  - Characterisation of the Firth of Forth Zone Phase 1 area into distinct 'characteristic areas' based on sea bed sediment character and sediment thickness, and the conceptual understanding of sea bed processes and morphological change
  - Estimation of scour hole development (possibly using 'most likely' and Rochdale Envelope 'worst case' scenarios due to uncertainties about foundation type(s) and available empirical approaches being largely focused on mono-pile foundations)
  - Identify critical receptors and their sensitivity to change(s)
  - Tidal excursion modelling to identify the direction of transport of any released scour material (i.e. towards / away from sensitive receptors)

- Use ecological expertise to interpret the significance of the impact caused by the transport of the scoured material, based upon understanding of the tidal excursion patterns and the sensitivity of the receptors.
- If initial assessments demonstrate no significant effect, no further consideration is necessary. If the assessment shows a significant potential impact sediment plume modelling may be required.

Data to Inform Assessment:

- Existing empirical methods and Best Practice documents for assessing scour hole development around particular foundation types
- Metocean survey data, including characterisation of existing suspended sediment concentrations and sea bed sediment types
- Geophysical survey data including sediment thicknesses and sea bed features

4.0 SUMMARY

COWRIE (2009) guidance for assessing coastal and sea bed impacts during the development of R3 offshore wind farms presents a question-led approach to assist in defining the appropriate approach. Table 1 follows these questions for the three potential impact categories identified as being relevant to the Firth of Forth development.

Seagreen is now seeking advice from Marine Scotland that they are in agreement with the information presented herein before embarking on these coastal and sea bed impact assessment.

Table 1 - Key impacts and questions to be addressed.

	Suspended Sediment Dispersion and Deposition Patterns Resulting From Foundation and Cable Installation or Decommissioning	**Changes in Coastal Morphology due to Cable Landfall**	**Scour and Scour Protection**
What are the sensitive receptors	Within Seagreen's Phase 1 development and wider assessment areas, the key sensitive receptors relate to the sandeel fishery, herring spawning and benthic ecology.	Areas of erosion and accretion and areas of intertidal habitat value.	Key sensitive receptors relate to suitable habitat for various lifecycle stages for sandeeel, herring and benthic ecology.
What information do we need to assess impacts on these?	Information on nature of mobile sediments and bedforms, particle size distribution, tidal and wave current profiles with depth, life cycle of sandeel and herring and their interactions with wider benthic and marine ecology.	Detailed information on metocean conditions, seabed and intertidal sediment distribution patterns and detailed conceptual understanding of coastal dynamics.	Broadscale habitat maps, iinformation on nature of mobile sediments and bedforms, particle size distribution, tidal and wave current profiles with depth, spatial distribution of herring spawning grounds, sandeel habitat and interactions with wider ecological linkages.

Can information be practicably and efficiently provided by existing knowledge and available field data without the need for numerical modelling?	Yes. Though there may be a requirement to investigate linkages in and between the various ecological niches via additional multi-variative data acquisition and analysis techniques which will need to be established.	Yes, though would be further strengthened by a Historical Trend Analysis of shoreline changes to set contemporary coastal change within a historical context.	• global sea bed scour – yes, including Historic Trends Analysis of sea bed • scour hole development – yes to an extent, existing empirical approaches are based on mono-pile foundations, but estimates of scour can be developed, perhaps best using sensitivity test approachesData likely to be suitable from Metocean survey. • fate of scour material – yes, if scour volumes are small and/or tidal excursion patterns take material away from sensitive sea bed areas; sediment plume modelling may be required if this is not the case.
If no, can numerical models represent the processes involved sufficiently to provide the required info?	For ecosystem changes No.	Not applicable	• global sea bed scour – no • scour hole development – not unless very complex Computational Fluid Dynamics and/or physical laboratory modelling are undertaken to improve existing empirical approaches, therefore sensitivity approaches are instead recommended in assessments • fate of scour material – yes, plume modelling can be undertaken to better quantify the effects of scour material dispersal if scoured volumes are large or if scoured material is transported towards sensitive sea bed receptors

If yes, can sufficient field data be obtained the adequately calibrate and validate the model to provide confidence in results?	For Ecosysytem modeling this can not be obtained within the time span of the development and consenting process.	Not applicable	• scour hole development – no, this needs to be industry-wide research if taken forward • fate of scour material – yes, from existing metocean and geophysical surveys
Does the regulating authority agree with the proposed approach?	To be established on 1st December 2010	To be established on 1st December 2010	To be established on 1st December 2010

Part II
Seagreen Position Paper Update:
Further Evidence Base
(June 2011)

DOCUMENT NO:

A4MR/SEAG-Z-DEV240-SRP-085

DOCUMENT TITLE:

Seagreen Position Paper Update: Further Evidence Base – Coastal and Seabed Processes

PROJECT NAME:

Round 3 Zone 2
Firth of Forth
Offshore Wind Farm Development

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1.0 BACKGROUND

In November 2010, Seagreen produced a Position Paper proposing its approach to the Coastal and Seabed Impact Assessments as part of the Environmental Impact Assessment (EIA) process associated with its development at the Firth of Forth Round 3 Zone.

Seagreen's Position Paper on Coastal and Seabed Impact Assessment (A4MR/SEAG-Z-DEV240-SRP-052), issued to Marine Scotland on 24/11/2010, and had three main aims:

1. To establish the relevant issues for Seagreen's Phase 1 EIA and cumulative assessment;
2. To propose a proportionate approach to the assessment of the issues in line with their potential environmental impact; and
3. To determine the requirement for modelling to assess these issues.

The Position Paper was aimed at addressing relevant issues identified in the *Best Practice Guidelines for Coastal Process Modelling for Offshore Wind Farms* (COWRIE, 2009), published specifically for Round 3 developments.

The COWRIE guidance document identified five principal areas for investigation:

Item	Issue
1	Suspended sediment dispersion and deposition patterns resulting from foundation and cable installation or decommissioning
2	Changes in coastal morphology due to cable landfall
3	Scour and scour protection
4	Wave energy dissipation and focussing for sites close to shore (<5km)
5	Wave and current processes controlling very shallow sandbank morphology especially with less understood foundations types

These issues were screened within the Position Paper for their relevance and applicability to Seagreen's Phase 1 development, based on site-specific information and characteristics, leading to detailed methods of assessment being proposed for items 1, 2 and 3. Initially items 4 and 5 were 'screened out' from needing further assessment since the Firth of Forth site is not located within 5km of the shore, and is not characterised by very shallow sandbank morphology.

A meeting was held with Marine Scotland in January 2011 to discuss the Position Paper. Whilst, overall, Marine Scotland agreed in principle with its content, particularly with regards to the key coastal and sea bed processes of interest and the staged approaches to their assessment, a more rigorous evidence base was requested in relation to the 'screening out' of items 4 and 5. Also, upon request from Marine Scotland, the term 'shallow sandbank morphology' in item 4 was reworded as 'sandbank and seabed morphology' to better capture water depth and seabed characteristics of the zone.

1.1 Report structure

This report provides the further evidence base requested by Marine Scotland to support Seagreen's proposal for the 'screening out' of detailed modelling approaches to address issues of 'wave energy dissipation and focussing for sites close to shore' (COWRIE guidance item 4) and 'Wave and current processes controlling very shallow sandbank morphology especially with less understood foundations types ' (COWRIE guidance item 5). It also provides an update on progress with desk-based research into empirical methods for making assessments of scour hole development associated with COWRIE guidance item 3.

This section **(Section 1)** provides a brief background to this report and should be read in conjunction with Seagreen's Position Paper on Coastal and Seabed Impact Assessment (A4MR/SEAG-Z-DEV240-SRP-052), issued to Marine Scotland on 24/11/2010. **Section 2** provides a review of scour and scour assessment and presents a First Order Scour Assessment for foundation types currently under consideration within Seagreen's Phase 1 developments. **Section 3** provides a review of Environmental Statements (ES's) in relation to Wave Energy Dissipation and Focussing for sites close to the shore. **Section 4** provides a review of wave and current processes in relation seabed features. Sections 2 and 3 provide supplementary information in relation to less understood foundation types. **Section 5** presents a Source-Pathway-Receptor model as requested by Marine Scotland to facilitate understanding of potential impacts upon sensitive receptors. **Section 6** presents a review of the relevant data pertaining to Seagreen's Phase 1 area and discusses the relevance of the presented information to Seagreen's Phase 1 developments. **Section 7** proposes the Way Forward with regards to assessment of key issues raised and discussed herein.

2.0 SCOUR AND SCOUR PROTECTION

This section of the report provides an update on progress to date with item 3, Scour and Scour Protection, specifically in relation to foundation scour.

To date, on Round 1 and Round 2 developments, empirical approaches have been used to assess scour hole formation locally around turbine foundations as part of the EIA process. For some, but not all, schemes, modelling of the fate of any scoured material has then been undertaken to determine the impact on sea bed receptors across the wider sea bed.

However, most previous work relating to foundation scour has been focused on relatively slender monopile foundations, for which considerable empirical theory exists. COWRIE guidance (2009) therefore suggests that there may be the need for further research in this area for Round 3 developments, which are likely to use different foundation solutions.

As an initial component of the assessments of foundation scour for the Firth of Forth Zone, Phase 1, a thorough desk-based review has been undertaken of existing literature and empirical methods for assessing scour development. This has led to the development of suitable methods for predicting scour holes and scour volumes around the particular foundation types currently under consideration at the site.

2.1 Scour Processes

Gradients in the sediment transport rate around a structure, caused by the disturbance exerted on the ambient flow field, have the effect of generating scour followed by the development of erosion holes. On sand or gravel, the process can also initiate local deposition of some of the eroded material, with the result that the size and shape of the scour hole can evolve and change over time. However, on a clay or silty seabed, the material that is eroded tends to be carried off in suspension and this leaves a scour hole that is not easily infilled by the natural processes.

In tidal environments, scour response is progressive and dynamic. Scour hole development is likely to develop more rapidly under storm conditions. When the storm or current duration is shorter than the time required for full scour to develop, then the scour hole will not achieve its complete equilibrium depth during that event. The pattern and depth of scour under combined waves and currents will fluctuate over time due to temporal and directional variations of different magnitudes.

The disturbance exerted on the ambient flow field will vary depending on what foundation type is considered. Due to this different assessment methods may be required for different generic 'types' of foundation. Based upon a range of empirical formulae, a suite of tools have been established to enable assessments to be made of scour around jacket, tripod, flat gravity base and conical (flask-shaped) gravity base structures.

These assessment approaches have been verified against published experimental data, including several previous physical modelling studies and both measured data and anecdotal field observations from existing offshore wind farm sites, providing a sufficiently robust scientific approach to enable first-order estimates to be made of scour volumes for the proposed Firth of Forth development. [Note: These methods were not developed with the intent of informing the engineering design process].

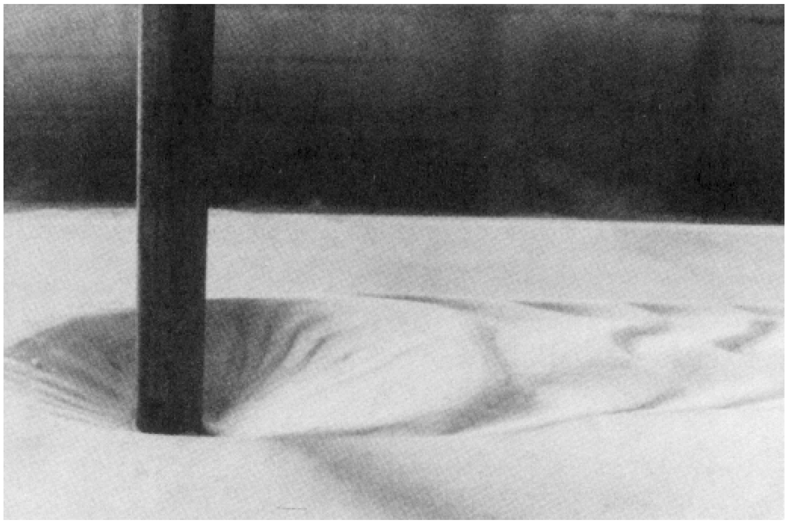
This paper summarises the approaches to predicting scour around vertical and horizontal cylinders, the approaches to predicting scour around gravity bases, and provides a first order estimate of scour around different foundation types based on example site conditions. [Note: It is intended that these estimates of scour volumes will be updated when more specific design conditions become available, including any sea bed preparation for foundation installation].

2.2 Scour Around Vertical and Horizontal Cylinders

Many Round 1 and Round 2 developments in the UK utilised monopile foundation designs. Well-established empirical methods by Sumer and Fredsøe (2002) were typically used to make estimates of scour hole formation and scour volumes.

Owing to the subsequent construction of a significant number of these developments, there is a significant body of recent field experience concerning scour development around monopiles (**Figure 2.1**). Whitehouse et al (2011) provide a comprehensive review of monopile scour sites, seven of which were in UK waters and three were off the north coast of continental Europe.

Figure 2.1 Scour hole around a monopile



[Source – this is believed to be from R. Whitehouse]

This information base therefore provides good predicted and observed data set relating to scour depth, the influence of sea bed conditions, and the extent of scour hole formation. Anecdotal evidence is also available from several other Round 1 and Round 2 developments.

Lessons learned from this information have been incorporated in the development of assessment methods for scour around the principal legs of a jacket or tripod design. These have then been complemented by the methods presented by Sumer and Fredsøe (2002) for estimating the scour volumes that could be generated under horizontal near-seabed bracing elements of a jacket or tripod type structure.

The assessment methods for jacket and tripod type foundations have therefore considered both the vertical and horizontal members and have incorporated separate steps for the calculation of:

- Scour due to currents
- Scour due to waves
- Timescales of scour development

Yang et al (2010) published results of a comprehensive set of scale physical model tests performed to assess scour under combined wave and current around a four-legged jacket support structure for use with offshore wind farms (see **Figure 2.2**). These have been used to satisfactorily verify the predictions made using the methods developed during the present project to assess scour around jacket foundations.

Figure 2.2 Extent of scour observed around the physical model experiments

(Source: Yang et al (2010))

Likewise the predicted scour depths around a tripod compare well to published physical model tests by Stahlman and Schlurmann (2010).

2.3 Scour Around Gravity Bases

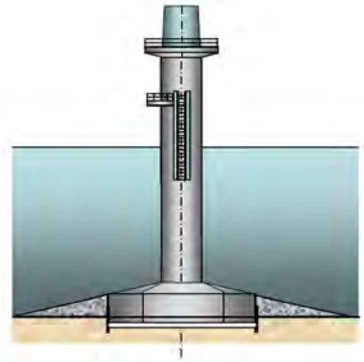
For caisson gravity bases, semi-empirical techniques available developed by Bos et al (2002) for predicting scour. These have been shown in the present study to successfully reproduce scour depths observed in physical model tests, also undertaken by Bos et al (2002).

Whitehouse (2004) observed in a series of physical model tests that the conical flask-type gravity base structure appeared to generate the largest scour depths among the possible gravity base configurations. He reported also that the maximum observed scour depth around the conical flask-type was around 0.45 times the diameter of the base. The present study shows that it is possible to reproduce such a depth by applying the solution proposed by Bos et al (2002) and assuming that the cylinder diameter is uniformly equal to that of the base. This suggests that the shape of the conical flask enhances the downward action of vortices near the seabed. As further evidence, investigations by Yeow and Cheng (2003) indicated that the relative proportions of the upper and lower elements of vertical cylinders situated on top of caissons exerted an influence upon the behaviour of vortices and hence upon the resulting scour behaviour around the foundation.

2.4 First Order Scour Estimates

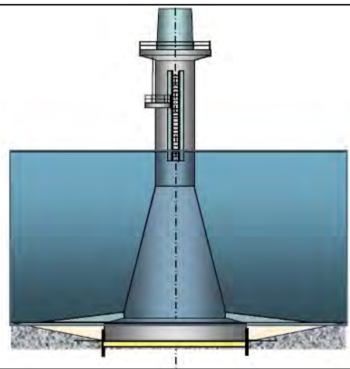
Using the methods developed, first order estimates have been made for generic dimensions and site conditions, using a water depth of 50m.

The foundation types assessed have been:



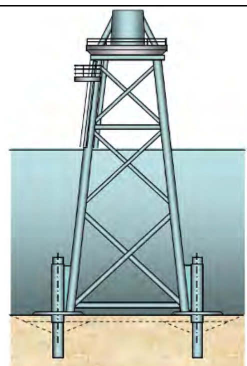
Narrow Shaft GBS

- Flat concrete gravity base foundation with 40m diameter x 10m high caisson



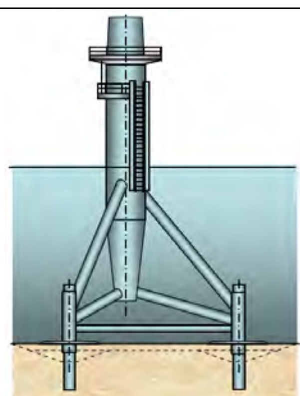
Conical GBS

- Conical flask type concrete gravity base structure (GBS), of 40m diameter at seabed level, with a 12m diameter main tower



Jacket

- Jacket with 2.2m diameter piles in each corner and with main columns of 1.34m diameter. The horizontal bracing is made of 0.62m diameter cylinders located at an elevation of 2m above the seabed



Tripod

- Tripod with 6m main central column, 3m diameter base piles and bracing legs of 3m diameter situated at a height of 3m above the seabed.

Scour volume predictions were based upon wave conditions with a return period of once in one-year, as presented in the Structural Basis of Design (GL Garrard Hassan, 2011). These wave conditions are characterised by a significant wave height of 6.7m with a typical peak period of 11s. In the assessments, these conditions have been accompanied by a depth-averaged current speed of 1.21m/s. The predicted scour volumes for typical generic structural forms are as follows:

- Flat concrete gravity base foundation: 3.2m equilibrium scour depth with a scour hole volume of *1,880m*^{3}
- Conical flask concrete gravity base foundation: a number of solutions are possible, but the one most likely, on the basis of scour results published by Whitehouse (2004) and supported by calculations undertaken here, is a scour depth of 9.5m, accompanied by a scour volume of *20,680m*^{3}. It is believed that more research work is needed on this type of structure, in order to better estimate the scour depth.
- Jacket: Worst case is wave plus current: scour hole volume of *1,540m*^{3}. This value is based on the main pile diameter since the scour under the bracing will be relatively negligible.
- Tripod, assuming that the total length of the bracing is 50m: Worst case is current only: scour hole volume of *6,719m*^{3}.

For jackets and tripods, the diameters of the scour holes around the piles under currents alone will be around 18m and 24m respectively, following the advice of Harris et al (2010) in respect of the slopes of the hole, which suggests that the holes from individual support piles could interact with one another, leading to a general reduction in bed elevation around the structure.

To take the predictions to the detailed stage, further field knowledge is required of the seabed sediment insitu density and size, along with the angle of friction. The fraction of clay or silt in the sea bed material is also required. The structural sizes of the support units and the environmental parameters also need to be finalised. The calculations given here are therefore first-order examples to demonstrate application of the methods that have been developed and are not final predictions.

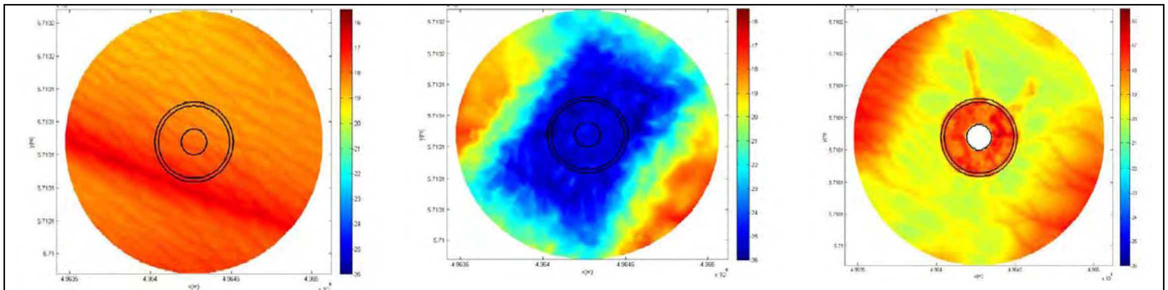
2.5 Scour Protection

Scour of the sea bed around the foundations could be prevented or reduced by the placement of scour protection materials (sometimes referred to as scour counter-measures). The estimates of foundation scour made in **Section 2.4** assume no scour protection is provided.

For pile-based foundations (e.g. monopiles, jackets or tripods) scour holes are often allowed to develop around the piles, and the holes are then in-filled with scour protection materials. In contrast, for gravity base structures (GBS) of either the flat base or conical base types and for caisson foundations (if used for tripods and jackets), substantial sea bed preparation may often be required to enable placement on the sea bed at a suitable depth and to a uniform level. In such cases, the backfilling operations following foundation placement often include scour protection which limits further scour from occurring. This process does, however, involve the removal (dredging or ploughing) of sea bed material to provide a suitable base. Where gravity bases have been used on existing wind farms, material has generally been locally ploughed and cast-aside adjacent to the foundation, subsequently becoming more widely dispersed by natural processes. For the larger foundations associated with Round 3 developments, there may be the need for dredging operations and disposal of the dredged material. Assessment procedures for determining the fate of dredge spoil deposited at licensed disposal grounds are well established and often involve hydrodynamic and sediment plume modelling.

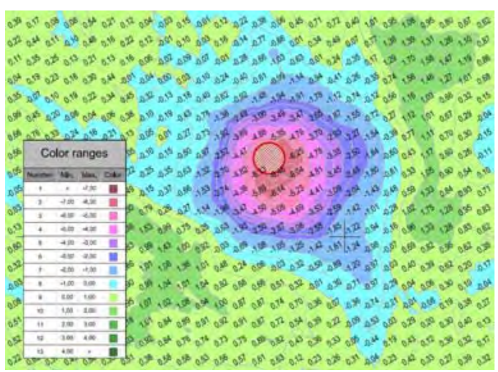
The most accessible example of the use of gravity base structures (GBS) to date is that of Thornton Bank off the coast of Belgium. The first six wind mills of the C-Power farm were installed in 2008 on Thornton Bank using GBS. Considerable seabed preparation (excavation, filter layer, gravel layer and foundation placement and backfilling) was undertaken prior to provision of both a filter layer and armour layer of scour protection materials. Bathymetric measurements were performed by Dredging International using multibeam for monitoring of erosion pits in the C-Power farm. Morphological evolution was intensively monitored. For each of the six GBSs, five surveys were executed: (i) prior to works; (ii) after dredging of foundation pits; (iii) after installation of gravel bed; (iv) prior to installation of filer layer; and (v) after completion of the works.

In the survey data below (source: Van den Eynde *et al*, 2010), the dredged foundation pit was clearly visible during construction, however after the installation of the foundation and the scour protection materials no secondary scour was observed.



Baseline Conditions **Dredged Foundation Pit** **Post Completion (no secondary scour)**

In addition, similar monitoring was also undertaken of the erosion pits around the monopiles installed on neighbouring Bligh Bank for the Belwind farm. Here the construction of 110 turbines on monopile foundations started in 2009. Dynamic erosion protection was used for the monopiles (i.e. allowing a scour pit to develop and backfilling with protective material). Erosion pits were observed up to 6.5m in depth (below) before being backfilled with erosion protection.



Scour hole around Monopile
Source: Van den Eynde *et al* (2010)

3.0 WAVE ENERGY DISSIPATION AND FOCUSSING FOR SITES CLOSE TO SHORE (<5KM)

The wave climate at the development site could, potentially, be affected due to the presence of tower and foundation structures creating a physical blockage to wave propagation, or due to the wind farm creating wind wakes which reduce the wave climate in their lee and hence result in hydrodynamic changes which may have potential impacts upon other receptors, such as coastal morphology and suspended sediment distribution and deposition patterns.

The tower and foundation of each of the turbines within the wind farm have the potential to create a physical interaction with the incident wave climate, leading to wave transformation processes due directly to the presence of these structures within the marine environment. To investigate this issue, a review has been undertaken of 8 Round 1 and 13 Round 2 *Environmental Statements* to identify the approaches previously adopted to investigate such issues and the scale of impact on the wave climate that was predicted. Where available, sites from Round 3, Scottish Territorial Waters and international developments have also been included.

Detailed findings are provided in Appendix A, with the key findings summarised below:

- There has been a great variety in the level of detail associated with wave impact assessments undertaken as part of previous *Environmental Statements*, ranging from desk-based reviews of existing literature and application of professional judgment, through numerical modelling using conservative blocking effects, to highly detailed assessments using parametric tests and a complementary suite of numerical models.

- Modelling studies have tended to focus on monopiles although tripods and narrow shaft GBS have both also been considered in equivalent detail for some developments and incorporated in the modelling studies.

- Schemes have ranged in size from 30 turbines for Round 1 up to between 80 (Westermost Rough) and 341 (London Array) turbines for Round 2. Distances from shore have ranged from 1.5km (Teesside) to 32km (Dudgeon).

- In terms of near-field effects, local radial wave scattering was predicted by the models, caused by waves reflected off the structures and then re-combining with the incident wave field. However, in all cases considered wave diffraction was not observed and wave trains re-grouped shortly after interaction with the structures and background conditions were restored.

- Monopiles are predicted to have least effect on the far-field wave climate, followed by tripods and with narrow shaft GBS having the greatest impact of the foundation types considered in Rounds 1 & 2. Typical reductions in wave height due to development were modelled to be in the range <0.5% (e.g. Scarweather Sands) to 9% (e.g. Teesside), but more typically were of the order of ~5% within a short distance from the array, dropping to lower levels further afield. Predicted reductions towards the higher end of the stated range tended to be derived from modelling studies that used an overly conservative approach to the blockage effects. In most cases the magnitude of the modelled change was considered to be immeasurable due to the variability in the natural baseline and the far-field impact was deemed negligible or low.

- For narrow shaft GBS, the greatest impact was in shallower water depths, where the GBS occupies a greater relative proportion of the water column.

NB: Where GBS is referred to in the Round 1 and Round 2 assessments, it relates to narrow shaft GBS (typically extending only a short distance off the sea bed) and not conical base GBS.

3.1 Research Projects

The Defra-funded research project '*Assessment of the Significance of Changes to the Inshore Wave Regime as a Consequence of an Offshore Wind Array'* (Cefas, 2005) has been reviewed to provide a complementary approach to modelling techniques and observed data to assess impacts and the accuracy of the model prediction methods. It provided evidence-based research from Scroby Sands OWF, a Round 1 development located within a dynamic sedimentary environment close to a section of East Anglian coastline that is vulnerable to erosion. The purpose was to use the findings to help refine any requirements for monitoring of waves that were already included within Round 1 licence conditions and help define requirements for future development rounds.

The project aimed to investigate wave interference and diffraction patterns following transmission of waves through an array of monopile structures. It was based on an extensive literature review, numerical wave modelling using MWAV_LOC with both flat-bed and realistic-bed bathymetry (covering a range of wave heights, periods and directions within 50 model test simulations), and measurements of waves and sea-surface roughness using wave gauges and x-band radar both pre- and post-development over consecutive winters in 2002/03 and 2003/04.

The main findings from the research were:

- The [natural] effects of wave refraction in shallow water (based on both flat-bed and realistic-bed bathymetries) were greater than any effects due to wave diffraction and interference directly from the monopiles.
- The quantitative value of predicted change in wave height as a result of the array was a maximum of 2% using realistic-bed bathymetry; a change so small as to not be detectable through pre- and post-development monitoring.
- Wave diffraction and interference effects arising from the monopole arrays are negligible. By inference, any effect on coastal erosion is therefore also likely to be negligible.
- At Scroby Sands, the results were significant because it confirmed that there was no further requirement to investigate and quantify the effect of the development on the wave regime or coastal erosion.
- On a broader scale, it was recommended that developers should not be required to monitor waves for diffraction/interference effects under licence conditions.
- Although it was recognised that for future developments the rotor blades and foundation structures are likely to increase in size, the controlling parameter for determining inter-turbine spacing is likely to remain that of maximising the efficiency

of the wind flow over the rotors, thus the spacing of 6-8 rotor diameters is unlikely to be significantly different and it is therefore very unlikely that wave diffraction and interference would require further investigation for monopole foundation types.

It was acknowledged that GBS foundations are likely to have a greater impact than monopiles due to their larger cross-sectional areas, but that this would be particularly relevant to effects on the sea bed in terms of scour.

3.2 Wind Wake Effects

Research has been undertaken in Denmark by Hasager *et al.* (2006), Christiansen and Hasager (2005) and Méchali *et al.* (2006) to quantify the available offshore wind resource using various satellite observation techniques. This was undertaken in the context of proposed extensions of the Horns Rev and Nysted offshore wind farms, the first phases of which became operational in 2002 and 2003 respectively.

Horns Rev is located in the North Sea and comprises 80 turbines located at 560m spacing's some 16-20km from shore. Nysted is located in the Baltic Sea and comprises 72 turbines with spacing's at 867m running east-west and 481m running north-south, some 10-13km from shore.

Using high-resolution Synthetic Aperture Radar (SAR) wind maps were generated to quantify the wake effect of the developments. Results indicated that wind speed reductions of up to 1m/s occurred in the wake of the wind farms, but that wind speed recovered to match free stream velocities over a downstream distance of around 10km. Near to the wind farm, between 0 – 3km, the velocity deficit due to the development was about 10%, but this reduced to about 4% at 10km (averaging 2% between 4 and 18km downwind). It was noted that the persistency of wind wakes in both time and space depended on atmospheric stability, with the wake remaining longer in more stable atmospheric conditions. Based on observed information from meteorological masts and turbine records within the Horns Rev site, Méchali *et al.* (2006) concluded that a steady state for a physical system operating across the size of a wind farm did not exist and therefore it must be expected that the incident wind field will vary from one point within the site to another and therefore wind wakes will not remain persistent or have far-reaching effects.

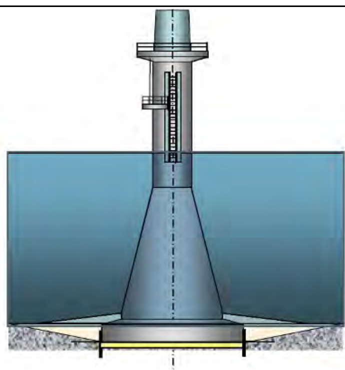
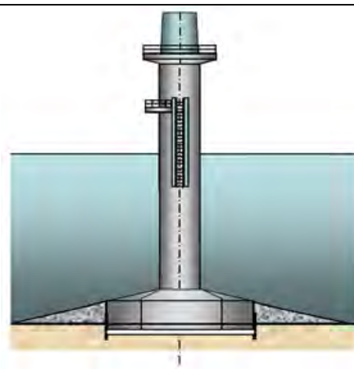
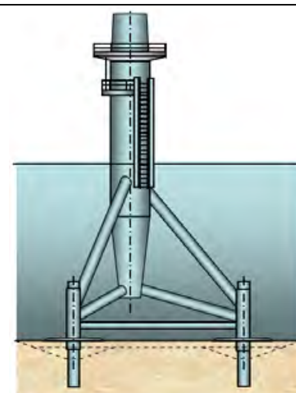
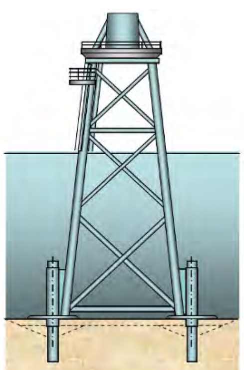
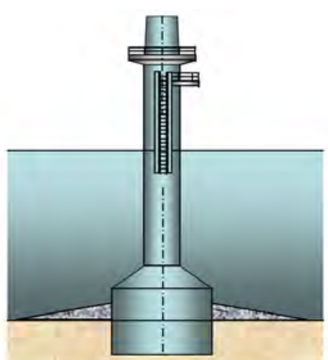
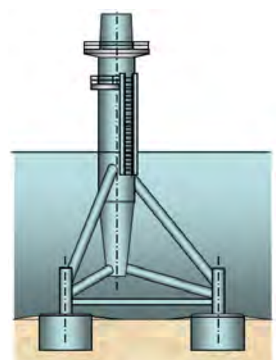
On 12th February 2008 wake clouds were observed and photographed at Horns Rev. Emeis (2010) analysed meteorological records on the day of the event and concluded that cold and very humid air was advected from the land over the warmer North Sea, leading to the formation of a shallow layer with fog close above the sea surface. The rotating turbine blades mixed a much deeper layer and thus provoked the formation of cloud trails in the wakes from the turbine. This was considered to be a rare event based on specific meteorological conditions.

Plate 1: Wind Wake Effect at Horns Rev, February 2008

3.3 Relevance of Findings to Firth of Forth (Phase I) Development

A *Screening Study* has been undertaken (GL Garrard Hassan, 2011) to determine potentially suitable foundation types for the wind turbine generators (WTGs) across the Phase I development site.

This has concluded that the following types are potentially suitable (all images extracted from GL Garrard Hassan, 2011):

 Conical GBS	 Narrow Shaft GBS	 Symmetric Tripod
 Jacket	 Suction Caisson - Single	 Suction Caisson - Multiple

Further considerations during scheme development will be given primarily to the concrete conical GBS, concrete narrow shaft GBS, piled jackets and piled symmetrical tripod structures, although the potential use of suction caissons as an alternative to piles will be considered in jacket or tripod structures, but this will only be potentially applicable to a maximum of 35% of the site due to site-specific conditions.

Based on the findings from Round 1 & 2 developments, including both predictive assessments made within *Environmental Statements* and post-scheme observations, it is considered that in terms of their potential impacts on the wave climate, the relevant issues are:

- For all foundation options other than conical GBS (which is discussed further below), the turbine tower and foundations will not cause a measurable impact on the wave climate.
  - There will be very local scale impacts directly at, and adjacent to, each turbine, but waves will not become diffracted (see Box A). There will therefore be no far-field effects due to diffraction caused by these foundation types.
  - Piled tripod and piled jacket foundations will cause relatively little interference with wave propagation due to their porous nature, slender pile sizes, slender diameters of principal load-bearing members for the jacket, slender central column size for the tripod, and slender sizes of horizontal and diagonal bracing members. The central column (for the tripod) and support members (for both types) will cause some interruption but this will be local and will have more influence on local scour processes (which will be addressed in the scour assessments) than far-field wave effects. With jacket foundations, the turbine tower is located above the water column and therefore there is even less interference with the wave propagation.
  - Narrow shaft GBS and both single and multiple suction caisson foundations (if used on tripod or jacket structures) protrude from the sea bed and therefore have the potential to induce wave breaking. However, given the water depths across the site, ranging from 33 – 86m, and the expected dimensions of the structures (both in terms of height above the bed and their overall base width) wave breaking is not expected to be induced (see Box B). There will therefore be no far-field effects due to wave breaking caused by these foundation types.
- The conical GBS may be expected to have a potential impact on wave processes since it physically occupies a larger proportion of the water column than the other types of structure. The precise nature of the potential impacts will depend on specific dimensions of the foundation, particularly in respect of its total height off the sea bed, its basal diameter, and the position below the water column of its interface with the turbine tower. However, based on the schematic representation currently under consideration, the structure will be expected to be subject to larger wave forces than the other foundation types and, due to its greater dimensions, will therefore be more likely to scatter waves. Notwithstanding this, however, the development site is located considerably greater than the 5km from shore cited in the COWRIE guidance document as being of concern and although conical shaped GBS may have a greater impact than other foundation types, it is still sufficiently far from shore to be likely to have no significant impact on far-field (regional scale) wave processes or those processes reaching the shore.

Box A - Wave diffraction around turbine towers

Diffraction around slender piles is determined by the ratio between the pile diameter (D) and the wave length (L) and diffraction processes become important if:

$$D/L > 0.2$$

A typical range of wave lengths has been calculated using Linear Wave Theory based on the site water depths (33 – 86m) and wave conditions for return period events ranging from 1 in 1 year to 1 in 100 years, as described in the report *Structural Basis of Design* (GL Garrard Hassan, 2011). This provides wavelengths in the range 97-99m. Under these water depth and wave conditions, diffraction will only become important if the turbine tower occupying the water column is in excess of 20m in diameter. As this is not the case, the waves will regroup on the down-wave side of the turbine tower will negligible far-field effect.

Box B - Wave breaking due to turbine foundations

To a first approximation, and assuming a horizontal sea bed, random waves of significant wave height (H_s) will break in a water depth (h) if:

$$H_s/h > 0.55$$

Given the range of water depths across the Phase I site, significant wave heights will need to be of the order of 18m – 47m for the narrow shaft GBS and both single and multiple suction caisson foundations to induce breaking. The report *Structural Basis of Design* (GL Garrard Hassan, 2011) determines a 1 in 100 year H_s value to be 9m.

4.0 WAVE AND CURRENT PROCESSES CONTROLLING VERY SHALLOW SANDBANK MORPHOLOGY ESPECIALLY WITH LESS UNDERSTOOD FOUNDATIONS TYPES

This section of the report addresses Point 5 of the COWRIE Guidance (2009), 'Wave and current processes controlling very shallow sandbank morphology especially with less understood foundations types'. At the request of Marine Scotland the term 'very shallow sandbank' is now interpreted to mean sandbanks, sandwaves and other sea bed features present within the site or on adjacent areas of sea bed.

The COWRIE Guidance(2009) states;

> 'regarding very near shore wave energy dissipation and shallow water wave/current processes, these may require numerical modelling as the wave, current and sediment interactions are potentially complex. It may not always be apparent when modelling is justified, and expert opinion from the regulators and specialist consultants should be sought'.

Of particular importance to the work presented herein with regard to the screening of potential impact assessment areas for Seagreen, the COWRIE Guidance (2009) further states 'the proposed Round 2 and 3 wind farm sites all specifically avoid sites close to shore or on shallow sand banks, so it is unlikely that modelling will be necessary'.

4.1 Wind and waves

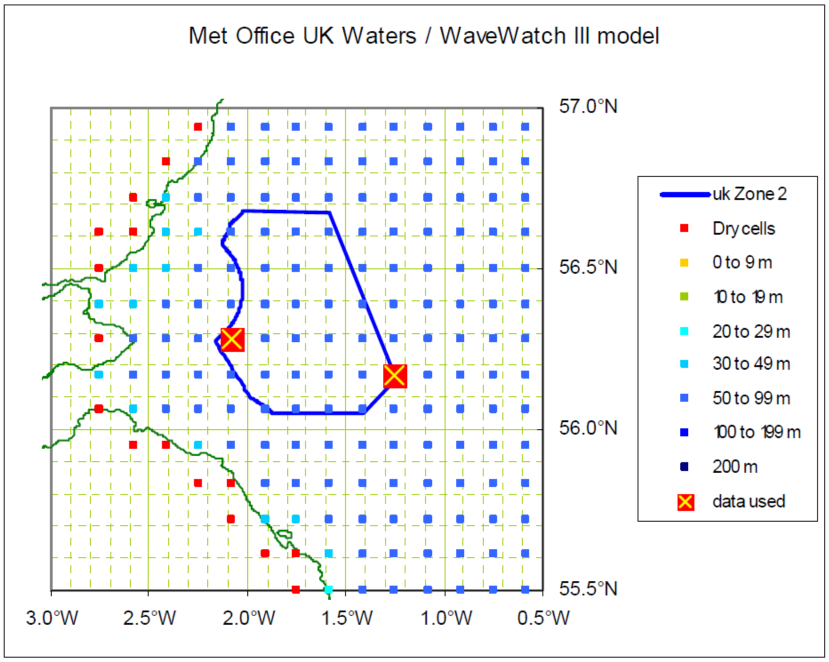
Table 4.1 presents the data sources which have been reviewed for the purpose of informing this screening exercise:

Table 4.1 Data sources reviewed to inform SPR model

Title	Author	Year
10 year Met Office wave analysis for the Firth of Forth Zone	Royal Haskoning	2011
Seagreen Metocean Campaign: Progress Report	Fugro	2011
Seagreen Phase 2 and 3 Scoping Report	Seagreen	2011b
Seagreen Position Paper: Coastal and Seabed Impact Assessment	Seagreen	2011a
Seagreen Phase 1 Scoping Report	Seagreen	2010a
Seagreen Zone Appraisal and Planning	Seagreen	2010b
UK Round 3 OWF Zone 2 Firth of Forth. Wave Height Spells for Survey Operability	Metoc	2010
Firth of Forth and Tay Developers Group, Collaborative Oceanographic Survey, Specification and Design. Work Package 1. Review of existing information.	HR Wallingford	2009
R3 Sediment Gap Analysis	ABPmer	2009
Coastal Cells in Scotland: Cell 2 – Fife Ness to Cairnbulg Point	SNH	2000
Angus Shoreline Management Plan (SMP)	Angus Council	Unknown

The data sources cited in **Table 4.1** relating to metocean conditions have been utilised to provide an evidence base for waves, tides and environmental receptors. Further work by Royal Haskoning, specific to this commission, has analysed a 10 year time series of Met Office forecast data at two grid points within the Zone (see **Figure 4.1**). The data includes wind (wind speed and direction), sea wave, swell and resultant wave (wave height, period and direction) and highlights that both points are representative of the Round 3 Zone by way of their location on the eastern and western periphery of the Zone.

Figure 4.1 Met Office forecast data locations



Met Office forecast data were analysed at two grid points of 56.17°N 1.25°W (referred as East Point) and 56.28°N 2.08°W (referred as West Point) within the Zone (see **Figure 4.1**). The data covers a ten year temporal period from June 2000 to February 2010. The analysed and presented data includes wind (wind speed and direction), sea wave, swell and resultant wave (wave height, period and direction). Significant wave height (Hs) is >6.7m and 8.7m for 1 year and 50 year return period waves averaged from all sectors respectively. Swell conditions tend to be dominated by waves generated from north and north-eastern sectors

Figure 4.2 illustrates the offshore wind climate at the East and West Points. Wind conditions at West Point are influenced by the Firth of Forth corridor leading to clearer predominance of south-westerly wind. The East Point displays more of a spread of wind directions across the south to western sectors. The wind climate is predominantly offshore. **Figure 4.3** presents the offshore sea wave climate for the East and West Points. The influence of land is more clearly defined than for the wind climate. In general for the area the sea wave rose plots show three dominant directions for sea waves, in the descending order of south-westerly, southerly and northerly waves. These predominant wave approaches do not impact upon any coastal receptors within the vicinity of the potential Export Cable Route landfall.

Figure 4.4 presents the offshore swell wave climate for the East and West Points. The resultant swell waves illustrate three dominant swell wave directions in a descending order of north-easterly, south-easterly and south-westerly. **Figure 4.4** suggests that the swell wave environment is dominated by swell waves incident from the north and north-eastern sectors. Both north-easterly and south-easterly swell waves may interact with STW sites within the wider study area.

Figure 4.2 Wind environment

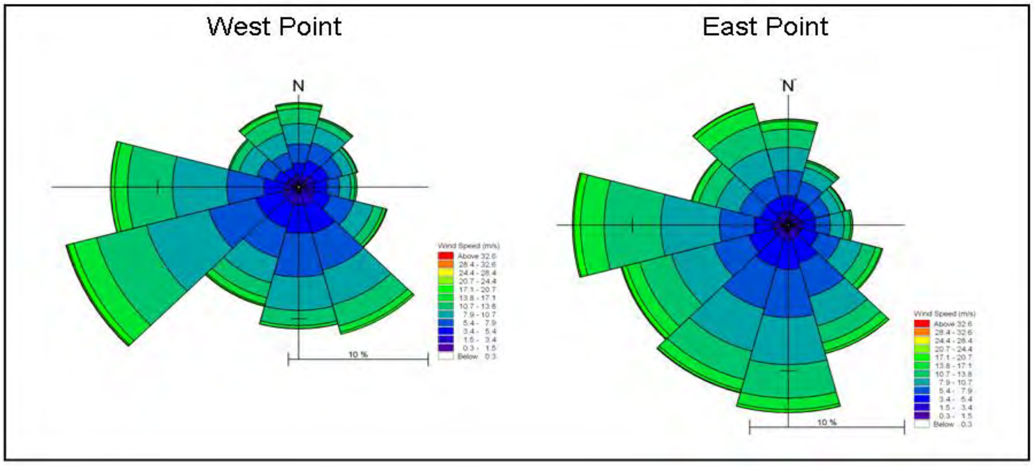


Figure 4.3 Sea wave environment

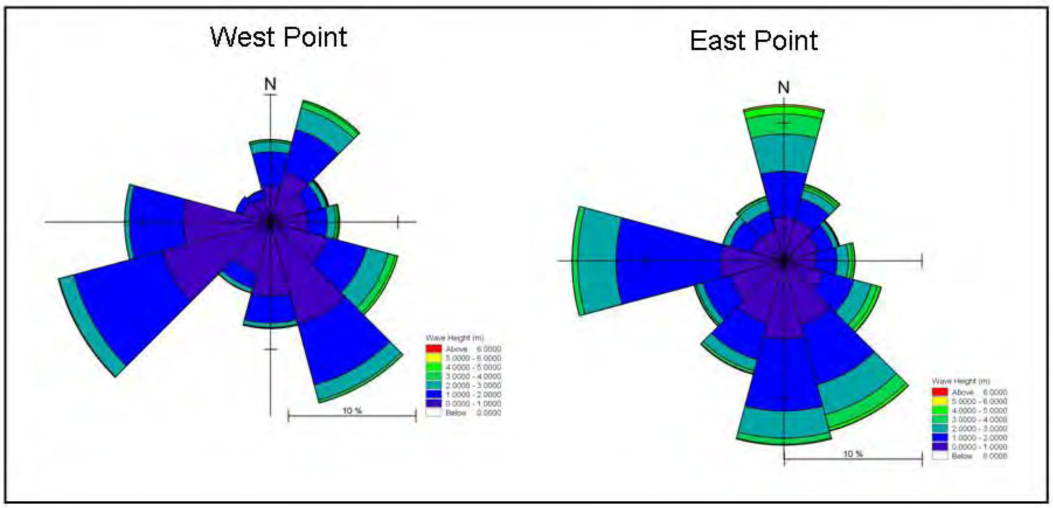
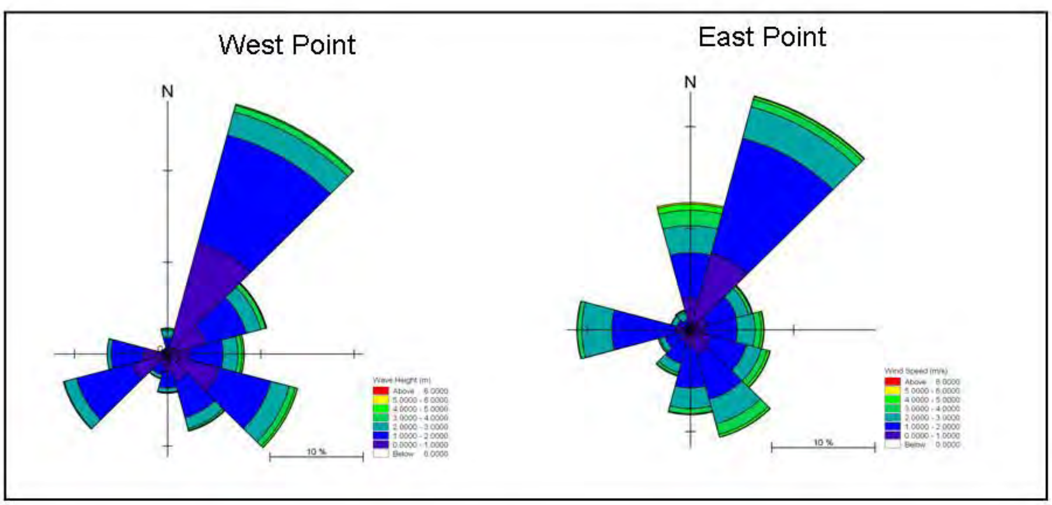


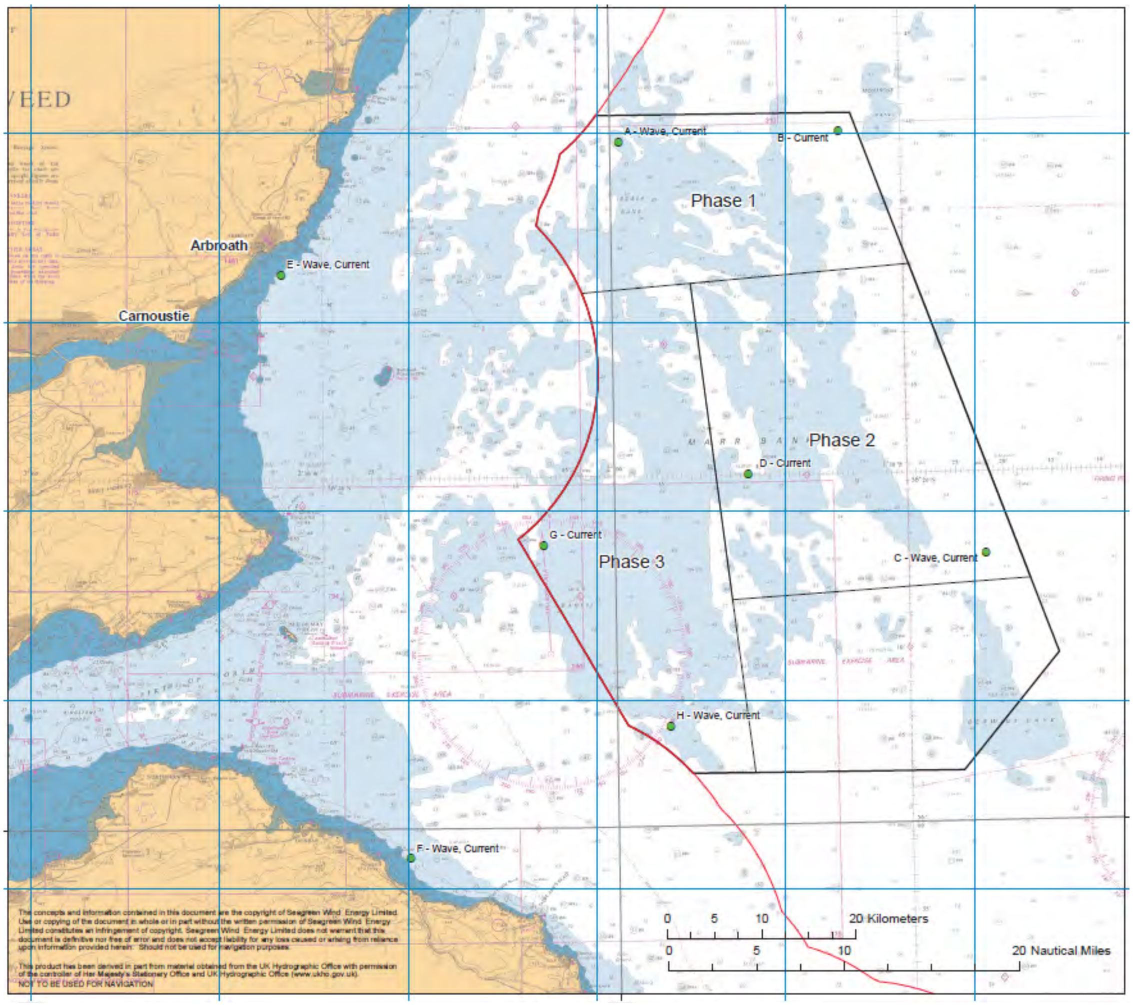
Figure 4.4 Swell wave environment



4.2 Tides, tidal currents and sea-level

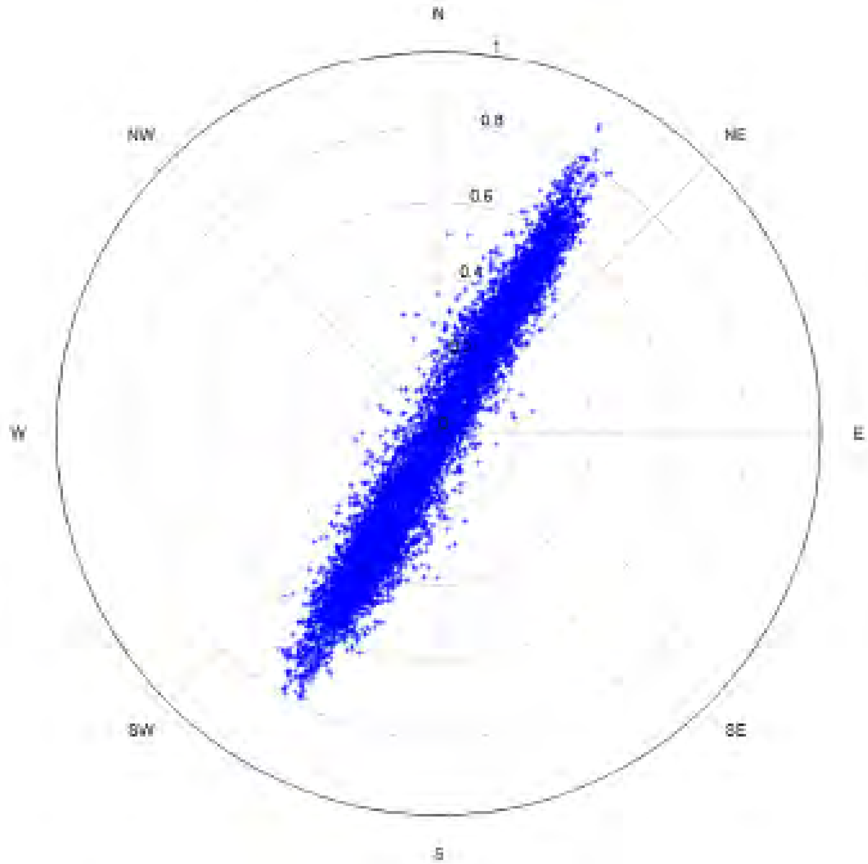
Figure 4.5 presents the location of Seagreen metocean deployments across the Firth of Forth.

Figure 4.5 Seagreen Metocean Deployments



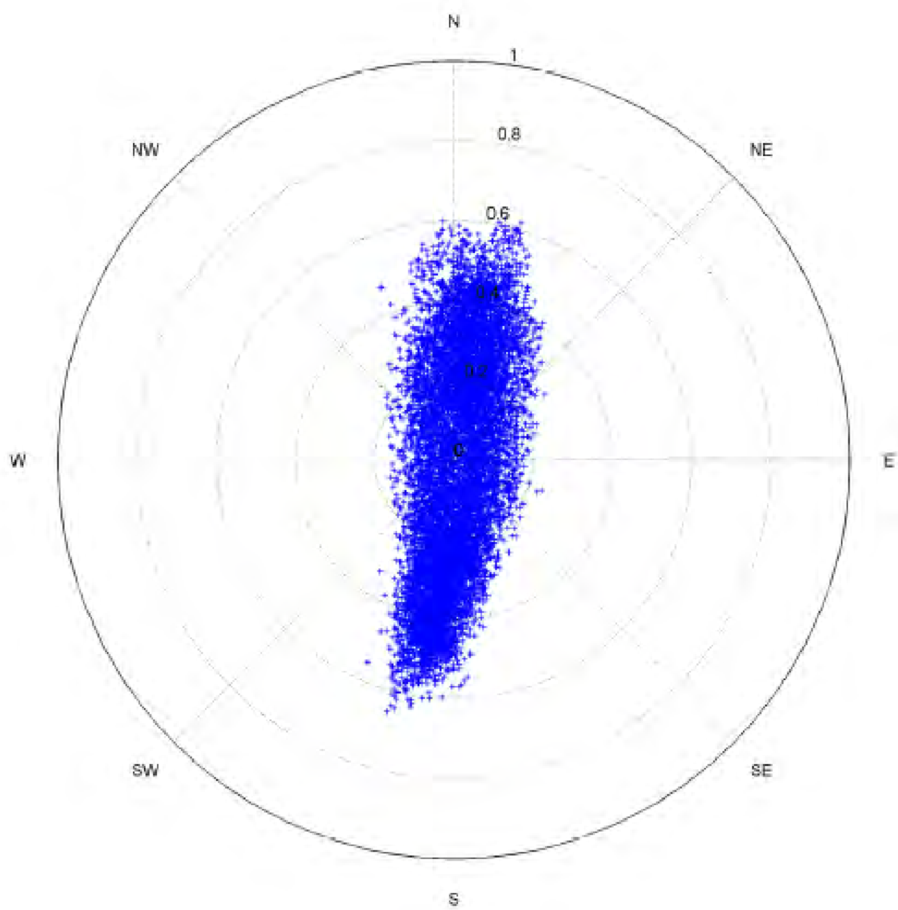
The pattern of tidal elevations across the Outer Forth (including the Round 3 Zone) is governed by a southerly directed flood tide that moves down along the eastern coastline of Scotland into the Firth of Forth around Fife Ness (HR Wallingford, 2009). This is supported by ongoing metocean campaigns which indicate reciprocal flood and ebb tidal currents (see **Figure 4.6**). The main peak flood tide occurs approximately 2 hours before HW, with the main peak ebb tide occurring approximately 4 hours after HW. This is supported by recently acquired metocean data within the regional and local study areas (Fugro, 2011).

Figure 4.6 Polar scatter plot of recorded current velocities at Site A at 20.5m below mean sea level (24 March – 05 June 2011).



According to Fugro (2011) the maximum observed tidal current speed at Site A was 0.91m/s. HR Wallingford (2009) state that tidal current velocities can reach 1.2m/s within the Tay estuary. In the Forth, at Rosyth, typical peak flood velocities are 0.4 to 0.7m/s and on the ebb 0.7 to 1.1m/s. Seaward of the estuaries, the tidal flows are typically weaker. This is supported by ongoing metocean campaigns which indicate maximum tidal current speed of 0.7 and a mean of 0.26 m/s at Site C (see **Figure 4.7**). Site C is characterised by a north to south tidal current flow regime.

Figure 4.7 Polar scatter plot of recorded current velocities at Site C at 21.3m below mean sea level (26 March – 06 June 2011).



Superimposed on tidal behaviour are non-tidal effects such as surges and sea-level rise. Surges can result in variation to tidal water levels above or below the predicted tidal level. The largest storm surge captured via Seagreen's on going metocean campaign to date has been 1.3m (Fugro, 2011). Over longer time periods (e.g. decades) relative to tidal (monthly) mean sea-level varies and hence the baseline datum is not stationary. Both storm surges and changes in sea level shall be considered in baseline definition and impact assessment for Seagreen's Round 3 developments.

4.3 Seabed features

The location of key potential seabed features (potential sensitive receptors) has been guided by recently completed and on-going survey works and supplemented by information gathered by Seagreen during the development and consenting process to date (e.g. Scoping and ZAP). **Table 4.2** presents the information used to identify receptors associated with this study.

Table 4.2 Data used to identify receptors

Data	Purpose	Source
GEMS Geophysical Results Report	Define bathymetry and seabed features of geomorphological and ecological importance	GEMS 2010
IECS Post Survey Report Benthic Services	Define benthic receptors	IECS 2011
International and national designated sites (Ramsar, SPA, SAC)	Define location of designated habitats and species	JNCC (http://jncc.defra.gov.uk)
SNH national designated sites (SSSI)	Define location of protected habitats and species	SNH (http://gateway.snh.gov.uk/portal/page)
Angus Shoreline Management Plan (SMP)	Define areas of soft sedimentary coast along potential cable landfall area.	Angus Council (http://www.angus.gov.uk/ac/documents/roads/SMP/default.html)

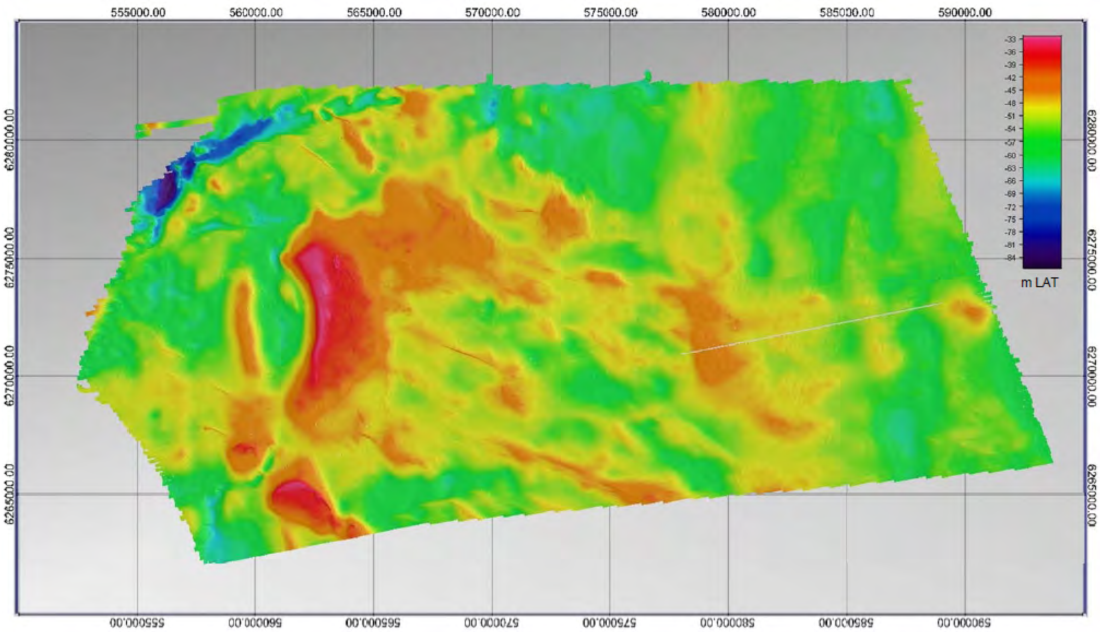
The identification of seabed receptors builds on the Phase 1 and Phases 2 and 3 Scoping Reports and Zone Appraisal and Planning (ZAP). The identification of seabed features was further guided by the COWRIE (2009) guidance. The above referenced reports are summarised in the following sub-section.

GEMS Phase 1 Geophysical Survey:

a) The majority of the Phase 1 area is within water depths of 40-60m LAT.
b) The maximum depths (86.2m LAT) are observed towards the inshore areas in the northwest, where a channel cuts across in a northeast to southwest orientation.
c) The minimum depth (32.5m LAT) is in the mid-west of the site. Here the shallowest areas are observed along the north-south orientated Scalp Bank.

Sea bed sediments have been classified by GEMS (2010) using an adapted Folk classification and are interpreted to consist of gravelly sand and slightly gravelly sand across the entire area. Three main features were identified which are indicative of active sediment transport (see **Figure 4.9**): megaripples, sandwaves and boulder fields (see **Table 4.3** for definition of terms). All these features are characteristic of active sediment transport zones, the most regularly occurring being megaripples. **Figure 4.9** presents the spatial distribution of these features across the Phase 1 area.

Figure 4.8 Phase 1 bathymetry

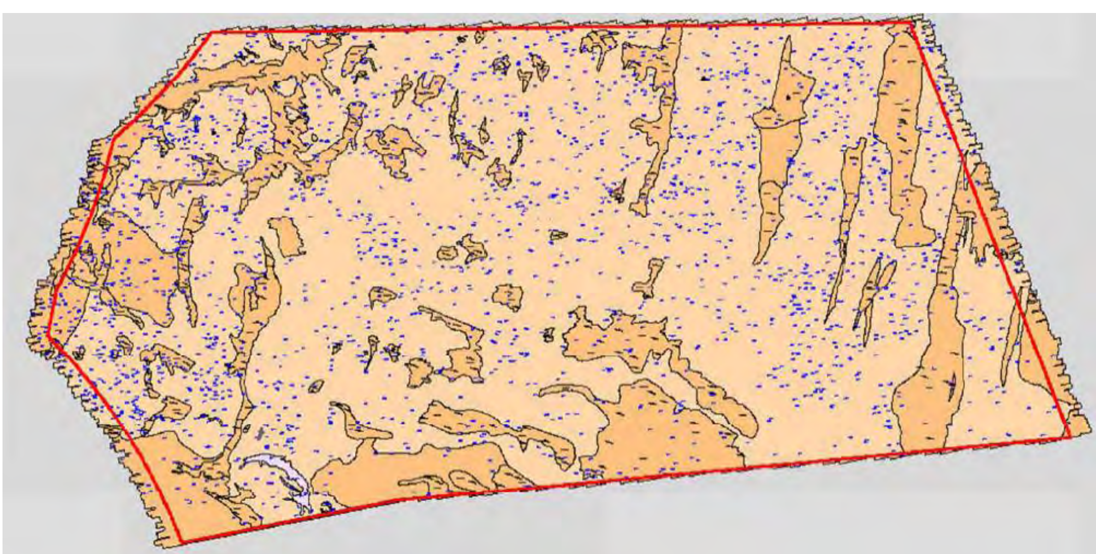


Source: GEMS Phase 1 Geophysical Survey 2010.

Table 4.3 Seabed features

Terminology	Definition
Ripple	Undulations (<0.5m λ) produced by fluid movement (waves and currents) over sediments
Megaripple	Undulations (0.5m to 25m λ) produced by fluid movement (waves and currents) over sediments
Sandwave	Undulations (>25m λ) produced by fluid movement (waves and currents) over sediments

Figure 4.9 First draft seabed substrate map



The GEMS report (2010) and relevant BGS charts (1986) identify that the majority of the site is subject to sediment transportation, with the dominant flow pattern approximately parallel to the coastline in a north-northeast to south-southwest direction with tidal flow. According to GEMS (2010) currents (near bed flows) are strong enough to move and potentially erode medium sand grade material. These flows may display spatial and temporal variation in strength as the isolated boulders are representative of a lag deposit from the active erosion and subsequent transportation of the quaternary sedimentary units (e.g. till).

The three main sea bed features from which proxy information on active sediment transport zones can be inferred are:

Megaripples (generally less than 0.5m in height) predominantly covering slightly gravelly sand are the predominant sea bed features across most of the site. Their crests are orientated perpendicular to the shoreline (WNW to ESE), suggesting sediment movement is parallel to the coast The bedforms are in general symmetrical, suggesting that sediment does not have one dominant direction of flow, but rather moves tidally parallel to the coast. There is a slight change in the build up of sediment either side of the Scalp Bank in the mid-west, with sediment build up to the south of bedforms (megaripples) west of the bank; suggesting northward dominant flow, and to the north of bedforms (megaripples) east of the bank; suggesting southward dominant flow. However, this is not conclusive.

There are large isolated **Sandwaves** in the western area, with approximately the same orientation as the megaripples. The sandwaves reach up to 10m in height from the sea bed.

Boulders, thought to be of glacial origin, are prevalent across the area, especially in northern and central parts, either as isolated boulders or clustered within boulder fields. Boulders are also present in southern areas, but these are not as large as those in northern and central parts.

Benthic ecology

Recently completed surveys and currently ongoing analysis (IECS, 2011) have indicated the presence of sandeel, Sabellaria .spp and Artica .spp as determined from visual inspection and drafting of field notes onboard the survey vessel at the benthic grab locations (see **Figure 5.1**). The above species are considered as sensitive receptors which subsequent coastal and seabed impact assessment must provide robust data on to assess direct and indirect impacts upon these features. **Figures 4.10** and **4.11** illustrate seabed types typical of large expanses of the seabed within the Phase 1 area. Figure 4.10 illustrates rippled seabed comprising coarse sand with occasional gravel. Figure 4.11 illustrates a mix clast seabed type, comprising a lag gravel and pebble on coarse sands.

Figure 4.10 Coarse sand rippled seabed type

Source: IECS DDV image, site V9, west of Scalp Bank, 62.3m depth

Figure 4.11 Mixed clast lag on coarse sand

Source: IECS DDV image, site V24, east of Scalp Bank, 44.5m depth

4.4 Relevance of Findings to Firth of Forth (Phase I) Development

Due to the predominantly offshore nature of the wind and wave environment the requirement for detailed, computational modelling of the wave regime is deemed to be not proportionate to the potential impact associated with the proposed development. As stated in the COWRE Guidance (2009) it may not always be apparent when modelling is justified, and expert opinion from the regulators and specialist consultants should be sought.

The sea wave rose plots show three dominant directions for sea waves, in the descending order of south-westerly, southerly (or south-easterly) and northerly (or north-easterly) waves. These predominant wave approaches do not impact upon any coastal receptors within the area of the potential Export Cable Route landfall. Therefore any assessment as part of the EIA can be sufficiently completed by way of the proposed HTA and EGA.

Though numerous designated sites are present within the wider study area, many are located within the far-field area and, therefore, shall not be directly impacted upon by way of Seagreen's Phase 1 wind farm developments. With regards to potential impacts upon designated coastal sites within the near-field study area for ECR and landfall infrastructure, this note has highlighted those sites which shall require further consideration as part of the EIA process. This is as a consequence of a clear potential for the ECR and landfall elements of the proposed development to effect physical processes (tidal currents and tidal currents combined with nearshore wave generated littoral drift). Resulting changes to alongshore (shore parallel) and nearshore (shore normal) processes could have the potential to impact upon the physical attributes of designated sites.

The potential effects from combined wave and tidal processes are considered, as with each constituent part (e.g. waves or tidal currents in isolation), to be limited in the immediate vicinity of the foundations with no significant interactions in and between foundation structures. Physical processes may be modified in the immediate vicinity of the foundations, though these changes have the potential to be significant ONLY if they result in impacts upon sensitive receptors.

The sensitive physical and biological receptors identified shall form the focus of Seagreen's phased assessment (see Seagreen's Position Paper on Coastal and Seabed Impact Assessment (A4MR/SEAG-Z-DEV240-SRP-052) and **Section 6**). With regards to wave and tidal processes and their control on seabed substrates and morphology, recently completed surveys (geophysics and benthic ecology) indicate the presence of only isolated sandwaves and geomorphic features on the seabed. The recently completed analysis of benthic ecology samples indicates diversity greater than was initially expected but no unusual or highly sensitive receptors have been identified. The potential impact of less understood foundation types has been initially assessed (**Section 2** presents a First Order Scour Assessment). The potential for the resultant scour materials to impact upon seabed features shall be addressed within the ES and be informed by ongoing Rochdale Envelope developments. The location of potentially sensitive receptors to be considered is presented in **Figure 5.1**.

5.0 SOURCE PATHWAY RECEPTOR

This section presents and discusses a Source-Pathway-Receptor (S-P-R) model which has been produced in support of 'screening' for further detailed assessment.

There is a need, as part of the EIA process, to develop an S-P-R model which clearly demonstrates linkages in and between receptors and pathways associated with the potential environmental impacts of the development. Where there is no pathway, Seagreen will highlight this and will seek to 'screen out' detailed modelling assessment on this receptor. The screening exercise is supported by the previously presented findings for each receptor. The purpose of the S-P-R model is to provide a visualisation tool for the location and spatial extent of sensitive receptors and assist the reader to identify the pathways between sources and receptors discussed herein. The SPR model is illustrated in **Figure 5.1**.

As highlighted previously (see **Section 1**), COWRIE (2009) has provided guidance for establishing the requirement for numerical modelling. This section expands on the key questions in light of the evidence base and proposes an S-P-R model.

The development of S-P-R models comprised the following key tasks:

1. Definition of spatial area of area of assessment;
2. Identification of data sources pertaining to the study area (see **Sections 2, 3** and **4**);
3. Identification of coastal and seabed processes (including oceanographic and hydrodynamic) (see **Sections 2, 3** and **4**);
4. Identification of sensitive receptors (see **Section 4** and below).

The spatial area of assessment includes near-field (within the immediate vicinity of the turbine array) and far-field (the coastline and sites of scientific and ecological importance). For the purpose of this screening exercise near-field is considered as within the Phase 1 boundary, far-field relates to the larger Zone, neighbouring STW wind turbine arrays and all sensitive coastal receptors.

5.1 What are the sensitive receptors?

Within Seagreen's Phase 1 development and wider assessment areas, the key sensitive receptors are identified under the headings physical, biological and designated sites as set out in **Table 5.1**.

Table 5.1 Sensitive receptors

Receptors
Physical
Bathymetry, sandbanks, sandwaves, megaripples, seabed morphology and unprotected soft sedimentary coasts
Biological
Sandeel habitat, Sabellaria .spp habitat/substrate, Benthic diversity and Herring spawning grounds
Designated sites
Forth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI, Barry Links SAC, Elliot Links SSSI, Easthaven SSSI

5.1.1 Physical Receptors

Bathymetry, sandbanks, sandwaves, megaripples, seabed morphology and unprotected, soft sedimentary coasts.

Bathymetric changes may not necessarily result in an adverse impact upon the expression of the physical environment. However, consideration of bathymetric change is fundamental, as the material removed from the seabed to affect any change ultimately contributes to the near-field sediment budget and sedimentary regime. This contribution may be directly attributable to erosion, transportation or subsequent deposition which can lead directly and indirectly to impacts upon other features of the physical environment, such as sandbanks, sandwaves, megaripples and seabed morphology, plus a wide array of biological receptors.

Changes to the physical baseline environmental conditions resulting from the development of Seagreen's Phase 1 wind farms may result in near-field effects upon physical processes (waves and tides) within the Zone. The construction phase of the Export Cable Route and associated landfall infrastructure may further result in potential changes to the nearshore physical conditions which may result in nearshore impacts upon sensitive receptors within the intertidal and coastal areas. Such potential impacts are limited to unprotected, soft sedimentary coast.

5.1.2 Biological Receptors

Sandeel habitat, Sabellaria .spp habitat/substrate, benthic diversity and herring spawning grounds

Biological receptors are wholly dependant upon the nature of the physical environment for the provision of suitable substrate and sedimentary environments for habitat type and use. Therefore any changes to the physical environment from the documented baseline shall have implications (beneficial and adverse) upon the observed biological assemblages present.

Sandeel distribution in UK waters is patchy, with distinct spawning aggregations resulting from the availability of sandy sediments, and the fact that adult sandeels are relatively sedentary; showing only limited movements between areas. Sandeels have been observed from benthic grab samples retrieved from the Phase 1 area as part of the benthic survey programme. When buried in the seabed, lesser sandeels require a very specific substratum, favouring coarse sand with fine to medium gravel and low silt content. Bottom depth and bottom current flow also play an important role.

Sabellaria spinulosa worms are well known for their reef-forming ability when they occur in very large numbers in the subtidal. The worms live in tubes that they build from sand or fine gravel which may stand proud from the sediment surface. *Sabellaria spinulosa* reefs have a rich fauna associated with them as they provide a substrate for burrowing, crevices for sheltering animals and a hard surface for other animals to attach to. It is likely that stability of the reefs is to some degree a function of the stability of the substratum. The more transient crusts probably occur principally on relatively unstable substrata, while longer-lasting reefs could be limited to more stable substrata.

Herring are a sensitive receptor as they are the only clupeid benthic spawners which deposit their sticky eggs on solid substrate, either course sand, gravel or boulders at depths from 20 m to 60 m and usually located in high energy environments. Herring spawning grounds in relation to the proposed development are illustrated in **Figure 5.1**.

As noted previously, biological receptors are wholly dependant upon the nature of the physical environment and any changes to this environment may have implications (beneficial and adverse) upon the observed biological assemblages and their diversity.

5.1.3 Designated Sites

Forth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI, Barry Links SAC, Elliot Links SSSI, Easthaven SSSI

Both Elliot Links SSSI and Easthaven SSSI have been discussed previously, in terms of their geomorphological interest and features that would require assessment as part of the EIA process (see **Section 3.1.4**). The key physical attributes of the Forth of Tay and Eden Estuary SAC, SPA and Ramsar and SSSI and Barry Links SAC are their Annex I features and their linkages with the external forcing parameters of wind, wave and tidal processes.

The following tables present physical process, potential pathways and potential effects upon the identified sensitive receptors for bathymetry and seabed features (**Table 5.2**), Benthic ecology (**Table 5.3**), Designated habitats and species (**Table 5.4**) and soft sedimentary coast (**Table 5.5**). The tables are provided to assist in the screening of potential impact assessment areas and are discussed in **Section 6**.

Where a pathway is 'not identified' this is taken to mean that there is no interaction between the source and its pathway (change to background process and natural variability) via the Phase 1 development that would result in any effect upon the receptor. Not identified relates to the requirement for (pathway/process) modelling to assess potential impacts upon a receptor. Notwithstanding, in some instances Seagreen sets out future non-modelling studies which shall address potential impacts in **Tables 5.2** to **5.5**.

Table 5.2 Effect assessment for bathymetry and seabed features based on physical process

Physical process	Potential pathway and change due to scheme	Potential effect
Wind waves	Wind wave environment dominated by waves incident from the western and southern sectors and characterised as being offshore. Potential wave energy losses and interactions with sensitive receptors downstream of pathway	Localised changes to bathymetry, sandwave and meggaripples morphology, and potential changes to seabed substrates due to mobile substrates and fine grained deposition due to turbine tower and foundations (see Scour Assessment).
Swell waves	Swell wave environment dominated by waves incident from the north-eastern sector and characterised as large period and wavelength.	**NOT IDENTIFIED** due to decreased likelihood of wave energy loss as a consequence of diffraction.
Tidal currents	Flow separation leading to localised increased flow speeds around foundations resulting in potential scour (see Scour Assessment)	Localised changes to bathymetry, sandwave and meggaripples morphology, and potential changes to seabed substrates due to mobile substrates and fine grained deposition due to turbine tower and foundations (see Scour Assessment).
Combined wave and tidal currents	Localised changes resulting in potential scour (see Scour Assessment)	Localised changes to bathymetry, sandwave and meggaripples morphology, and potential changes to seabed substrates due to mobile substrates and fine grained deposition due to turbine tower and foundations (see Scour Assessment).

Table 5.3 SPR for benthic ecology

Physical process	Potential pathway and change due to scheme	Potential effect
Wind waves	Wind wave environment dominated by waves incident from the western and southern sectors and characterised as being offshore. Potential wave energy losses and interactions with sensitive receptors downstream of pathway	Localised impacts upon sensitive sandeel habitat, Sabellaria .spp habitat/substrate, benthic diversity and herring spawning grounds.
Swell waves	Swell wave environment dominated by waves incident from the north-eastern sector and characterised as large period and wavelength.	**NOT IDENTIFIED** due to decreased likelihood of wave energy loss as a consequence of diffraction.
Tidal currents	Flow separation leading to localised increased flow speeds around foundations resulting in potential scour (see Scour Assessment)	Localised impacts upon sensitive sandeel habitat, Sabellaria .spp habitat/substrate, benthic diversity and herring spawning grounds.
Combined wave and tidal currents	Localised changes (potential increase to tidal current speed) resulting in potential scour (see Scour Assessment)	Localised impacts upon sensitive sandeel habitat, Sabellaria .spp habitat/substrate, benthic diversity and herring spawning grounds.
	NOT IDENTIFIED Localised changes resulting in potential scour (addressed in Scour Assessment) not of spatial extent to impact upon identified spawning grounds	**NOT IDENTIFIED** due to location within the far-field.

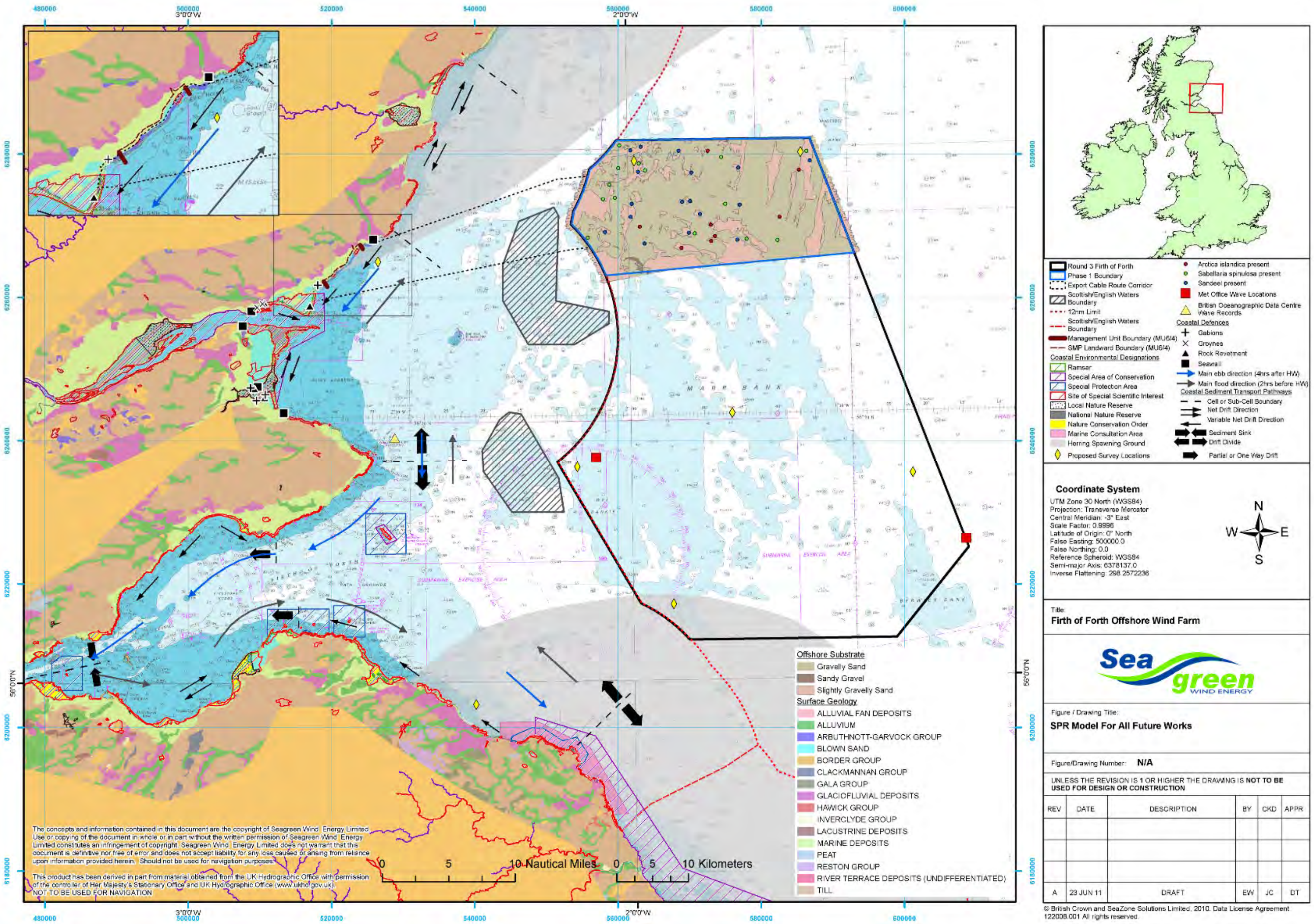
Table 5.4 SPR for designated habitats and species

Physical process	Potential pathway and change due to scheme	Potential effect
Wind waves	Locally generated and not affected by offshore development (addressed in Phase 1 Landfall EGA)	**NOT IDENTIFIED** However, consideration of Forth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI, Barry Links SAC, Elliot Links SSSI, Easthaven SSSI within EIA
Swell waves	**NOT IDENTIFIED** Predominantly incident from the north-east and not effected by offshore development (addressed in Phase 1 Landfall Expert Geomorphological Assessment (EGA)	**NOT IDENTIFIED** However, consideration of Forth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI, Barry Links SAC, Elliot Links SSSI, Easthaven SSSI within EIA
Tidal currents	**NOT IDENTIFIED** Near-shore and shore-parallel to the south and not effected by offshore development. Potential effects from ECR and landfall infrastructure (Addressed in Coastal Historical Trend Analysis (HTA) and EGA).	**NOT IDENTIFIED** However, consideration of Forth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI, Barry Links SAC, Elliot Links SSSI, Easthaven SSSI within EIA
Combined wave and tidal currents	**NOT IDENTIFIED** Localised changes to hydrodynamic and associated sedimentary regime resulting in potential spatial and temporal effects upon observed regime (Addressed in Coastal HTA and EGA).	**NOT IDENTIFIED** However, consideration of Forth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI, Barry Links SAC, Elliot Links SSSI, Easthaven SSSI within EIA

Table 5.5 SPR for soft sedimentary coast

Physical process	Potential pathway and change due to scheme	Potential effect
Wind waves	**NOT IDENTIFIED** Locally generated and not affected by offshore development	Unprotected soft sedimentary coasts (Arbroath to Carnoustie)
Swell waves	**NOT IDENTIFIED** Predominantly incident from the north-east and not effected by offshore development	Unprotected soft sedimentary coasts (Arbroath to Carnoustie)
Tidal currents	**NOT IDENTIFIED** Near-shore and shore-parallel to the south and not effected by offshore development. Potential effects from ECR and landfall infrastructure (Addressed in Coastal HTA and EGA).	Unprotected soft sedimentary coasts (Arbroath to Carnoustie)
Combined wave and tidal currents	Localised changes to hydrodynamic and associated sedimentary regime resulting in potential spatial and temporal effects upon observed regime (Addressed in Coastal HTA and EGA).	Unprotected soft sedimentary coasts (Arbroath to Carnoustie)

Figure 5.1 Source-Pathway-Receptor Model



The S-P-R highlights those receptors (spatially) which require further consideration during the EIA process. Significant background data exists to adequately characterise the physical environment, in terms of wave, tidal current and combined wave and tidal regimes and to assess potential impacts.

In line with the COWRIE guidance, **Table 5.6** sets out 'What information do we need to assess impacts on these? And whether the information is practicably and efficiently provided by existing knowledge and available field data without the need for numerical modelling?

Table 5.6 Information requirement and availability for impact assessment

Receptor	Information required for assessment	Is the information available?
Physical		
Bathymetry	Detailed high-resolution bathymetry data, seabed substrate data and Information on the hydrodynamic regime	Yes Phase 1 geophysical survey Phase 1 Geological Ground Model Temporal and spatial variation in hydrodynamic processes (Metocean survey results) Detailed project description
Sandbanks	Information on the location and extent of sandbanks and their hydro-morphological response to changes in the physical environment	Yes As above
Sandwaves	Information on the location and extent of sandwaves and their hydro-morphological response to changes in the physical environment	Yes As above
Megaripples	Information on the location and extent of megaripples and their hydro-morphological response to changes in the physical environment	Yes As above
Seabed substrate	Information on the location and extent of seabed substrates and their hydro-morphological response to changes in the physical environment	Yes As above
Unprotected soft-sedimentary coast	Information on the location and extent of unprotected soft-sedimentary coasts and its hydro-morphological response to changes in the physical environment	Yes Angus SMP SNH Coastal Cells Seagreen Phase 1 Landfall: Geology, geomorphology and intertidal ecology Survey Temporal and spatial variation in hydrodynamic processes Detailed project description
Biological		
Sandeel habitat	Information on location and extent of sandeel habitat and information on life cycle	Yes (in part) Observed Sandeel records from benthic survey Information on Sandeel distribution Marine Scotland Detailed project description Scour volumes Scour areas Suspended sediment transport and deposition
Sabellaria .spp habitat/substrate	Information on location and extent of Sabellaria .spp habitat and	Yes (in part) Observed Sabellaria records from

Receptor	**Information required for assessment**	**Is the information available?**
	information on life cycle	benthic survey. Outputs from side-scan sonar and broadscale habitat mapping Detailed project description Scour volumes Scour areas Suspended sediment transport and deposition
Benthic diversity	Information on location, extent and diversity of benthic habitats and species	Yes Outputs from geophysical survey and broadscale habitat mapping Detailed project description Scour volumes Scour areas Suspended sediment transport and deposition
Herring spawning grounds	Information on location and extent of Herring spawning habitat and information on life cycle	Yes Location and extent of spawning grounds (Cefas) Detailed project description Scour volumes Scour areas Suspended sediment transport and deposition
Designated Sites		
Forth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI	General site character, habitats that are a primary reason for site selection and Natura 2000 data sheet. Hydrodynamic and sedimentary regime	Yes JNCC and existing studies supplemented by Seagreen surveys and studies Detailed project description
Barry Links SAC	General site character, habitats that are a primary reason for site selection and Natura 2000 data sheet Hydrodynamic and sedimentary regime	Yes As above
Elliot Links SSSI	Geological and geomorphological characteristics Hydrodynamic and sedimentary regime	Yes As above
Easthaven SSSI	Geological and geomorphological characteristics Hydrodynamic and sedimentary regime	Yes As above

As illustrated in **Table 5.6** 'the information needed to assess the potential impacts upon the identified sensitive receptors can be practicably and efficiently provided by existing knowledge and available field data without the need for numerical modelling. Therefore, the remaining COWRIE questions are not relevant to the proposed methodology for impact assessment requiring numerical modelling. The proposed way forward is set out in the proceeding section.

6.0 PROPOSED WAY FORWARD

6.1 Scour

This initial desk-based review of existing literature and empirical approaches for assessing scour development has led to the establishment of a suite of assessment methods that are appropriate for the foundation types being considered at the Firth of Forth and have been verified against published results from previous physical model tests, field measurements and anecdotal observations from existing sites.

The scour volumes predicted for all foundation types (assuming no scour protection) are relatively large compared against that arising from Round 1 and Round 2 sites and are especially large for the conical gravity base structures (GBS).

It is expected that during installation of the foundations, especially for flat bed and conical gravity bases, considerable volumes of sea bed materials will also be displaced or removed and these quantities will therefore also need to be considered.

It is also possible that scour protection materials will provided as part of the scheme design. This will be taken into consideration in determining the final volumes of sea bed sediment that will be disturbed.

Based on the findings of this initial desk-based review our proposed approach for the Firth of Forth is as follows:

- If sea bed preparation and scour protection is undertaken during installation of GBS or caissons, then the assessment will focus on the fate of the dredged/ploughed material during construction, with no secondary scour during operation (due to the scour protection measures).

- If no scour protection is provided during installation of GBS or caissons, then the assessment will focus on the fate of the dredged/ploughed material during construction and the material scoured (using the methods described in **Section 2**) during operation.

- If dynamic scour protection is used for pile-type foundations (i.e. allowing a scour hole to develop and then back-filling with scour protection) then the assessment will focus on the fate of the material scoured (using the methods described in **Section 2**) during operation.

- If scour protection for pile-type foundations is applied to the existing sea bed (i.e. to prevent a scour hole from developing), then no assessment of the fate of scour is required.

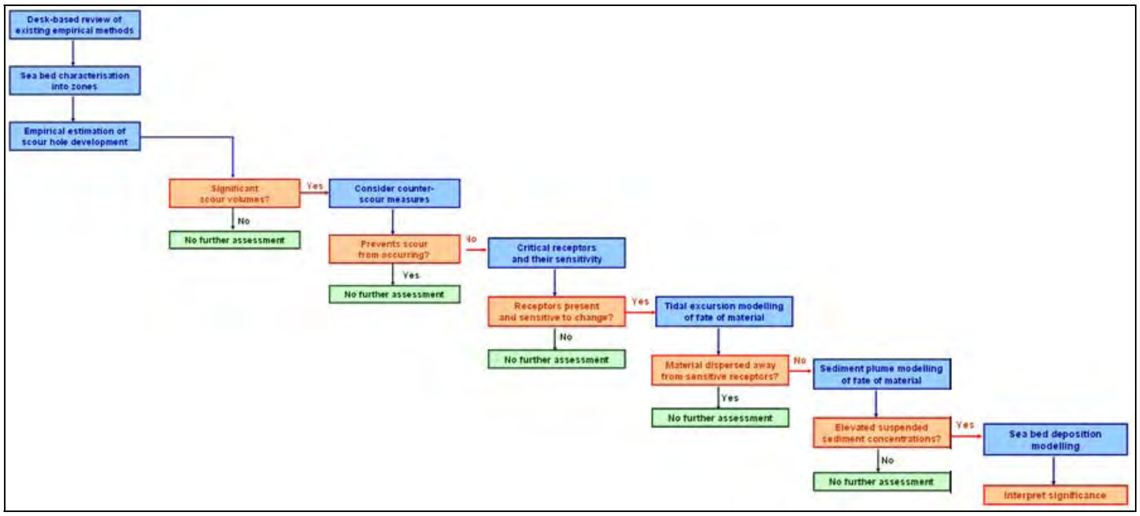
The assessments of the fate of scoured or dredged/ploughed material will be undertaken as part of the EIA process in line with the staged approach set out in the original Position Paper. This involved:

- Desk-based review of existing empirical methods for assessing scour hole development around particular foundation types (presented herewith)

- Characterisation of the Firth of Forth Zone Phase 1 area into distinct ‘characteristic areas’ based on sea bed sediment character and sediment thickness, and the conceptual understanding of sea bed processes and morphological change

- Estimation of scour hole development using methods presented herewith

- Expertise-based assessment of whether or not scour or dredged/ploughed material volumes are significant
- If so, identify whether scour countermeasures will be used to prevent scour from occurring.
- If not, identify susceptible receptors and their critical sensitivity to change(s)
- If susceptible receptors present, interpret existing results from tidal ellipse (excursion) modelling to identify the direction of transport of any released scour material (i.e. movement towards / away from sensitive receptors)
- Use ecological expertise to interpret the significance of the impact caused by the transport of the scoured material, based upon understanding of the tidal excursion patterns and the sensitivity of the receptors.
- If initial assessments demonstrate no significant effect, no further consideration is necessary. If the assessment shows a significant potential impact, sediment plume and sea bed deposition modelling may be required to further quantify the impact, with each supported by ecological assessments of significance.



Findings from the above assessment will be reported in the resulting Environmental Statement.

6.2 Waves

If any of narrow shaft GBS, piled tripod, piled jacket, suction caisson tripod or caisson suction jacket (either alone or in any combinations) are identified as the preferred foundation types across the site, then there will be only very minor interaction with wave propagation across the site locally confined to each turbine (e.g. locally due to wave reflection). As key wave transformation processes such as diffraction and breaking will not be induced by these structures, waves will re-group on the down-wave side of each turbine and there will be no far-field effect from Phase I of the development. Furthermore, due to the turbine spacing, which is optimised to yield greatest energy production, there will no significant effect on the wider wave climate from wind-wakes. There is a strong scientific base of knowledge derived from empirical wave theory, modelling and field observations to support such a conclusion. Under this scenario, it is recommended that no further modelling work is necessary to determine the effect on the wave climate.

There has been little previous work on the impact of conical GBS on wave transformation processes and these structures will have the greatest potential impact of any foundation type that is presently being considered for Phase I. The issue of scale of impact on the wave climate largely depends on the extent to which conical GBS are used across the development site and the final design dimensions.

7.0 CONCLUDING REMARKS

7.1 Does the regulating authority agree with the proposed approach?

The purpose of Coastal and Sea Bed Impact Assessment is to assess and, where necessary and practicable, mitigate the environmental impact of offshore wind farm developments on the marine environment. This Position Paper update is presented to Marine Scotland to assist in their decision making process and to provide the evidence base required to inform statutory and key consultees on the justification for a proportionate approach to the assessment of potential impacts upon sensitive receptors. It is Seagreen's view that the evidence base presented herein supports the position that the EIA can be adequately informed by empirical approaches and existing data sources coupled with expert judgement.

The presented sensitive receptor locations and evidence base strongly suggests that the assessment upon sensitive receptors can be practicably and efficiently provided by existing knowledge and available field data without the need for numerical modelling, with the possible exceptions of assessing the fate of scour material. This will be determined through the sequential approaches established in Seagreen's Position Paper and on the effects of the conical GBS (if selected) on wave climate. This which will depend on the specific dimensions of the structure, especially with respect to the height of the structure off the sea bed and the position of its transition with the tower with respect to the water depth. To this end the existing tidal data will provide information on the direction of transport and assessment of potential fate of the materials

Seagreen considers a presumption for further numerical modelling would not represent a cost effective approach to the assessment upon the receptors. Seagreen's programme of field survey and studies can provide sufficient field data to complete the required assessments.

This supplementary information taken together with Seagreen's Position Paper on Coastal and Seabed Impact Assessment (A4MR/SEAG-Z-DEV240-SRP-052) highlights those areas for continued assessment as part of Seagreen's ongoing EIA process.

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APPENDIX A:

REVIEW OF ROUND 1 & 2 ENVIRONMENTAL STATEMENTS

IN SPECIFIC RELATION TO WAVE IMPACT ASSESSMENTS

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R1	Scarweather Sands	▪ Bristol Channel ▪ 30 turbines in array ▪ 5.6m tower diameter ▪ Monopole foundations ▪ Closest point around 5km offshore	▪ Review of data and literature to characterise baseline wave climate. ▪ Evaluation of offshore extreme return period wave heights based upon Met Office modelled data. ▪ Near field modelling using MIKE 21-Boussinesq Wave Model and a 20m by 10m grid size to determine 'transmission coefficient' across development site. ▪ Near field assessment, using empirical formulae, of diffraction effects around the turbine towers. ▪ Far field modelling using HISWA Wave Model and a 500m by 250m rectilinear grid, with a 100m by 50m grid nested inside across the development site. Turbines and foundations represented using a 'transmission coefficient' within appropriate grid cells. Model runs for 0.01 year, 0.1 year, 1 year and 10 year offshore return period wave events (with H_s ranging from 4.96m to 11.68m).	▪ Data extracted from model output files in an array of points extending between the site and the shore. Particular concern about impacts on surfing conditions. ▪ Near field assessment showed some local interaction between the incident waves and reflected waves off the structure, with some radial scattering and shadow effect, but that since diffraction was not occurring (due to tower diameter relative to wavelength) the waves regroup on the down-side of the turbine and background conditions were restored. ▪ Wave shadow effect occurs (typically reduction in wave heights of <1% - and often <0.5% - of baseline conditions) but effect is close to site and does not extend to shoreline. Concluded that development has no significant effect on far field wave regime, including surfing conditions.
R1	Cromer	▪ Off North Norfolk coast ▪ 30 turbines ▪ 23m water depth ▪ Tripod foundations	▪ Review of data to characterise baseline wave climate. ▪ Far field modelling using SWAN Wave Model. Runs under different wave directions with a 1 in 1 month and a 1 in 1 year return period event. Conservative blockage effect adopted in model grid cell.	▪ Within site changes conservatively modelled as up to 0.5m but becoming negligible (<0.1m) away from the site.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R1	Teesside	▪ Tees Bay ▪ 30 turbines in array ▪ 5.5m tower diameter ▪ Monopole foundations most likely but tripods also considered ▪ Closest point around 1.5km offshore	▪ Review of data and literature to characterise baseline wave climate. ▪ Evaluation of offshore extreme return period wave heights based upon Met Office modelled data. ▪ Near field modelling using MIKE 21- Boussinesq Wave Model and a 6m by 6m master grid size, with 3m by 3m sub-grids, to determine 'transmission coefficient' across development site. ▪ Far field modelling using SWAN Wave Model and a 200m by 100m rectilinear grid, with a 100m by 50m grid nested inside and a finer 50m by 25m grid nested inside again. Sensitivity tests to look at wave and tidal level interactions, and direction of wave approach. Model runs for a 1 in 10 year return period event, plus two 'morphological wave' conditions. ▪ The effects of wave height reduction were fed into modelling of longshore sediment movement along the shoreline using LITDRIFT.	▪ Particular concern about impacts on beach stability (sea defence and nature conservation value of backing dunes). ▪ Tripod foundations showed greater wave shadow effects than monopiles. ▪ Wave shadow effects reduced wave heights by a worst case of 9% for tripods and 6% for monopiles. Since the wind farm is close to shore, the shadow effect had not dissipated before reaching the shore and therefore there was a reduction in longshore drift potential along the shore. ▪ Concluded that development may require post-construction monitoring of beach stability due to the reduction in longshore drift potential.
R1	Lynn	▪ Off Lincolnshire coast ▪ 30 turbines ▪ 5km from shore, about 13m water depth ▪ Monopile foundations	▪ Review of data and literature to characterise baseline wave climate. ▪ SWAN Wave Model based on Met Office data and bathymetric survey, verified using metocean survey data. ▪ 1 in 1 months and 1 in 1 year return period events run from three offshore directions.	▪ Within the area of the wind farms the wave height may be reduced by up to 0.25 m. ▪ Negligible changes in wave heights (<0.1m near the shore)

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R1	Inner Dowsing	▪ Off Lincolnshire coast ▪ 30 turbines ▪ 5km from shore, about 13m water depth ▪ Monopile foundations	▪ Review of data and literature to characterise baseline wave climate. ▪ SWAN Wave Model based on Met Office data and bathymetric survey, verified using metocean survey data. ▪ 1 in 1 months and 1 in 1 year return period events run from three offshore directions.	▪ Within the area of the wind farms the wave height may be reduced by up to 0.25 m. ▪ Negligible changes in wave heights (<0.1m near the shore)
R1	Kentish Flats	▪ Outer Thames Estuary ▪ 8.5km from shore ▪ 30 turbines ▪ Monopile (6m diameter) or GBS (20m base width) considered in ES	▪ Review of data to characterise baseline wave climate. ▪ Application of wave theory in relation to diffraction.	▪ Waves are not likely to be significantly altered by the presence of the wind farm and there will be no observable effects in the behaviour of waves in the far-field.
R1	Gunfleet Sands	▪ Outer Thames Estuary ▪ 7km south-east of Clacton-on- Sea, Essex. ▪ 30 turbines founded on monopiles (up to 5 in diameter)	▪ Review of data and literature to characterise baseline wave climate. ▪ Approaches only briefly summarised in ES (with reference to a separate Coastal Processes Study) but included wave modelling, which appears to be near-field Boussinesq (or similar) and far-field SWAN (or similar), although these are not stated.	▪ Intermittent local effect on wave climate – therefore of minor significance ▪ Influence on far-field wave regime is negligible. Maximum change is 6% reduction in wave height – therefore of negligible/low significance

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R1	North Hoyle	▪ 4 miles from the North Wales coast ▪ 30 turbines arranged in a grid (4m diameter monopiles and 3x 4m diameter multipile arrangement considered in ES).	▪ Development of a suite of nested hydrographical models of the area. ▪ Initially used to create baseline for adding wind farm scenario and performing secondary assessment. ▪ Model used to predict all hydrodynamic parameters for a month to include a mean spring and mean neap cycle. ▪ Used for most extreme conditions with respect to wave height - highest significant wave height and highest wind speed from 10yr summary Met Office data representing well in excess of a 1 in 10yr event.	▪ Effect of array on wave height is seen only within 100m of any given structure. Changes in significant wave height are of less than 0.1m. ▪ Far-field modelling did not indicate any effects on coastal erosion between Prestatyn and the Point of Ayr.
R1	Burbo Bank	▪ 25 turbines on 5m diameter monopiles of 52m length ▪ Liverpool Bay at entrance to River Mersey approx. 4 miles from Sefton coastline	▪ Review of available hydrodynamic information to define the main properties of the existing tidal and wave regimes. ▪ DELFT3D modelling has been undertaken configured across the regional coastal area. Use of 4 vertical layers to represent variable flow speeds and directions through depth. ▪ Model used to create a baseline before wind farm introduced and a second assessment then undertaken with scheme represented. Used for near-field and far-field effects. ▪ POL tidal data/predictions used from 1998-2016 inclusive. ▪ Wave conditions modelled for return period events of 0.1 in 1yr, 0.5 in 1 yr, 1 in 1yr, 1 in 10yr and 1 in 50yr.	▪ Main effect shown to be small reductions in wave height in the lee of the offshore structures. ▪ Near-field, monopile foundations serve to reflect oncoming waves and scatter them radially causing a slight increase in wave heights in front of each unit. Reflected waves from one structure do interact with those from other structures but at a height small in comparison to the incident wave. ▪ Far-field, wave height reductions do not extend far past development site and do not reach coastlines. Limited opportunity for cumulative effects.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	Westermost Rough (scoping)	▪ 8km offshore from Holderness coast (relocated from 15km offshore due to conflicts with other marine interests) ▪ Up to 80 turbines with monopole foundations (4-6m diameter)	[Proposed during Scoping Report] ▪ Review of data and literature to characterise baseline wave climate. ▪ SWAN Wave Model based on Met Office data and bathymetric survey, verified using metocean survey data. ▪ 1 in 1 months and 1 in 1 year return period events run from three offshore directions.	▪ ES not available for review.
R2	Thanet	▪ Outer Thames Estuary ▪ Closest point approx. 11km from shore ▪ 83 turbines and foundations considered in coastal processes assessment ▪ GBS (up to 35m diameter) and monopiles (6m diameter) considered ▪ 6m diameter turbine tower	▪ Review of data and literature to characterise baseline wave climate. ▪ Application of theoretical formulae relating to wave diffraction. ▪ Review of previous research including: o modelling of near field effects of 5m and 20m diameter cylinders by Oxford University o monitoring by CEFAS from Scroby Sands o DTI generic research project o CEFAS/Defra research project ▪ No modelling work undertaken.	▪ No diffraction effects caused by the monopiles or the GBS. ▪ Even with the largest cylinders, the downstream effect is negligible outside of the area of the turbines. ▪ Given the diameters, foundation types and spacing between turbines, there is no potential for significant cumulative (wake) impacts ▪ Negligible effect on wave climate.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	Sheringham Shoal	▪ North Norfolk ▪ Up to 108 turbines and foundations considered in coastal processes assessment ▪ Monopiles (6m diameter) and GBS (up to 35m diameter) considered ▪ 6m diameter turbine tower ▪ 14-22m water depths	▪ Review of data and literature to characterise baseline wave climate. ▪ Application of theoretical formulae relating to wave diffraction. ▪ Review of previous research including: o modelling of near field effects of 5m and 20m diameter cylinders by Oxford University o monitoring by CEFAS from Scroby Sands o DTI generic research project o CEFAS/Defra research project ▪ No modelling work undertaken.	▪ No diffraction effects caused by the monopiles or the GBS. ▪ The downstream effect is negligible outside of the area of the turbines. ▪ Given the diameters, foundation types and spacing between turbines, there is no potential for significant cumulative (wake) impacts. ▪ Negligible effect on wave climate from monopiles or small GBS. Effect of larger GBS is less certain due to lack of research and modelling. Impacts could be further improved using an appropriate numerical model capable of resolving the structures. However, natural variations over time in the level and extent of Sheringham Shoal will have a much greater impact on nearshore wave conditions than any effects caused by turbine foundations, regardless of type.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	Greater Gabbard	▪ Outer Thames Estuary ▪ Up to 140 turbines, with monopole (up to 6.5m diameter), GBS (36m width base) and multi-pile (i.e. tripod with each pile up to 2.1m diameter) all considered in ES ▪ 23km offshore from the Suffolk coast ▪ Partly located on two shallow underwater sandbanks known as the Inner Gabbard and The Galloper	▪ Review of data and literature to characterise baseline wave climate. ▪ Parametric tests on an individual structure scale under a range of water depths from 10m to 50m to assess appropriate wave theories (and hence help select appropriate models). ▪ Near field modelling using MIKE21-Boussinesq Wave Model to test different foundation options within a flume, with a row of three turbines and foundations incorporated. Transmission coefficient calculated for different foundation types. ▪ Far field modelling using DELFT3D-HISWA Wave Model with appropriate transmission coefficient (derived from near-field modelling) in each grid cell to represent a turbine tower and foundation. ▪ Wave conditions modelled from predominant wave direction under return period events of 0.01 in 1yr, 0.1 in 1 yr, 1 in 1 yr, 1 in 10yr and 1 in 50yr.	▪ The wave transmission factor showed that, within the water depths under consideration for development, the gravity base structures represent little obstruction to the both frequent and infrequent wave events because the base of the gravity structure, although large, is too deep to impact upon the wave forces acting from the water surface. ▪ The far field modelling showed that under all conditions, the potential impact of the wind farm is limited to the development site, or immediately adjacent to it. ▪ Maximum changes in the wave regime were of the order of +0.1m (under the 10 year return period event). ▪ Impacts on both the near-field and far-field wave regimes were considered insignificant, largely due to the high water depths the development is located within.
R2	Lincs	▪ 8km off Lincolnshire coast, with Lynn and Inner Downsing R1 OWFs between site and shore. ▪ 83 turbines with monopole (5-6.5m diameter), GBS (25-29m base width) and jacket (1-1.2m pin-pile diameter) foundations all considered in ES.	▪ Review of data and literature to characterise baseline wave climate. ▪ Evaluation of offshore extreme return period wave heights based upon Met Office modelled scatter diagrams, fitted with a Weibull distribution by regression analysis ▪ Far field modelling using MIKE 21-NSW Wave Model with 10 in 1 yr and 1 in 1 yr wave conditions considered.	▪ Although anticipated changes to the regional wave climate extended to the Lincolnshire coast, a conclusion was made that since the changes were relatively small in the context of absolute values, the impacts was insignificant.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	London Array	▪ Outer Thames Estuary ▪ 341 turbines and foundations considered in coastal processes assessment ▪ Closest point approx. 25km from shore ▪ 6m diameter turbine tower considered 'realistic worst case' tower option ▪ GBS considered 'realistic worst case' foundation option, but monopole and tripod also remained viable options ▪ 1 in 50 year H_s typically in range 3.9m to 5.3m (depending on direction of approach)	▪ Review of data and literature to characterise baseline. ▪ Evaluation of offshore extreme return period wave heights based upon Met Office modelled scatter diagrams, fitted with a Weibull distribution by regression analysis ▪ Near field modelling using MIKE 21-Boussinesq Wave Model in a 'flume model' approach with water depths of 5m and 10m, incorporating three adjacent turbine towers and GBS foundations aligned to the wave approach direction. GBS had 30m hexagonal base (represented in model as rectangular) protruding 4m from sea bed, taken with 6m diameter tower ▪ Calculation of wave power absorption by the 'realistic worst case' GBS foundations under water depths varying from 0m to 28m using coastal engineering formulae to determine a 'transmission coefficient' and comparison with results from the near-field model for calibration. ▪ Calculation of wave power absorption by the other foundation options of monopiles and tripods for confirmation of GBS as 'realistic worst case'. ▪ Far field modelling using Delft3D-SWAN with a curvilinear grid and incorporating a wind effect across the water surface as well as transformation of waves from offshore. Model covered the site and extended to the shoreline using nominally 350m grid cells. Cells covering turbines were partially blocked using a 'transmission coefficient' (over-conservatively applied across whole 350m wide cell) dependent on water depth at specific turbine location. Model runs undertaken for GBS, monopole and tripod foundation types. Sensitivity tests to look at wave and tidal current interactions, wave and tidal level interactions, and direction of wave approach. Model runs selected for 0.01 year and 0.1 year return period events.	▪ GBS has greater impact on wave transmission than monopiles or tripods, which had almost negligible impact in all water depths. ▪ GBS had almost negligible impact on wave transmission in water depths greater than 15m, with greater impact in shallower water as the structure occupies more of the water column. ▪ Near field changes considered insignificant if local expected changes to wave climate do not translate to a significant change to the regional wave climate Criteria of significance: ▪ Far field changes considered insignificant if no anticipated changes to the regional wave climate that would be expected to impinge on other sea bed users / features or along adjacent coastline. Model results showed GBS had greater impact than monopiles and tripods, and but that no change extended to reach the shore. The maximum modelled change from the over-conservative far-field modelling approach was a reduction of around 0.2m in wave height, which was not considered to be significant based on the sea bed users and uses present.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	Gwynt-y-Môr	▪ Liverpool Bay ▪ Two foundation scenarios considered in modelling, monopole and GBS ▪ Closest point to shore only about 12km ▪ Two R1 sites (Rhyl Flats and North Hoyle) between Gwynt-y- Môr and shore	▪ Review of data and literature to characterise baseline wave climate. ▪ No near-field assessment of waves (only tidal currents assessed) ▪ Far field modelling using unspecified Wave Model (but appears to be SWAN) under 0.1:1 year, 1:1 year and 1:50 year return period wave condition for monopole foundations and largest potential gravity base foundations (this was a worst case as in shallower parts of the site smaller gravity bases would be considered).	▪ General pattern of change is for a reduction in wave heights in a 'down-wind' direction ▪ GBS has greater impact on wave transmission than monopiles (for which changes are very small and remain within site). ▪ Under GBS foundations the wake effect extends to the adjacent coastline under certain scenarios, although reductions were generally <0.2m from baseline conditions for more operational wave conditions. ▪ For extreme wave conditions (1:1 year return period event) GBS reduced wave heights by 3.6% at the shore. ▪ The effect on the far field wave regime using monopile foundations was considered negligible, the effect using GBS was considered to be a low impact (due to conservative modelling approach to GBS scenario and low magnitude of the changes).
R2	West Duddon	▪ West of Duddon Sands, offshore from Morecambe Bay ▪ Barrow R1 OWF between it and the shore ▪ Adjacent to Walney R2 OWF (which has Ormonde R1 OWF between it and the shore) ▪ 83-139 turbines, with gravity/ pile/ tripod/ bucket/ jacket foundations all considered within ES	▪ Review of data to characterise baseline wave climate. ▪ Application of wave theory relating to wave scattering. ▪ Conclusions drawn from previous modelling of Shell Flat, Walney and Ormonde OWFs; no new modelling undertaken.	▪ Foundation bases are considerably narrower than the typical wavelength of most waves affecting the study area, and therefore it is considered that the direct impact on waves will be small, other than immediately around each structure, and there will be no discernable interaction between the foundations. ▪ No discernable effect on wave climate.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	Dudgeon	▪ Off Norfolk coast ▪ Relatively flat, uniform seabed between the Cromer Knoll and Inner Cromer Knoll sandbanks ▪ 32km from shore ▪ 56-168 turbines, with monopiles (5-8m diameter), GBS (30-35m base width), tripods (2.0-2.7m pin-pile diameters) and jackets (2.5-2.7m pin-pile diameters) all considered in ES.	▪ Review of data and literature to characterise baseline wave climate. ▪ Application of theoretical formulae relating to wave diffraction. ▪ Review of previous research including: o modelling of near field effects of 5m and 20m diameter cylinders by Oxford University o monitoring by CEFAS from Scroby Sands o DTI generic research project o CEFAS/Defra research project ▪ No wave modelling work undertaken.	▪ Given the foundation dimensions and spacing between turbines, there is no potential for significant cumulative (wake) impacts. ▪ Negligible effect on wave climate from all foundation types.
R2	Gunfleet Sands II	▪ Outer Thames Estuary ▪ 7km south-east of Clacton-on- Sea, Essex. Located on and adjacent to Gunfleet Sands sand bank ▪ Extension of consented R1 Gunfleet Sands OWF (comprising 30 turbines) ▪ A further 22 turbines founded on monopiles (up to 5 in diameter)	▪ Review of data to characterise baseline wave climate. ▪ Conclusions from previous coastal process study for Gunfleet Sands extended to Gunfleet Sands II on the basisi of similar layout, spacing and foundations. ▪ References made to findings from post-scheme research completed at Scroby Sands (CEFAS, 2007)	▪ Negligible impact on near-field and far-field wave regime.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	Walney	▪ Offshore from Walney Island ▪ 93 turbines to be constructed in two phases ▪ Ormonde R1 OWF between it and the shore ▪ Adjacent to West Duddon (which has Barrow R1 OWF between it and the shore) ▪ Monopile, GBS and jackets considered as foundation options.	▪ Review of data and literature to characterise baseline wave climate. ▪ Application of theoretical formulae relating to wave diffraction. ▪ Review of previous research including: o modelling of near field effects of 5m and 20m diameter cylinders by Oxford University o monitoring by CEFAS from Scroby Sands o DTI generic research project o CEFAS/Defra research project ▪ No modelling work undertaken.	▪ Direct impacts on waves will be small and there will be no discernable interaction between the piles. ▪ Assumed that GBS have sufficiently low profile off the sea bed not to cause wave breaking ▪ No diffraction effects caused by monopiles or turbine towers on GBS since D/L < 0.2
R2	Humber Gateway	▪ North of the River Humber 15km offshore from Spurn Point ▪ Water depths of 15m ▪ Between 42 and 83 wind turbines considered in assessment. Monopile and gravity base foundations considered	▪ Gravity base foundation considered as 'worst-case' due to increased physical presence. ▪ Two layout options considered - 'largest number of smaller turbines with closer spacing' and 'smallest number of larger turbines with wider spacing'. ▪ Wave assessment carried out for return periods of 0.1 in 1yr, 1 in 1yr, 1 in 10yr and 1 in 50 yr using most three extreme directions.	▪ For all hydrodynamic parameters, layout with closer spacing has greatest potential to induce change to the regime. ▪ 1% reduction in wave height reduction for 0.1 in 1yr return period and 3% reduction for 1 in 50yr. Considered no significant impacts to near-field wave regime. ▪ Shoreline wave changes anticipated to be <0.02m and predicted to be insignificant. ▪ Considered that wave heights will only be slightly reduced by the project. Summarised that no significant impacts to coastal erosion.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R2	Triton Knoll	▪ 33km from the Lincolnshire coast ▪ Up to 333 turbines to generate 1200MW ▪ Foundations to be determined by detailed design. Worst-case scenario considered in ES following Rochdale envelope approach	▪ Baseline determined through analysis of data and information from a variety of sources. Metocean surveys and strategic environmental assessments utilised. ▪ Waves assessed on a far-field basis with respect to both Lincolnshire and Norfolk coastlines considering N and NE events on return periods of 0.1 in 1yr, 1 in 1yr and 1 in 10yr. ▪ Waves assess on a near-field basis uses same return periods and 7 wave directions.	▪ Wave height changes greater than 0.1m occur only in a zone within 25m of the OWF boundary. ▪ Along the coastline wave height changes of less than 0.02m are expected with period changes of less than 0.04s. ▪ Effects found to be of negligible to minor significance. Limited potential for long-term effects.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
R3	Atlantic Array (Scoping)	▪ Bristol Channel ▪ Expected to use between 187 and 416 turbines to generate 1,500MW ▪ 14km from the North Devon coastline ▪ Water depths from 23-56m LAT	▪ Use of 'Rochdale envelope' approach where worst-case scenario foundations used to model largest possible impacts on hydrology. ▪ Hydrodynamic regime characterised by desk-based review of existing reports (Bristol Channel Marine Aggregates Study) amongst others. ▪ Mean significant wave height established as 1.52m - 1.79m. ▪ Approach outlined in scoping to be analysis of wave data and wave modelling. No modelling type stated. Method of establishing baseline and applying worst-case scenario array. To be analysed for near-field on the leeward side of turbines and far-field for coastline and sediment effects. ▪ Cumulative effects to be disregarded.	▪ States impacts to be unlikely but full impacts unknown as only scoping report available.
Scottish Waters	Beatrice (Scoping)	▪ Adjacent to Moray Firth Round 3 site 13.5km from Caithness coast ▪ 184 turbines proposed on monopile / pre-fabricated jacket structures ▪ Water depths of up to 45m encountered on pilot project	▪ Review of UK resource atlas used to characterise baseline wave climate. ▪ Desk-based analysis of historical environmental data and data gap analysis. ▪ Scientific monitoring equipment deployed by developer to gather wave climate data. ▪ Proposed use of MIKE21 numerical modelling.	▪ EIA currently under production.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
Other	Nysted, Denmark	▪ Around only 10km from shore ▪ Rectangular array of 72 turbines	▪ Modelling of array (9 rows by 8 columns) using MIKE21-SW	▪ Reduction in wave heights of up to about 10% modelled at peak of wave shadow; this was considered acceptable by regulators. ▪ Wave shadow effects extended to show (typically 5-7% reduction in wave height at shoreline)
Other	Horns Rev 1, Denmark	▪ 80 turbines (8 sets of 10 rows) founded on monopiles of assumed diameter 3.5m with penetration depth of 20-22m ▪ Located 15-20km west of Blåvands Huk, Denmark ▪ Water depths of approx. 9m	▪ Previous technical report (unavailable in English) undertaken to establish baseline conditions of a Hmax of 8.1m and Hs of 5-5.5m. ▪ Use of paper-based calculations (with assumption that all wave energy hitting the foundations is reflected) to compare incoming wave height to wave height once windmill is passed. Diameter of 4m used in calculations. ▪ MIKE21 modelling used for sediment movement but not for wave impacts.	▪ Calculations show wave height to reduce by 0.36% after each windmill is passed based on energy loss. ▪ Nine rows of windmills leads to wave height reduction on the leeward side of 3.3% as a conservative estimate. ▪ Nearshore wave climate 'practically unaffected' by the presence of the wind farm. ▪ Considered to have no measurable effect on hydrography or sediment transport.
Other	Oriel, Ireland	▪ 55 turbine wind farm located in the NW Irish Sea, 6km NE of Clogher Head ▪ Water depth ranges from 15-30m ▪ Concrete caisson gravity foundations preferred option with 45-50m diameter	▪ Baseline studies of hydrography undertaken. Marine geophysical and hydrographical surveys undertaken. ▪ Wave height measurements not available for the location so used readings from a buoy east of Dublin from 2001-2006. ▪ No mention of modelling or analysis on effect on waves directly.	▪ Presence of turbine foundations not considered to have an effect on flows or waves in the location. ▪ Assessment more concerned with settlement of foundations and sediment effects.

Name		Comments	Wave Impact Assessment Methods	Wave Impacts
Other	Rodsand II, Denmark	▪ Extension to Rodsand 1 existing wind farm located 8.8km south of Lolland ▪ 90 turbines with gravity base foundations preferred due to ice conditions ▪ Water depths of approx. 4m	▪ Local wave energy losses calculated using WAMIT. Bed friction and possible wave breaking neglected. ▪ Use of a spectral wave model MIKE21 SW. ▪ Boundary conditions established using offshore wave data from Baltic Sea Database. ▪ MIKE21 used to calculate baseline without wind turbines, then with Rodsand I, then with Rodsand I + II ▪ Wave statistics for near-shore area established for use in LITPACK. ▪ Analysis of 1 in 1yr and 1 in 10yr return periods.	▪ Wave height is not significantly affected by presence of the wind turbines. ▪ Reduction of wave height due to natural processes of refraction and wave breaking is significantly higher than that due to the presence of the turbines. ▪ Maximum damping is expected to be close to 1.5% for extreme waves. ▪ Only a minor impact on morphology is to be expected as a consequence.
Other	Anholt, Denmark	▪ Water depths of between 15-19m ▪ 15km NE of Djursland and 20km from Anholt ▪ Planned 111 turbines supported by monopile foundations of diameter approx. 5m driven to 20-30m penetration depths	▪ Wave behaviour around a single wind turbine modelled by WAMIT. ▪ Worse case scenario method used for wave modelling. Considered 174 turbines on gravity base foundations. ▪ Use of spectral wave model MIKE21 SW modelled wind effects. Wind effects considered by DHI to be dominant mechanism over short fetches.	▪ Maximum reductions in wave heights are 3% between the windmill rows. Consistent with Horns Rev and Nysted. ▪ Reductions in wave heights due to diffraction/refraction do not exceed 1% at 10km from the development. ▪ Wave height changes are larger for smaller waves (Hs<2m) so effects greater for annual wave climate rather than storm wave climate. ▪ Wave height change due to diffraction/refraction at the coasts of Anholt and Djursland will be insignificant. ▪ Wave height change due to wind effects at the coasts of Anholt and Djursland are expected to be 1-2%.