CHAPTER 7: PHYSICAL ENVIRONMENT

Technical Summary

Seabed and sediment data was collected for the Zone and the export cable route corridor and wave, current and turbidity measurements were obtained at key locations in the Seagreen Project area. An assessment was undertaken to investigate the potential changes that the offshore wind farms and export cables would have on the local waves, currents, sediment distribution, the sediment transport regime and features of the seabed. Project Alpha, Project Bravo and the Transmission Asset Project are predicted to have some localised effect in the immediate vicinity of the infrastructure within them, but they will not have any significant effect further away from the sites. There is potential for localised scour around the base of each foundation structure, although the detailed design will take this into account.

Changes due to the presence of the offshore structures are considered to be less than those experienced due to the natural variation in both the seabed and shoreline and as such the likely effects are considered to be low. Mitigation measures have been suggested which are likely to reduce all effects to not significant, including for the potential use of a conical gravity base structure design option, for which the effect remains low but not significant. No cumulative effects are anticipated with other projects.

INTRODUCTION

7.1. This chapter of the ES describes the physical environment of the Seagreen Project, which comprises Project Alpha, Project Bravo and the Transmission Asset Project that connects the Project Alpha and Project Bravo sites via the Export Cable Route (ECR) corridor to land on the east coast of Scotland at Carnoustie.

7.2. This chapter provides a baseline description of physical processes (wave and tidal regimes), bathymetry, geology, geomorphology (seabed and coastal), and sedimentary processes (sediment transport and deposition). The baseline description is followed by an assessment of the magnitude of the effects resulting from the construction, operation and decommissioning of the Seagreen Project, as well as those resulting from cumulative interactions with other existing or planned projects. Also provided are considerations with regard to potential mitigation measures and outline monitoring plans, where appropriate.

7.3. This chapter was written by Royal Haskoning, and incorporates results from other contributors including GEMS (2010), Fugro GEOS (2011), Osiris Projects (2011), Partrac (2012) and Intertek Metoc (2012).

7.4. This chapter should be read in conjunction with Appendices E1, E2, E3 and E4 which can be found in ES Volume III: Appendices.

7.5. Appendix E1 contains selected consultation documents of relevance to the physical environment, Appendix E2 contains reports from metocean and geophysical surveys, Appendix E3 contains a Geomorphological Assessment and Appendix E4 contains a Foundation Assessment.

7.6. All figures referred to in this chapter can be found in ES Volume II: Figures.

CONSULTATION

7.7. As part of ongoing consultation, stakeholders have provided comment on issues relating to the physical environment through review of Seagreen's Phase 1 Scoping Report, produced as part of the Environmental Impact Assessment (EIA) process (Seagreen, 2010a).

7.8. Table 7.1 summarises issues of relevance to the physical environment that were highlighted by the consultees as requiring assessment within the EIA, and indicates which sections of this chapter address each issue.

Table 7.1 Summary of consultation and issues

Date	Consultee	Issue	Relevant Chapter/ Section
January 2011	Marine Scotland and Scottish Environment Protection Agency (SEPA)	The baseline assessment should identify: • Sediments • Hydrodynamics • Sedimentary environment • Sedimentary structures • Suspended sediment concentrations	Existing Environment
January 2011	Scottish Natural Heritage (SNH) and the Joint Nature Conservation Committee (JNCC)	Due consideration should be given to coastal erosion as this has been the dominant force along this (Angus) coastline to date, although there are a few areas of accretion and land claim. The coastline is influenced by the varying presence of intertidal and subtidal rock platform and a relatively gentle rise into the interior.	Existing Environment and Appendix E3
January 2011	SNH and JNCC	Cable landfall could (potentially) interrupt sediment moving towards Barry Links Site of Special Scientific Interest (SSSI) & Geological Conservation Review (GCR) site, and potentially the Firth of Tay and Eden Special Area of Conservation (SAC) and Special Protection Area (SPA). This would need to be mitigated / minimised by sensitive design options.	Existing Environment and Appendix E3
January 2011	SNH and JNCC	Much of this coast has experienced longstanding erosion problems and, given tidal observations and climate projections, it is likely that these management concerns will worsen during the lifetime of the Seagreen Project. Given the developed nature of this coastal zone, it would be prudent to safeguard the land-based elements of this proposal from the likely effects of climate change. A Shoreline Management Plan has been drawn up for this section of coast.	Existing Environment and Appendix E3
January 2011	SNH and JNCC	There may be a need to address the cumulative effects of several offshore wind farms on coastal processes depending upon array density and location with respect to existing renewable and coastal developments.	Assessment of Effects – Cumulative and Combination Effects
October 2011	SNH and JNCC	Both organisations would welcome sight of further information regarding potential effects associated with the ECR element of the Seagreen Project.	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase and Appendix E3
November 2011	Marine Scotland	Further information regarding the proposed ECR landfall location and installation techniques is required.	Assessment of Effects – Construction Phase

7.9. Consultation was initially carried out with Marine Scotland during the preparation of the geophysical and metocean survey to determine the requirement for data to inform this chapter.

7.10. Further consultation was undertaken with Marine Scotland on the development of Seagreen's Position Paper on Coastal and Seabed Impact Assessment (Seagreen, 2010b, see Appendix E1) in January 2011. Subsequent consultation with Marine Scotland, Scottish Natural Heritage (SNH) and Joint Nature Conservation Committee (JNCC) on this position paper led to the submission of a further evidence base to support Seagreen's proposed position on future impact assessment (Seagreen, 2011, see Appendix E1).

7.11. Marine Scotland, SNH and JNCC confirmed via a joint response that the position paper provided "*a robust piece of work, providing a valuable contribution to assessing the impacts of wind farms*". Some additional aspects for clarification were also identified with regards to the assessment on the effects upon the wave environment and sediment transport processes associated with the worst case scenario for the Transmission Asset Project and landfall option (see Appendix E1).

ASSESSMENT METHODOLOGY

Study Area

7.12. The physical environment is considered over two spatial scales:

- Immediate Study Area (ISA) – the footprint of the Seagreen Project that resides in the marine environment, including Project Alpha, Project Bravo and the Transmission Asset Project; and
- Regional Study Area (RSA) – the coastal area surrounding the Seagreen Project area over which remote effects may occur and interact with other activities, including the Outer Forth and Outer Tay areas and encompassing the Zone and Scottish Territorial Waters (STW) sites.

Note: There are no effects of significance on the physical environment over the Wider Study Area (WSA).

Data Collection and Survey

7.13. In order to inform the EIA process, metocean, geophysical, benthic, and geotechnical data were collected for the ISA (see Table 7.2). A summary of the data that has been used to inform this chapter is discussed in the following paragraphs.

Table 7.2 Summary of key survey data

Title	Source	Year
Firth of Forth Offshore Wind Farm ECR: Geophysical survey	Osiris Projects	2011
Firth of Forth Offshore Wind Farm Development: Benthic survey	IECS	2011
Firth of Forth Zone Development: Metocean survey	Fugro GEOS	2011
Seagreen Winter Metocean Survey Final Report	Partrac	2012
Geophysical Results Report Phase 1	GEMS	2010
Wave Height Spells for Survey Operability	Metoc	2010

Metocean

7.14. On behalf of the Applicants, Fugro GEOS Ltd. undertook a programme of meteorological and oceanographic (metocean) measurements across the ISA and the Firth of Forth Zone between 13th December 2010 and 7th June 2011.

7.15. A total of eight moorings (A-H) were deployed throughout the ISA and the Zone (Figure 7.1) to measure a variety of parameters, including; water levels, wave height, wave period, wave direction, tidal current velocity at different depths in the water column, turbidity and seawater properties (temperature and salinity).

7.16. The directional wave buoy located at site C was retained in its position until 4th August 2011, when it was serviced and re-deployed. It then remained recording further directional wave data until mid May 2012.

7.17. The results from this programme are reported in full in Fugro GEOS (2011). A summary of the resulting data produced by Intertek Metoc (2012) is provided in Appendix E2.

7.18. Partrac Ltd. completed an Acoustic Wave and Current (AWAC) and Seapoint® Optical BackScatter (OBS) survey on behalf of the Applicants (Partrac, 2012). AWAC and OBS were deployed at two locations (E and F) near the coast, with data collected between the 15th December, 2011 and 18th June 2012. This captured similar data to that described above, except for salinity which was not recorded.

7.19. The results from this programme are reported in full in Partrac (2012), which is provided in Appendix E2. A summary of the resulting data produced by Intertek Metoc (2012) is also provided in Appendix E2.

7.20. The time series of metocean parameters collected to inform this ES is listed in Table 7.3.

7.21. In addition to these measured data, UK Meteorological Office (Met Office) hindcast model wind and wave time series results were used to provide details on the wave climate across the RSA. The locations of the Met Office forecast data points (West and East) are also shown on Figure 7.1.

Table 7.3 Metocean data available from instrument deployments

Site	Deployment Dates	Parameters [Instrumentation]	Comments
A	13 December 2010 to 5 June 2011	Wave / Current / Water Level / Temperature / Turbidity / Salinity [AWAC plus 14-day ADCP]	No data recovered in Dec 2010 and Jan 2012, so AWAC redeployed and successful data recovery achieved across 10 weeks from March to June 2011. Near-bed ADCP deployed for 14 days in March 2011 to provide near bed current data
B	25 March 2011 to 6 June 2011	Current / Water Level / Temperature / Salinity [ADCP]	10 weeks of successful data recovery.
C	24 March 2011 to 6 June 2011	Current / Water Level / Temperature / Salinity [ADCP]	10 weeks of successful data recovery.
	12 December 2010 to date 15 May 2012	Wave [DWR]	Directional wave buoy serviced and redeployed on 4th August 2011.
D	26 March 2011 to 6 June 2011	Current / Water Level / Temperature / Salinity [ADCP]	10 weeks of successful data recovery.
E	18 January 2011 to 5 June 2011	Wave / Current / Water Level / Temperature / Turbidity / Salinity [AWAC]	No data recovered in Jan 2012, so AWAC redeployed and successful data recovery achieved across 10 weeks from March to June 2011.
	15 December 2011 to 18 June 2012	Wave / Current / Water Level / Temperature / Turbidity [AWAC and OBS]	21 weeks of successful data recovery. No AWAC data obtained between 5th May and 18th June 2012
F	18 January 2011 to 7 June 2011	Wave / Current / Water Level / Temperature / Turbidity / Salinity [AWAC]	No data recovered in Jan 2012, so AWAC redeployed and successful data recovery achieved across 10 weeks from March to June 2011.
	15 December 2011 to 18 June 2012	Wave / Current / Water Level / Temperature / Turbidity [AWAC and OBS]	27 weeks of successful data recovery.
G	24 March 2011 to 6 June 2011	Current / Water Level / Temperature / Salinity [ADCP]	10 weeks of successful data recovery.
H	24 March 2011 to 6 June 2011	Wave / Current / Water Level / Temperature / Turbidity / Salinity [AWAC]	No data recovered in Dec 2010 and Jan 2012, so AWAC redeployed and successful data recovery achieved across 10 weeks from March to June 2011.

Note: ADCP is ADCP is Acoustic Doppler Current Profiler, AWAC is Acoustic Wave and Current Meter, DWR is Directional Wave Rider and OBS is Optical Back Scatter

Geophysical and benthic

7.22. A geophysical survey including swathe bathymetry, side scan sonar and sub-bottom profiling was undertaken for Projects Alpha and Bravo (GEMS, 2010) and along the ECR corridor (Osiris Projects, 2011). The extent of the geophysical surveys is presented in Figure 7.2 and reports are available in Appendix E2. The surveys included provision of:

- full multi-beam bathymetry coverage of the Seagreen Project area;
- a classification of the seabed sediments for the refinement of a detailed benthic survey;
- information on the shallow geology of the Seagreen Project area and mapping of any variations in thickness and mobile sediment cover; in particular the height, length and slopes of sand waves;
- identification and location of any existing artefacts or obstructions within the Seagreen Project area, i.e. cables, pipelines, wrecks, trawler marks, etc.;
- information on where the seabed has steep sided features within the Seagreen Project area;
- re-interpretation of bathymetry data to determine seabed habitat types and locate biogenic features by means of an Acoustic Ground Discrimination System (AGDS);
- soil stratigraphic sections summarising the range of inferred ground conditions for preliminary substructure/ foundations design; and
- location of discernible large surface lying boulders within the sediment plain.

7.23. Maps and charts, including track plots, bathymetric charts, seabed features with sonar and magnetic contacts, isopach maps and reduced level to significant reflectors (including recent sediments) relative to Lowest Astronomical Tide (LAT) were provided as deliverables.

7.24. Surface sediment characterisation and particle size analyses (PSA) were carried out on samples recovered as part of the benthic survey campaign (see Chapter 11: Benthic Ecology and Intertidal Ecology). The campaign utilised a mini-Hamon grab to collect a single replicate sample for infaunal analysis, from which a sub-sample was taken for PSA. Further details on the sampling campaign and the subsequent analyses are provided in Chapter 11: Benthic Ecology and Intertidal Ecology and Appendix F1 and locations are shown in Figure 7.3.

7.25. PSA was carried out by dry sieving sediments of sand size and coarser and by laser size analysis using a Coulter counter system for fine sediments (i.e. those not considered suitable for sieving).

7.26. The results were then used to determine sediment type according to the definitions of the Folk and Ward classification system used by the British Geological Survey (BGS).

7.27. In addition to the ISA-specific surveys, other data and literature was obtained, reviewed and in some cases further interpreted to add value to the baseline understanding (see Table 7.4).

Table 7.4 Summary of key reports

Title	Authors / Source	Year
Seagreen Phase 1: Geomorphological Assessment	Seagreen	2012
A methodology to assess causes and rates of change to Scotland's beaches and sand dunes – Phase 1	SNH	2011
Round 3 Firth of Forth Phase 1 Preliminary Geological Report	Cathie Associates	2011
Firth of Forth Offshore (Round 3) Wind Farm Phase 1: Preliminary Geological Report	Cathie Associates	2011
UK Round 3 OWF Zone 2 Firth of Forth. Wave Height Spells for Survey Operability	Metoc	2010
Firth of Forth Developers Group: Review of existing Information	HR Wallingford	2009
Coastal Cells in Scotland: Cell 1 – St Abb's Head to Fife Ness	Ramsay & Brampton	2000
Coastal Cells in Scotland: Cell 2 – Fife Ness to Cairnbulg Point	SNH	2000
Angus Shoreline Management Plan (SMP)	Angus Council	2001

Approach to Assessment

7.28. During development of Round 1 and Round 2 offshore wind farms, coastal process impact assessments were undertaken in accordance with best practice guidance from Energy Technology Support Unit (ETSU, 2000 and ETSU, 2002) and Centre for Environment, Fisheries & Aquaculture Science (CEFAS, 2005). 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.

7.29. These reviews have 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 Collaborative Offshore Wind Research into the Environment (COWRIE) guidance (COWRIE, 2009) highlights five key areas for consideration in relation to OWF development, which have been screened for their applicability to the Seagreen Project (see Table 7.5). For further details on Seagreen's Position Paper, Supplementary Information and Consultation please see Appendix E1.

Table 7.5 Screening of COWRIE-identified potential effects with relevance to the Seagreen Project

Ref.	Issue	Screening	Relevant
1	Suspended sediment dispersion and deposition patterns resulting from substructure / 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.	YES
2	Changes in coastal morphology due to cable landfall	While changes in coastal morphology due to landfall cannot be discounted, 'mitigation by design' shall seek to reduce any potential impact to environmentally acceptable levels.	YES
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.	YES
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.	NO
5	Wave and current processes controlling very shallow sand bank morphology especially with less understood substructure / foundations types	The majority of Project Alpha and Project Bravo are located in an area of seabed with no major sand banks and in water depths of approximately 35-60m below LAT. However, where isolated sand waves are present they attain elevations of ~10m above the seabed, with overlaying water depths of approximately 40m.	NO

7.30. The nature of any potential changes to physical processes that occur due to the presence of the Seagreen Project will be highly variable, both temporally and spatially. The following short sections illustrate this inherent variability within the spatial and temporal domains of physical systems, which sets them apart from other environmental receptors.

7.31. Temporal variation: Changes to physical processes naturally vary over a wide range of timescales. Variations can occur over a tidal cycle, monthly, seasonally, annually or over a period of decades. For example, changes to tidal currents are observed at peak flood, high water and low water. Furthermore, changes to the wave climate display a marked seasonality and are highly variable on all temporal scales from minutes to decades. Physical processes are therefore by their nature highly variable in time. Variation will also occur over other timescales, for example, seasonal variations are considered significant at different times of year.

7.32. Spatial variation: Changes to physical processes vary significantly according to location. For example, increased tidal flow velocity may occur at one location while a marked decrease in flow velocity may occur at another location.

7.33. A change to any physical process (e.g. wave height, duration of peak tidal current flow) may, in some instances, be beneficial to some environmental or physical receptors while simultaneously being detrimental to other receptors. This disparity relates to the relative nature of the change and adds to the difficulty in assigning significance to the magnitude of change.

7.34. It is not possible, when assessing the effect of the Seagreen Project on physical processes, to categorically state that a change in a particular physical parameter can be robustly defined to be of negligible, minor, moderate or major adverse or beneficial significance. Although the application of significance in accordance with the definitions previously described in Chapter 6 is standard practice when assessing other parameters within the EIA process, it is not good practice for the assessment of physical processes.

7.35. The assessment methodology used in this chapter is therefore different to those adopted in other Chapters of this ES. This is because the Seagreen Project will have effects on the hydrodynamic and sedimentary process regimes, but these effects in themselves are not considered to be impacts; the impacts will manifest upon other receptors such as marine ecology, fish and shellfish resources, sediment and water quality, seabed morphology, coastal geomorphology, and designated sites. Hence, the assessment in this chapter focuses on describing the changes/ effects rather than defining the impact. Where an effect is identified upon a physical process (i.e. waves or tidal currents) the assessment assigns a magnitude to the degree of change. The resultant changes/ effects are subsequently assessed for their potential to impact upon other environmental receptors, including their sensitivity, and discussed in the following Chapters:

- Chapter 8: Water and Sediment Quality;
- Chapter 9: Nature Conservation Designations;
- Chapter 10: Ornithology;
- Chapter 11: Benthic Ecology and Intertidal Ecology;
- Chapter 12: Natural Fish and Shellfish Resource;
- Chapter 13: Marine Mammals; and
- Chapter 17: Archaeology and Cultural Heritage.

7.36. The assessment of potential effects on the physical environment from construction, operation and decommissioning of the Seagreen Project is largely based on detailed technical studies on scour potential, coastal and seabed Historical Trend Analysis (HTA) and Expert Geomorphological Assessment (EGA), supplemented by a broad conceptual understanding of hydrodynamic and sedimentary processes (see Appendix E3) and, for cumulative effects, detailed mathematical modelling of wave and tidal regimes and sediment transport processes.

7.37. The HTA involved a review of the past data and available records that relate to the Projects set within the broader context of the RSA. HTA considers both natural and anthropogenic changes, which are particularly relevant in the context of morphological evolution. HTA provides an analysis of the historic behaviour of the system; from such an analysis, assessment can be made of potential future change.

7.38. EGA is informed by the HTA and has been utilised to inform the assessment. EGA is a technique which involves interpreting a range of data and applying expert judgment to evaluate the functioning of hydrodynamic and sedimentary regimes and how any changes to these regimes may affect other physical receptors, such as geomorphology and sediment distribution.

7.39. To date, on Round 1 and Round 2 developments, empirical approaches have been used to assess scour hole formation locally around turbine substructures as part of the EIA process. As an initial component of the assessments of scour for the substructure/ foundation types proposed for the Project Alpha and Project Bravo developments, a thorough desk-based review has been undertaken of existing literature and empirical methods including previous numerical and physical modelling studies undertaken for other OWFs. This has led to the development of suitable methods for predicting scour holes and scour volumes around the particular substructure/ foundations types currently under consideration at the site (see Appendix E4).

7.40. The assessment methods have considered global seabed scour (i.e. general erosion, cable burial depths and the potential for free-spanning of cables) and scour around turbine and substation substructures/ foundations via HTA and EGA. The assessment methods have considered: (i) jacket substructures; (ii) tripod substructures; (iii) rectangular / square gravity base structures (GBS); and (iv) conical GBS. For the jacket and tripod substructures, both the horizontal and vertical members of the lattice structures have been considered. The assessment methods have incorporated separate steps for the calculation of:

- scour due to currents;
- scour due to waves; and
- timescales of scour development.

7.41. The assessment of scour and scour protection considers both global seabed scour (i.e. general erosion) and scour around turbine and substation substructures/ foundations, via:

- HTA of seabed morphology, including sand wave and megaripple migration rates and spatial and temporal changes in seabed morphology;
- development of a conceptual understanding of the evolution of the seabed, and the influence of waves, tides, currents, and seabed features such as sand waves and megaripples; and
- EGA to assess the impacts of substructures and foundations, sub-sea cables and OWF infrastructure.

7.42. The definitions of effect magnitudes described in this chapter follow that set out in Table 7.6.

Table 7.6 Definition of terms relating to the magnitude of change upon the physical environment

Magnitude	Definition
High	Fundamental, permanent / irreversible changes, over the whole feature / asset, and / or fundamental alteration to key characteristics or features of the particular environmental asset's character or distinctiveness. Effect certain or likely to occur.
Medium	Considerable, permanent / irreversible changes, over the majority of the feature / asset, and / or discernible alteration to key characteristics or features of the particular environmental aspect's character or distinctiveness. Effect certain or likely to occur.
Low	Discernible, temporary (throughout project duration) change, over a minority of the feature / asset, and / or limited but discernible alteration to key characteristics or features of the particular environmental aspect's character or distinctiveness. Effect will possibly occur.
Negligible	Discernible, temporary (for part of the project duration) change, or barely discernible change for any length of time, over a small area of the feature or asset, and/ or slight alteration to key characteristics or features of the particular environmental aspect's character or distinctiveness. Effect unlikely or rarely occurs.
No change	No loss of extent or alteration to characteristics, features or elements.

EXISTING ENVIRONMENT

7.43. The existing environment is described in the following sections, covering Project Alpha, Project Bravo and the Transmission Asset Project. For the purposes of the physical environment the Project Alpha and Project Bravo sites may be considered as offshore. Whilst the Transmission Asset Project has elements which are offshore, the primary effects are associated with the nearshore environment, particularly where the ECR makes its landfall.

Project Alpha, Project Bravo and the Zone

Wind and waves

7.44. Strong winds can occur throughout the North Sea, wave heights vary greatly due to fetch limitations and water depth effects. Waves in the northern North Sea can be generated either by local winds or from remote wind systems (swell waves).

7.45. A summary of wave parameters for the Zone, as recorded at Sites A, C and H (sites B, D and G did not collect wave data) during the main metocean deployment, is presented in Table 7.7. Site A is located west of Project Alpha whereas Sites C and H are located in the rest of the Zone (see Figure 7.1 for locations).

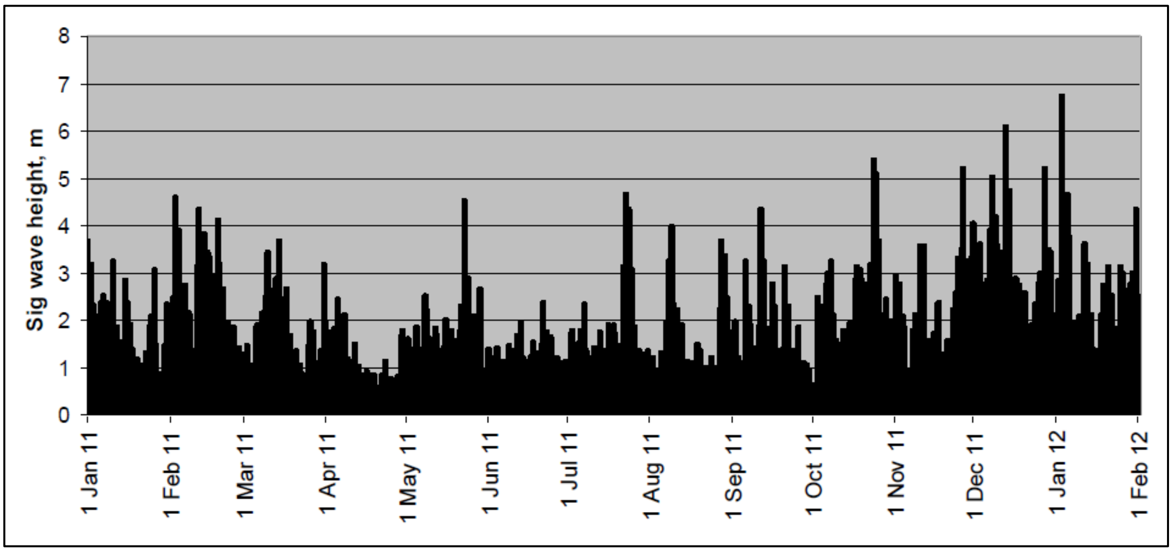
Table 7.7 Summary of wave parameter statistics for the Zone

Site	Parameter	Maximum	Mean	Direction (°) at time of maximum
A	Hs (m)	4.6	0.9	212
	Hmax (m)	7.2	1.4	215
	Tp (s)	14.3	5.9	052
	Tz (s)	8.5	4.3	028
C	Hs (m)	5.0	2.0	236
	Hmax (m)	9.2	1.3	244
	Tp (s)	20.0	7.2	071
	Tz (s)	9.9	4.8	017
H	Hs (m)	3.9	0.9	248
	Hmax (m)	7.1	1.4	248
	Tp (s)	14.9	6.4	042
	Tz (s)	8.7	3.7	012

Note: Hs is significant wave height, Hmax is maximum wave height, Tp is period of peak spectral energy and Tz is mean wave period

7.46. Based on analysis of the metocean data (see Appendices E2 and E3), wave heights are dominated by large winter storms generating large wind seas. During the initial deployment of the wave buoy at Site C, between 12 December 2010 and 4 August 2011, the highest significant wave height was 5.0m, recorded on the 23 May 2011 (Plot 7.1). Following servicing and re-deployment of the wave buoy at Site C on 4 August 2011, stormier conditions were recorded on several occasion during autumn 2011 and winter 2011/ 12. During the stormiest event, a significant wave height of 6.7m was recorded on 3 January 2012 (Plot 7.1). This correlates with a 1 in 1 year sea wave climate return period event.

Plot 7.1 Timeseries record of significant wave height, recorded at Site C

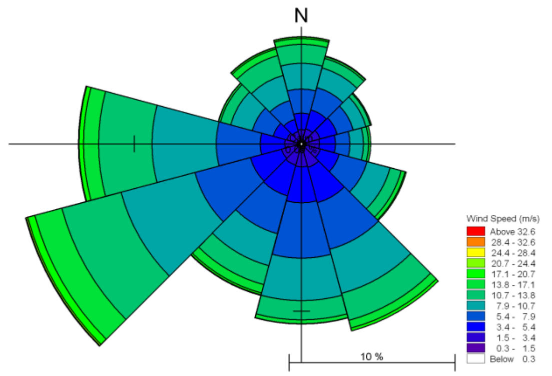


7.47. A long-term (10-year) wind and wave record has been obtained from the Met Office wave model for UK Waters. Forecast data for two grid points, referred to as East (southeast corner of the Zone) and West (southwest corner of the Zone) (see Figure 7.1 for locations), have been interpolated for the period June 2000 to February 2010. The parameters include wind (speed and direction), sea wave, swell and resultant wave (height, period and direction).

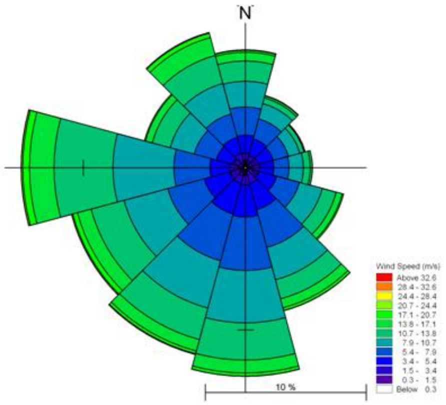
7.48. Plot 7.2 illustrates the offshore wind climate at the East and West Points from the Met Office model data. Wind conditions at the West Point are influenced by the Firth of Forth corridor, leading to a predominant south westerly wind. The East Point displays more of a spread of wind directions across the south to western sectors. The wind climate is predominantly offshore.

Plot 7.2 Wind climate from Met Office model

West Point



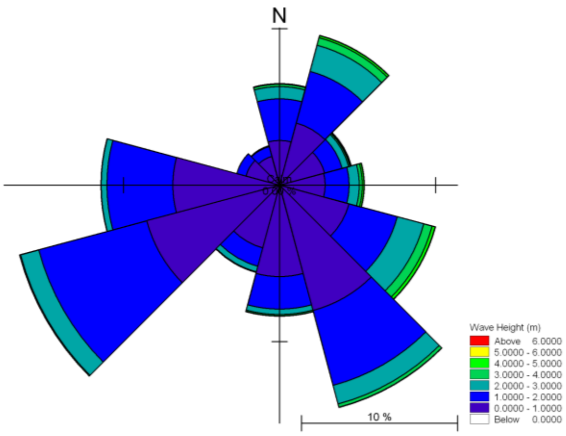
East Point



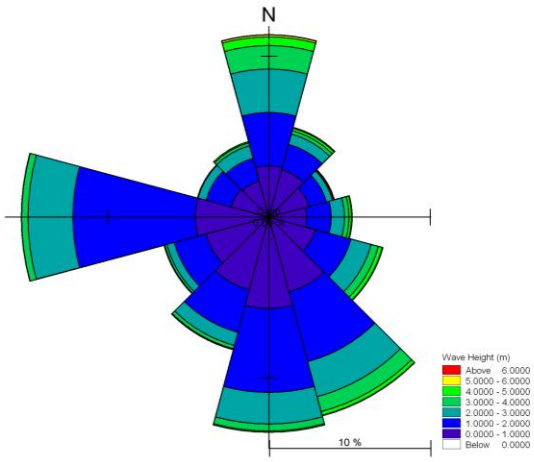
7.49. Plot 7.3 presents the offshore sea wave climate for the East and West Points. The influence of land is more clearly defined than for the wind climate, with the predominant incident waves being aligned with the coastline. In general, the sea wave rose plots show three dominant directions, in descending order of dominance; south westerly, southerly and northerly waves.

Plot 7.3 Sea wave climate from Met Office model

West Point



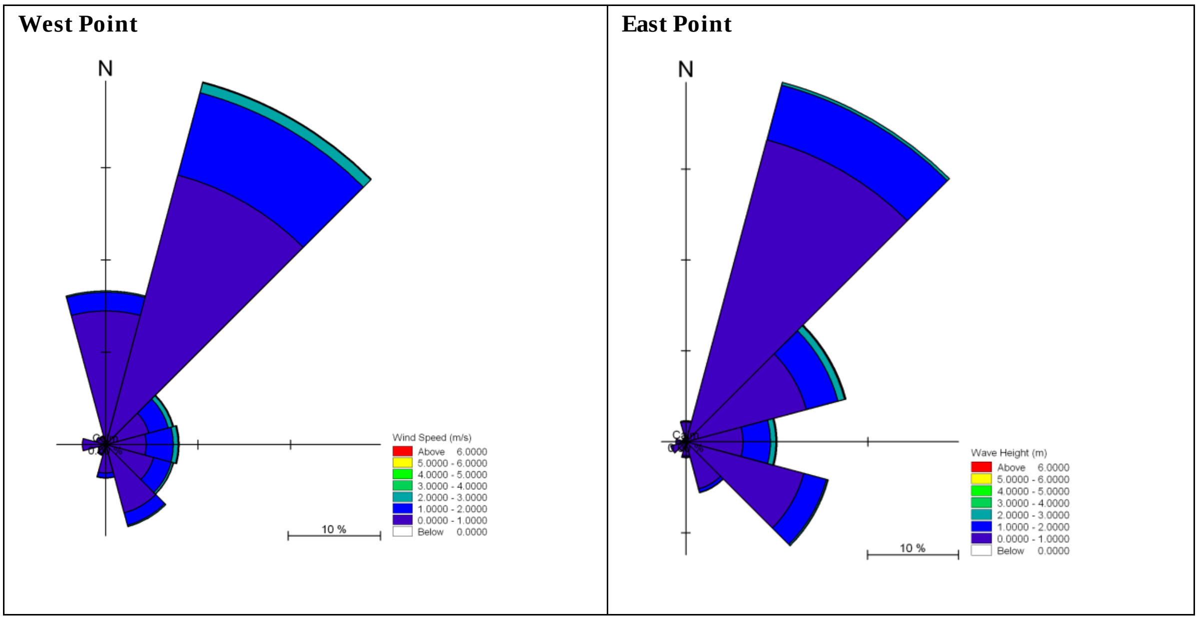
East Point



7.50. Based on the combined Met Office wave data for the East and West Points, significant wave heights (Hs) are 6.7m and 8.7m for 1-year and 50-year return period waves (averaged from all sectors), respectively.

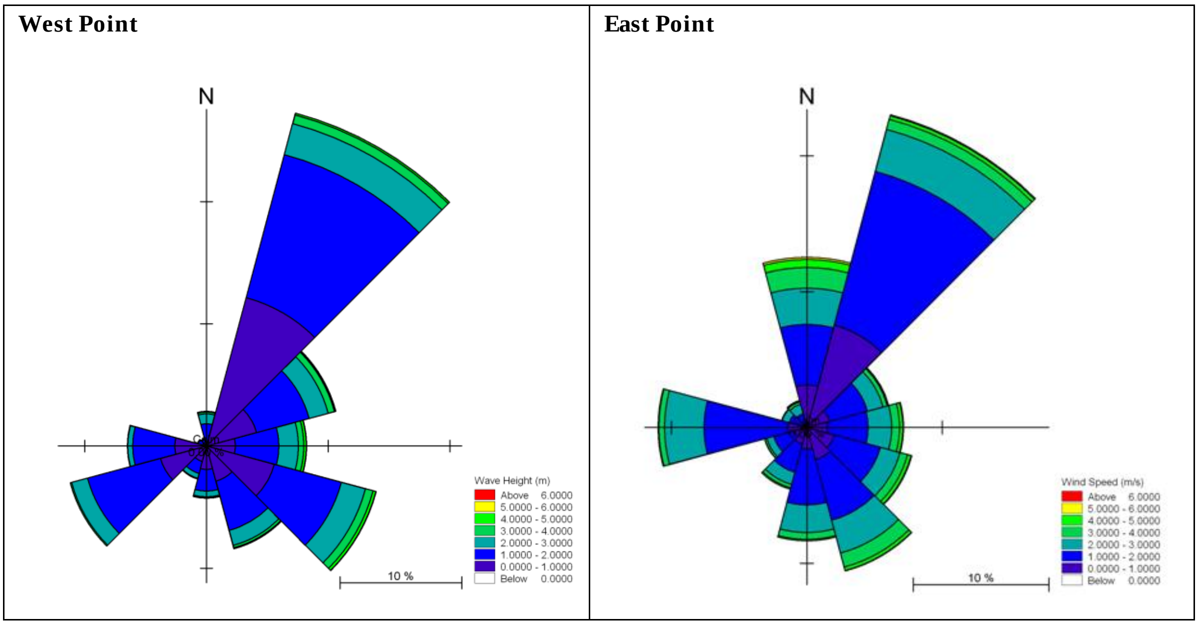
7.51. Plot 7.4 presents the offshore swell wave climate for the East and West Points. Swell waves are from two dominant directions in a descending order of dominance; north easterly and south easterly. Both north easterly and south easterly swell waves may interact with Scottish Territorial Waters (STW) sites within the far-field.

Plot 7.4 Swell wave climate from Met Office model



7.52. Plot 7.5 presents the resultant wave climate combining sea waves and swell waves. Resultant waves are from three dominant directions in a descending order of dominance; north easterly, south easterly and south westerly.

Plot 7.5 Resultant wave climate from Met Office model



Water levels

7.53. A summary of water levels for the Zone as recorded during the metocean deployment is presented in Table 7.8. Tidal measurements demonstrated a strong semi-diurnal signal throughout the duration of metocean deployment. Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT), relative to Mean Sea-Level (MSL) were greatest at Site A with levels of 2.6m and -2.6m, respectively.

Table 7.8 Summary water level statistics for the Zone

Site	Water level (m relative to MSL)	
	Maximum	Minimum
A	2.6	-2.6
B	1.9	-2.3
C	2.0	-2.3
D	2.1	-2.5
G	2.3	-2.7
H	2.3	-2.6

Source: Fugro GEOS (2011)

7.54. Superimposed on the regular tidal pattern, various non-tidal effects may occur, many of which originate from meteorological influences. Strong persistent winds can result in elevated water levels above those predicted from tidal influences alone. Furthermore, atmospheric pressure variations can also result in the depression or elevation of the water surface, thereby generating negative or positive surges, respectively.

7.55. Water level maxima observed during the metocean deployment are interpreted to result from two different phenomena depending on the presented data (Fugro GEOS, 2011). The water level maximum at Site A was the result of a storm surge on 4th February 2011 that produced residual water levels 1.4m above predicted tidal elevations. Maxima at all other Zone sites were caused by spring tides on 19 February 2011.

Tidal currents

7.56. The tidal regime within the Zone is semi-diurnal in nature and characterised by a variable mean spring tidal range. Currents are primarily driven by tides with a residual component generally dominated by storm driven currents (Ramsay & Brampton, 2000). The pattern of tidal elevations across the outer Firth of Forth is governed by a southerly directed flood tide that moves along the eastern coastline of Scotland into the Firth of Forth and around Fife Ness. The main peak flood tide occurs approximately 2 hours before high water (HW), with the main peak ebb tide occurring approximately 4 hours after HW.

7.57. HR Wallingford (2009) stated that tidal current velocities can reach 1.2m/s within the Tay Estuary. In the Firth of Forth, at Rosyth, typical peak flood velocities are 0.4m/s to 0.7m/s and on the ebb are 0.7m/s to 1.1m/s. Seaward of the estuaries the tidal flows are typically weaker.

7.58. A summary of tidal current statistics for the Zone, as recorded during the metocean deployment, is presented in Table 7.9.

Table 7.9 Summary of tidal current statistics for the Zone

Site	Depth (metres below mean sea-level)	Height (metres above seabed)	Speed (m/s)		Direction at Maximum (°N)
			Maxi-mum	Mean	
A (AWAC)	10.5	43.0	0.91	0.35	029
A (ADCP)	45.25	8.25	0.74	0.28	017
B	8.8	52.7	0.88	0.32	196
C	7.3	50.7	0.72	0.26	000
D	6.1	48.7	0.77	0.28	178
G	9.8	44.7	0.72	0.26	001
H	10.0	43.0	0.76	0.23	136

Source: Fugro GEOS (2011)

7.59. The strongest current flows were observed at the two most northerly sites, A and B. Site A recorded a maximum current of 0.91m/s on 18th April 2011 during a period of spring tides that correlated with the maximum water level at most sites. Maximum current speeds were slightly slower at the other sites with maxima ranging from 0.72m/s to 0.77m/s. Directions varied little between sites. Sites A and B were characterised by current directions along a north-northeast to south-southwest axis, while Sites C, D and G were characterised with a tidal axis of north to south (see Figure 7.4). Site H had an axis parallel to its respective nearby coastline, which is northwest to southeast.

Bathymetry

7.60. The maximum depth across the ISA (86.2m LAT) is observed to the northwest of Project Alpha where a relatively deep northeast to southwest orientated channel crosses the sea floor (Figure 7.5). The shallowest areas within the ISA occur along the north-south orientated Scalp Bank to the west of Project Alpha. The majority of both Project Alpha and Project Bravo are within 40–60m LAT.

7.61. There are limited areas of steeply sloping seabed associated with the channel feature across the northwest of Project Alpha. However, the majority of Project Alpha and Project Bravo can be characterised as having a slight gradient (0 to 5°), though in areas of mobile bedforms (i.e. megaripples), localised gradients (<11.9°) exceed these values.

Geology

7.62. The geological sequence across Project Alpha and Project Bravo is presented in Table 7.10. While the sequence is relevant to both Projects, localised variations occur in and between the two OWFs which are set out in the following sections.

7.63. The geology is complex with a well-defined boundary between bedrock and Quaternary sediments across Projects Alpha and Bravo (GEMS, 2010). However, the western boundary of Project Alpha is marked by a more chaotic internal structure, resulting in difficulty distinguishing the boundary between bedrock and overlying Quaternary stratigraphic units. Where it was not possible to distinguish between the Quaternary units, sediments are treated as undifferentiated Quaternary sediments.

Table 7.10 Geological sequence of Projects Alpha and Bravo

Stratigraphy		Depth (m below seabed)	Properties	Predicted Soils
Epoch/ Period	Name			
Holocene	Undifferentiated Holocene	Generally less than 0.5m thick	Superficial sediments: thin veneer of sediments generally less than 0.5m thick and locally absent.	Sand, slightly gravelly sand, gravelly sand and also some small patches of sandy gravel.
Holocene		Up to 35m to base of formation	Forth Formation: occurs as blanket deposit or infills depositional hollows on the surface of the Wee Bankie Moraine, or late Weichselian channels. Internal erosion surfaces common. Mainly amorphous; some well-layered sediments in north and west. Present across most of the site.	Sand (fine grained, well to poorly sorted, soft to firm, olive to grey brown, with lithic pebbles, shells and shell fragments in variable amounts) and some possible mud/ silt towards its base. Fluviomarine.
Quaternary (pre-Holocene)	Wee Bankie Formation	Up to 63m to base of formation	Sheet-like deposit on rugged bedrock topography. Covers most of west of area; grades into Marr Bank Formation. Generally <20m thick, up to 40m thick in some places.	Till (hard, dark grey to red-brown, gravelly, angular to rounded clasts) with thin interbedded sand and pebbly sand. Basal till.
Quaternary (pre-Holocene)	Marr Bank Formation	0 to 38m to base of formation	Sheet-like deposit on flat basal surface. Covers most of east of area; grades into Wee Bankie Formation.	Sand (fine grained, poorly to well sorted, soft to firm, grey to red-brown with abundant lithic granules) and pebbles. Locally silty. Glaciomarine.
Quaternary (pre-Holocene)	Aberdeen Ground Formation	In excess of 85m to base of formation in places	Occurs as blanket deposit or occupies hollows of the underlying bedrock. Present across less than half of the site.	Interbedded mud (hard, brown to grey) and sand (fine to coarse grained). Glaciomarine.
Triassic	Triassic group	more than 85m to top of formation in places	Underlying bedrock. Present across whole site.	Red sandstones, siltstones, mudstones and marls, flat to current-bedded with sporadic thin bands of gypsum, intra-formational conglomerate and disseminated pseudomorphs after halite.

Source: GEMS (2010)

7.64. The bedrock typically comprises Triassic bedrock over the majority of the Project Alpha and Bravo area (Cathie Associates, 2011). It forms a well-layered unit and is heavily folded and faulted. It is often found at or close to the surface and shows some channelling, especially in the far north, far west and the south of the area. The area just west of the centre of the Project Alpha and Project Bravo areas is characterised by a deep north-south trending trough where the bedrock has been deeply eroded and the depression has been infilled with a thick succession of Quaternary sediments (GEMS, 2010). Carboniferous strata occur in the southwest edge of the Projects area only.

7.65. During the Quaternary, several glacial and interglacial episodes resulted in the deposition of a highly variable sequence of formations. The offshore Quaternary sequences generally form cyclical depositional patterns marked by glacio-lacustrine and glacio-marine conditions. Quaternary deposits from the upper Pleistocene that are present across both the Project Alpha and Project Bravo areas comprise the Marr Bank, Wee Bankie and Aberdeen Ground Formations.

7.66. The Aberdeen Ground Formation is identified as either a channel deposit or a sheet-like deposit and rests between the overlying Marr Bank/ Wee Bankie Formations and the Triassic bedrock. It is not ubiquitous across the Project Alpha area and also covers some of the east and south of the Project Bravo area as a sheet-like deposit. It also appears as fill of a north-south channel up to 75m deep below the seabed in Project Bravo area.

7.67. The geophysical survey (GEMS, 2010) identified the Wee Bankie Formation as a sheet-like deposit with a base occurring up to 63m below seabed. The Wee Bankie Formation is distributed throughout most of the Project Alpha area, grading into the Marr Bank Formation in the Project Bravo area.

7.68. After the Pleistocene glacial cycles, the Holocene transgression resulted in the extensive reworking of the Pleistocene deposits and their subsequent deposition as near contemporary (Holocene) seabed sediments comprising both terrigenous and biogenic constituents.

7.69. In the Project Bravo area, the undifferentiated Holocene sediments are extensive and form generally north-south trending channels at depths up to 22m. They are characterised by erosional bases that cut into the underlying Marr Bank/ Wee Bankie formations and occasionally penetrate the Aberdeen Ground Formation and cut into the Triassic bedrock.

7.70. Holocene sediments comprise mostly sand with some finer sediment towards their base. Surface seabed sediments are characterised in places by higher gravel content. The depth to the base of the Holocene sediments is generally greater within Project Bravo where it is up to 30m.

Seabed substrate

7.71. Analysis of the geophysical datasets (GEMS, 2010) facilitated identification of seabed substrate and features including isolated boulders and sand bars, sand waves and megaripples (see Table 7.11 for a definition of key seabed morphological features). Megaripples are the predominant feature across the seabed, with isolated sand waves in the Project Alpha area (see Figure 7.6). Boulders are prevalent across the area and are either represented as isolated boulders or as clusters. All of the features are characteristic of various stages of sediment erosion and transportation produced by fluid movement (waves and currents) over sediments.

Table 7.11 Definition of key seabed morphological features

Terminology	Definition
Ripple	Undulations (<0.5m wavelength)
Megaripple	Undulations (0.5m to 25m wavelength)
Sand wave	Undulations (>25m wavelength)

7.72. Interpretation of the results from the benthic survey (Envision Mapping, 2012, provided in Appendix G2) indicate that the predominant sediment types within both Project Alpha and Project Bravo are rippled medium to fine sand with varying amounts of coarse shell, and mixed mosaics of gravel, cobbles and coarse shell lying on or embedded within the sand (Figure 7.7). Gravel sediments derived from erosion of Quaternary Formations present at the seabed are widespread across the south western extent of Project Alpha.

Sediment transport

7.73. Megaripples, predominantly comprised of slightly gravelly sand, are present across both Project Alpha and Bravo (Figure 7.6). Their crests tend to be orientated perpendicular to the coastline (north-northwest to south-southeast). The height of the megaripples is generally less than 0.5m, with the larger megaripples having gently sloping sides of up to 6° – 7°.

7.74. Sand waves are observed predominantly across Project Alpha and in the southwest corner of Project Bravo. These larger bedforms have the same orientation as the megaripples and are up to 10m higher than the surrounding seabed with relatively steep side slopes (9° – 11.9°).

7.75. Bedform morphology is in general symmetrical and HTA analysis (see Appendix E3) indicates that crest positions have not changed significantly over time. This suggests limited migration of the bedforms and hence limited sediment transport.

7.76. Analysis of spatial shifts in the bathymetric contours between 2006 and 2010 indicate that both the Project Alpha and Bravo areas are characterised by an overall accreting environment. However, parts of Projects Alpha and Bravo may be characterised by net erosion resulting in exposure of isolated boulders on the seabed (Figure 7.6). The maximum recorded size of a single boulder was 4m x 5m x 0.5m and the maximum recorded area of a boulder cluster field was $0.5km^2$. These boulders are interpreted to derive from erosion of glacial deposits and represent lag deposits. Vertical changes in the seabed do not exceed ±0.25m/ yr (see Appendix E3).

Suspended sediment

7.77. Results from water sampling carried out at two offshore stations (A and H) during two sampling events, in March and June 2011, show total suspended solids (TSS) to be low (see Table 7.12). The samples had TSS of <5 mg/ l with a maximum reading during March of 18 mg/ l (Site H, bottom; 30 and 90 minutes). Although all values are low, a slight increase in TSS is observed in March compared to June. This distinction is more evident at Site H.

Table 7.12 Total Suspended Solids (mg/l), March and June 2011 within the Zone

Site	Time after sampling started (mins.)	March					June				
		0	30	60	90	120	0	30	60	90	120
A	Top	10	<5	<5	<5	<5	<5	<5	<5	<5	<5
	Middle	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	Bottom	8	<5	5	6	<5	<5	<5	<5	<5	<5
H	Top	5	<5	<5	<5	<5	<5	<5	<5	<5	<5
	Middle	<5	<5	<5	10	<5	<5	<5	<5	<5	<5
	Bottom	6	18	<5	18	<5	6	<5	<5	<5	6

7.78. Tidal currents are the principal mechanism governing suspended sediment concentrations in the water column, with fluctuations across the spring-neap cycle and throughout different stages of the tide (high water, peak ebb, low water, peak flood) observed throughout both datasets. However, suspended sediment concentrations can temporarily be elevated by wave-driven currents during storm events.

Transmission Asset Project

Wind and waves

7.79. The offshore wave climate, both total sea and significant wave height for return periods of 1-100 years, have been reported by Ramsey & Brampton (2000) for coastal cells to the north and south of Fife Ness. The predicted wave climates were derived from the Met Office Wave Model and are stated to be representative of the general offshore wave climate i.e. they do not represent one particular location (see Table 7.13).

Table 7.13 Total sea and significant wave height (offshore conditions)

Return Period (years)	Total sea significant wave height (m)	Significant wave height (m)
1	6.23	3.56
10	7.62	4.49
100	8.95	5.36

Source: Ramsey & Brampton (2000)

7.80. Offshore of the Firth of Forth, wave conditions are experienced from between 200°N and 340°N with, on average, approximately 35% of conditions occurring from between 20°N and 60°N (Ramsay & Brampton, 2000). Significant wave heights of over 4m can be experienced from any direction in the easterly sector (0°N – 180°N). There is a tendency for more extreme wind conditions from the northeast than from the southeast.

7.81. Little information exists on the nearshore wave climate. HR Wallingford (2009) stated that the largest wave heights are incident from the east-northeast sector (45°N – 90°N) with inshore wave height varying due to complex nearshore bathymetry and coastal planform.

7.82. A summary of wave parameters for Site E during the initial metocean deployment is presented in Table 7.14. Waves at metocean Site E are predominantly from the north or east due to the sheltering of all sites from the west and to a lesser extent from the south. However, wave directions during the 23rd May 2011 storm event were from the southwest.

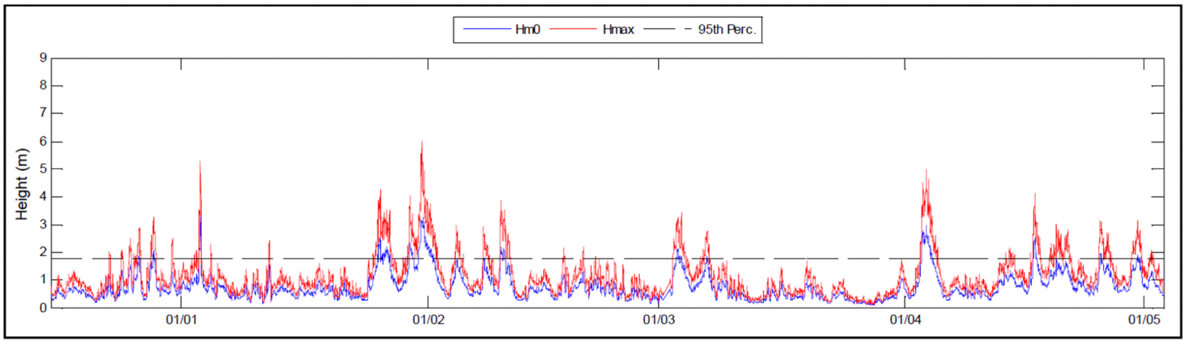
Table 7.14 Summary of wave parameter statistics at site E from initial deployment

Site	Parameter	Maximum	Mean	Direction (°) at time of maximum
E	Hs (m)	4.0	0.6	201
	Hmax (m)	7.1	1.0	201
	Tp (s)	14.1	4.9	080
	Tz (s)	6.6	3.2	096

Source: Fugro GEOS (2011)

7.83. An AWAC located at Site E during a subsequent metocean deployment recorded wave data from 15th December, 2011 through to 5th May, 2012 (Plot 7.6), during which time a significant wave height of 3.4m was recorded on the 3rd January 2012 (Partrac, 2012). This is coincident with the maximum wave height recorded by the wave buoy at Site C, within the Zone. This peak event occurred in a rapidly increasing sea state from an initial benign condition. Indeed, the lowest recorded suspended sediment concentrations during the period were recorded on 2nd January 2012; the day preceding the highest recorded wave conditions. A series of notable storm wave events also occurred later that month, progressively building up between 25th and 27th January, 2012 and again between 29th January and 1st February, 2012. The data record shows that the largest waves are incident from between 90° and 135° (east to southeast).

Plot 7.6 Timeseries record of maximum (Hmax) and significant (Hm0) wave height, recorded at Site E



Tides and tidal currents

7.84. The tidal regime along the Transmission Asset Project is semi-diurnal in nature and characterised by a variable mean spring tidal range. Tidal range varies spatially along the coast in response to the interaction of incident tidal energy, bathymetry and coastal planform, and orientation of the coastline. Tidal range along the eastern Scottish shoreline, to the west of the Zone, is 4.6m at Dundee, 4.8m at Anstruther and 4.5m at Dunbar (Ramsay & Brampton, 2000).

7.85. North of the Firth of Tay, the flood and ebb tides are rectilinear, flowing parallel with the coast. Offshore of the River Tay estuary the flood current flows in a southerly direction across the mouth. The tide rotates in a clockwise direction with a maximum spring tidal velocity of 0.6m/ s. The same tidal current processes are observed within the Firth of Forth with tidal flow moving south along the coastline via Fife Ness (Ramsay & Brampton, 2000). Between St. Abb's Head and Barns Ness tidal streams run east-southeast and west-northwest on the flood and ebb tide with a peak tidal velocity of 0.5m/ s off the coast.

7.86. A summary of tidal current statistics for Site E, as recorded during the metocean deployment, is presented in Table 7.15 and Figure 7.4. Tidal current data show a consistent variation in both magnitude and direction throughout the water column and this is correlated with the tidal phase. The predominant current direction is along a northeast to southwest axis (Partrac, 2012) (see Figure 7.4). Current direction shows variation through the spring-neap cycle and slight ebb dominance (with stronger magnitudes seen on an ebbing tide).

Table 7.15 Summary of tidal current statistics at site E

Site	Depth (metres below mean sea-level)	Height (metres above seabed)	Speed (m/s)		Direction at Maximum (°N)
			Maximum	Mean	
E	6.3	19.0	0.76	0.29	064

Source: Fugro GEOS (2011)

Freshwater inputs

7.87. Density-driven currents, freshwater inputs and meteorological events can also have an effect superimposed on tidal currents. Various rivers and estuaries discharge into the wider regional study area with these freshwater inputs contributing to the hydrodynamic regime. SEPA monitors freshwater flows upstream of the tidal limits of the estuaries and these river flows are presented in Table 7.16.

Table 7.16 River inputs into the Regional Study Area

River	Catchment area (km^2)	Mean flow (m^3/s)	95% exceedance (m^3/s)	10% exceedance (m^3/s)
Forth	1036.0	47.0	5.5	115.0
Tay	4587.1	169.2	43.0	335.2
Eden	307.4	3.9	0.96	5.6
Tyne	307.0	2.8	0.58	5.6
Total	6237.5	223.0	50.1	464.4

Source: HR Wallingford (2009)

7.88. Table 7.16 does not provide an exhaustive list of river discharges. Previous work has stated that "*the remaining rivers contribute negligible freshwater input*" (HR Wallingford, 2009). Notwithstanding, the Tay and Forth rivers, account for 97% of the total mean flow. By way of comparison of freshwater quantities, Table 7.17 provides a summary of the average tidal volumes exchanged between MLW and MHW.

Table 7.17 Estimated tidal exchange within the main rivers

River	Volume at MLW (m^3)	Volume at MHW (m^3)	Volume exchanged per tide (m^3)
Forth	1.61×10^{10}	2.01×10^{10}	0.4×10^{10}
Tay	1.31×10^{8}	5.40×10^{8}	4.09×10^{8}
Eden	7.05×10^{5}	1.16×10^{7}	1.09×10^{7}
Tyne	6.92×10^{7}	8.94×10^{7}	2.02×10^{7}

Source: HR Wallingford (2009)

7.89. It is evident from Tables 7.16 and 7.17, that the tidal influence is dominant. The Firth of Forth regional study area can generally be considered as being well mixed (HR Wallingford, 2009). However, the freshwater contribution will lead to a local net residual ebb flow (HR Wallingford, 2009).

Water Levels

7.90. Water levels fluctuate predictably according to the ebb and flow of the tide, but can be elevated above predicted levels by positive surge effects. Table 7.18 presents information on the top ten positive surges recorded at Leith over the last 20 years (HR Wallingford, 2009). Surge heights of 1.2 m are exceeded, on average, around every 5 years (Intertek Metoc, 2012).

Table 7.18 Top ten positive surges recorded at Leith over the past 20 years

Date	Surge (m)
14th April 1989	1.38
20th February 1990	1.30
10th November 1998	1.26
20th February 1997	1.25
20th February 1993	1.15
10th January 1995	1.14
19th December 1991	1.13
17th January 1993	1.07
11th January 2006	1.06
30th January 2000	1.03
Average	1.12

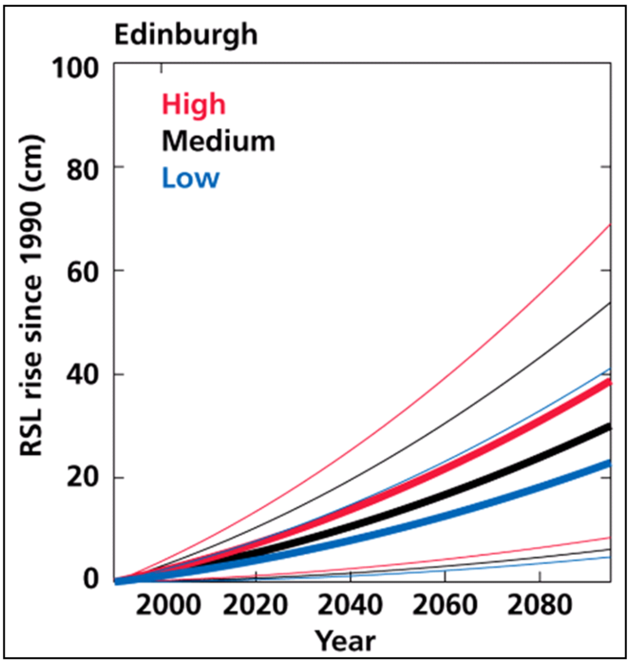
Source: HR Wallingford (2009)

Sea-level rise

7.91. Over relatively short temporal periods (e.g. months to a small number of years) the tidal signal can be regarded as varying relative to the datum of MSL. However, over longer temporal periods (e.g. beyond the duration of the 18.6 year lunar nodal cycle) MSL varies in response to sea-level rise. Hence, the datum of MSL is non-stationary. Future sea-level rise results from the net effect of global change to sea-level and local changes to land levels due to post-glacial isostatic readjustment (rebound or subsidence).

7.92. Global warming is predicted to increase pressure on the coastline due to increased storminess and rising sea levels from thermal expansion of seawater and melting of far-field glaciers. The UK Climate Projections 2009 (UKCP09) provides estimates for each decade of relative sea-level changes with respect to 1990 levels. Central estimate values and 5th and 95th percentile limits of the range of uncertainty for three emissions scenarios (high, medium and low) are provided in Plot 7.7 for Edinburgh. Values for relative sea-level rise indicate between 23.4cm (low) and 39.2cm (high) by the end of the 21st century.

Plot 7.7 Future sea-level rise curves for Edinburgh



Source: http://ukclimateprojections.defra.gov.uk/images/stories/marine_pdfs/UKP09_Marine_report.pdf

7.93. The implications of sea-level rise over the coming century require consideration for the Seagreen Project, particularly with respect to ensuring that any nearshore development components are ‘future-proofed’.

Bathymetry

7.94. Depths along the Transmission Asset Project range from 3m above LAT close to the coast to approximately 69m below LAT in close proximity to Project Alpha (see Figure 7.5).

7.95. Seabed levels within the central section of the Transmission Asset Project undulate between 39m below LAT and 69m below LAT, as the route crosses a series of frequently broad, gently-sloping (≤2.6°) ridges or mounds of gravelly sands/ sandy gravels. It should be noted that the actual slope gradients may be steeper because the survey lines cross the mounds obliquely (i.e. they do not cross in the direction of the steepest part of the mound slope).

Geology

7.96. The solid geology beneath the Transmission Asset Project comprises a thick sequence of sandstones, siltstones and mudstones of Lower (Emsian) and Upper (Famennian) Devonian ages. To the east, these Devonian rocks are, in turn, overlain by Permo-Triassic rocks.

7.97. The solid geological units are in turn overlain by Quaternary deposits, comprising variable materials ranging from soft clayey silts/ silty clays of the Forth Formation to gravelly clays/ clayey gravels of the Wee Bankie Formation. The soft clayey silts/ silty clays can be up to 40m thick and are more prevalent in the western section of the Transmission Asset Project, whereas the gravelly clays/ clayey gravels are thought to represent glacial tills and are generally present throughout the area, reaching thicknesses of up to 40m in places.

7.98. The Quaternary deposits are frequently capped by very thin finer-grained surface sediments, generally less than 2.0m thick. These Holocene materials comprise gravelly sands/ sandy gravels or clayey gravelly sands, which may exhibit very little variation in character compared to the underlying strata. A geological model for the Transmission Asset Project is presented in Table 7.19 (Cathie Associates, 2011; Osiris Projects, 2011).

Table 7.19 Geological model for the Transmission Asset Project

Unit	Member	Approximate thickness (m)	Description
Holocene	N/ A	<2	Silty or gravelly sands to sandy gravels, with occasional clayey, gravelly sands on part of northern corridor.
Holocene to Quaternary (Forth Formation)	St Andrews Bay Member	5-40	Estuarine gravelly clayey sands and silty clays to fluviomarine clayey sands and silts.
Quaternary – Forth Formation	Largo Bay Member	5-30	Interbedded marine clays, silty clays and silts, with rare gravel.
Quaternary – St Abbs Formation	N/ A	Generally 10m, locally ≤20	Glaciomarine silty and gravelly clays.
Quaternary – Wee Bankie Formation	N/ A	5-40	Hard sandy and gravelly till, with interbedded fluvial sands and gravelly sands. Locally coarse sands and gravels in erosion channels.
Permo-Triassic	Undivided	N/ A	Generally sandstones and/ or mudstones.
Upper Devonian	Clashbenny Formation	N/ A	Sandstone, locally conglomeratic at base.
Lower Devonian	Strathmore Group	N/ A	Sandstone, locally conglomeratic, overlying siltstone and mudstone.

Source: Osiris Projects (2011)

Seabed substrate

7.99. Geophysical data indicate that variable, generally granular sediments are present on the seabed across much of the Transmission Asset Project. The seabed sediments comprise silty fine sands, only broken by a number of irregular patches of coarser grained, fine to medium sands and larger patches of much coarser sandy gravels, with frequent small boulders (see Figure 7.6).

7.100. Osiris Projects (2011) interpreted these coarser grained materials as representative of strata of the underlying Wee Bankie Formation, which are known to comprise stiff, frequently granular till, with interbedded sands and gravelly sands. The patches of coarse grained sediments are characterised by discrete bathymetric relief, forming ridges or mounds, which frequently attain elevations of up to 20m above the intervening seabed depressions with slopes of ≤9.5°.

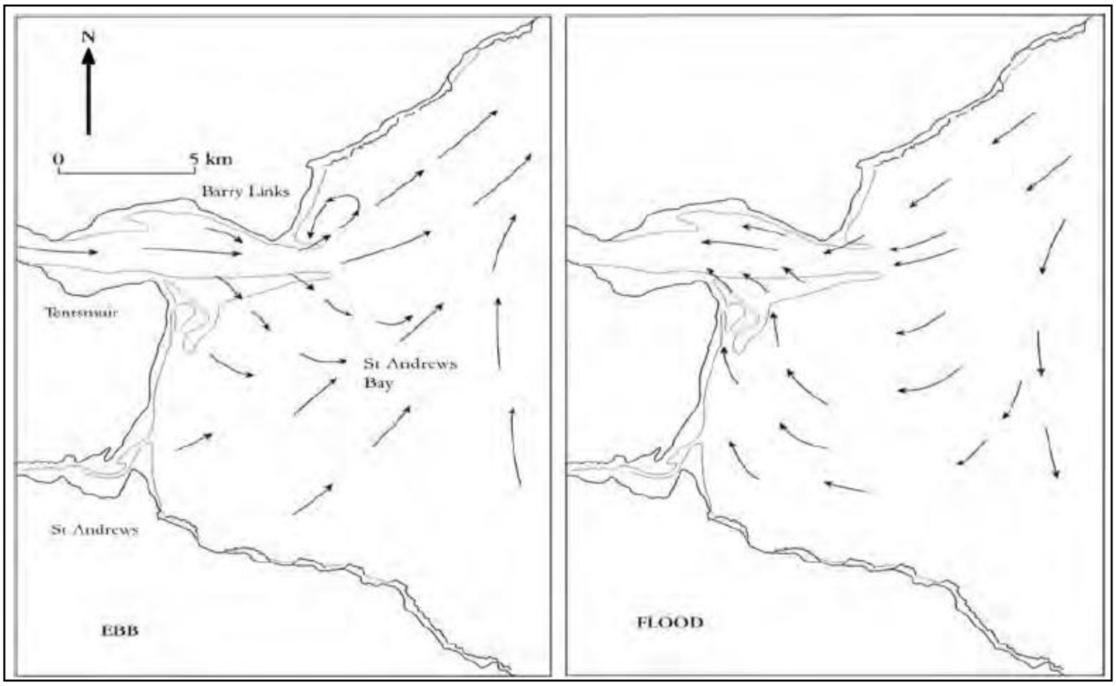
7.101. The fine sand seabed is generally characterised by gentle gradients (maximum 2.5°) with megaripples (Figure 7.6). These bedforms are orientated approximately northwest-southeast with crest elevations of up to 0.4m and an average wavelength between 6 and 15m.

Sediment transport

7.102. Due to its location close to a major port and estuary, there is a substantial amount of research concerning tidal conditions in the Tay that bears upon the intertidal sediment transport regime and thus the geomorphology at Barry Links (SNH, 2011).

7.103. The flood tide flows south along the shore to the east of Buddon Links. Offshore, within the Outer Tay, the flood tidal stream divides into two constituent parts, one flowing westwards into the Tay Estuary and the other forming an offshore clockwise rotation, moving into St. Andrews Bay to move north towards the south bank of the Tay (HR Wallingford, 1997) (see Plot 7.8).

Plot 7.8 Flood and ebb tidal pattern within the Regional Study Area



Taken from SNH, 2011. Original source: Ferentinos and McManus, 1981

7.104. The ebb flows eastwards out of the Tay and is deflected to the north over the Gaa Sands by the open coast northward ebb, forming an anticlockwise eddy sweeping back onto the east shore of Buddon Ness from the north (Ferentinos and McManus, 1981) (Plot 7.8). Thus, on both flood and ebb, tidal currents sweep sediment south along the east shore of Barry Links towards Buddon Ness. On the western shore of Buddon Ness, ebb tide is stronger than the flood and tends to sweep sediments eastwards towards Buddon Ness.

7.105. As a result of both waves and tides, the Tay entrance is characterised by a complex interchange of sediment and, although local variability exists, the resultant net longshore sediment transport direction is from the north onto the eastern coast of Buddon Ness and from the east onto the southern coast of the Ness (HR Wallingford, 1997). The nearshore bathymetry is shallow and characterised by shore-parallel sand bars, with the extensive intertidal sand banks of Gaa Sands, lying to the east of Buddon Ness, being submerged during most of the tidal cycle. Offshore, in the Firth of Tay entrance, the seabed consists mainly of sands except in the centre of the estuary itself where gravel occurs (Barne *et al*., 1997).

7.106. HR Wallingford (HR Wallingford, 1997) noted in a detailed study of littoral processes that erosion dominated the northern part of Carnoustie Bay between 1969 and 1988 with the transport of material subsequently towards the south. On the beach, historical map analysis (Mitchell, 1997) at Barry Links illustrated a substantial seaward movement of the MHWS tide line over the period 1865 to 1959, with erosion and retreat since 1959. The recent erosion and coastal retreat is attributed to the formation of a large anti-clockwise eddy on the ebb tide to the east of Barry Links, which tended to re-circulate material towards the shoreline at Buddon Ness. This pattern is reinforced by wave activity.

7.107. The net longshore drift of beach sediment within Carnoustie Bay is north to south, with the rate of coastal retreat slowing notably to the north of Carnoustie, due to the geological character of the coastline, with coastal erosion being limited to episodic (storm) events.

Suspended sediment

7.108. A summary of suspended solid concentrations (SSC), expressed as mg/l, as recorded at Site E during two recording events as part of the metocean deployment, is presented in Table 7.20. The following baseline characterisation therefore relates solely to the nearshore extent of the Transmission Asset Project.

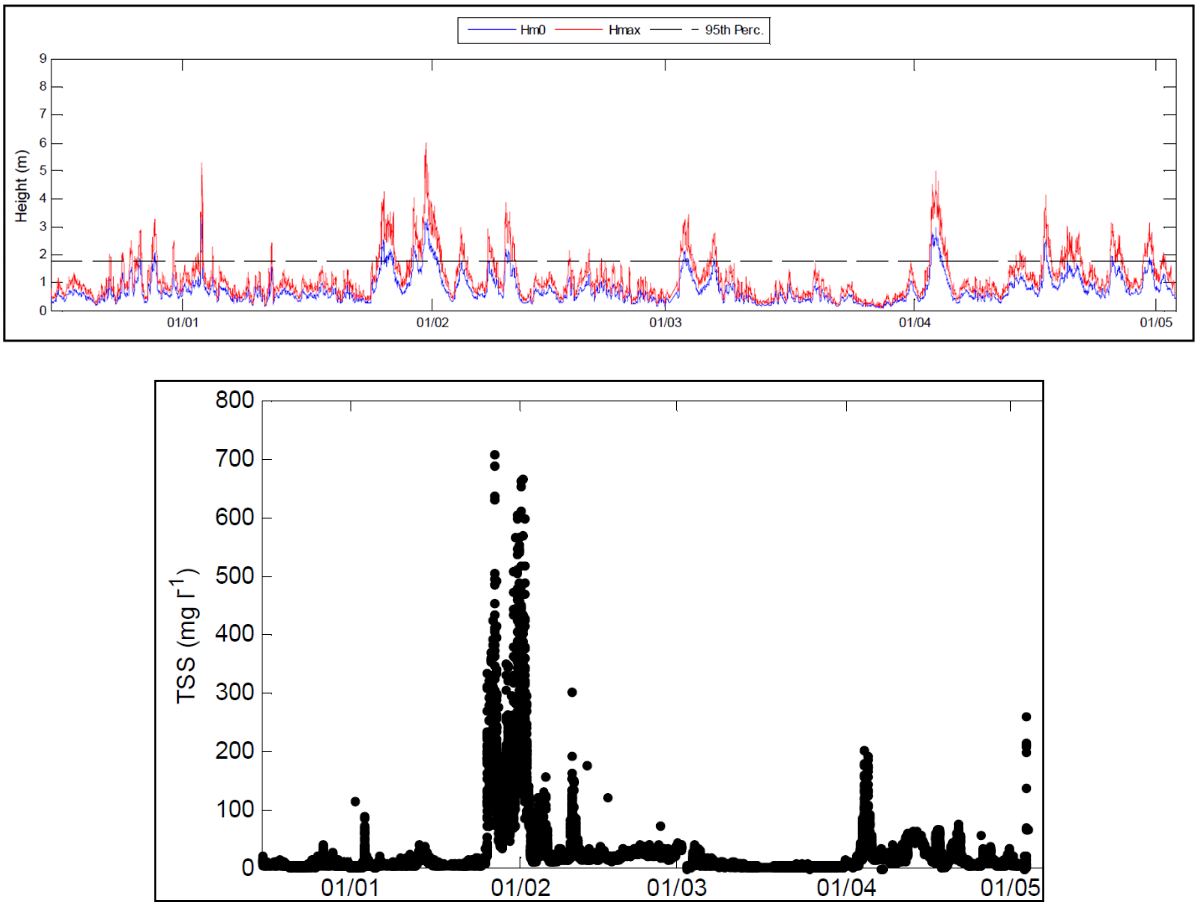
Table 7.20 Total Suspended Solids (mg/l), March and June 2011 at site E

Site	Time (mins)	March					June				
		0	30	60	90	120	0	30	60	90	120
E	Top	5	6	7	11	10	8	<5	<5	<5	<5
	Middle	6	8	10	10	11	<5	6	<5	<5	<5
	Bottom	11	10	11	10	11	<5	<5	<5	<5	<5

SSC data were also recorded at Site E during a subsequent deployment from 15th December, 2011 through to 5th May, 2012 (Partrac, 2012).

7.109. The minimum recorded SSC value during this deployment was recorded on the 2nd January 2012 at 2mg/l. The maximum recorded value occurred on the 27th January 2012 at 709mg/l. This coincided with a prolonged sequence of storm events which were observed at the end of January 2012 (as shown in Plot 7.9). The mean SSC concentration during the recording period was 34mg/l.

Plot 7.9 Relationship between wave height (upper plot) and total suspended solids (TSS, lower plot), recorded at Site E



Coastal geomorphology

7.110. The coastline at Carnoustie consists largely of an elevated hinterland characteristic of coastal dune heathland overlain by a variety of sand dunes which are in turn fronted by sand dominated beaches with areas of exposed rocky foreshore to the north towards Arbroath.

7.111. During the last glaciation ice flow was predominantly towards the east (offshore) from onshore. The major effect of the glaciation in terms of coastal geomorphology was the widespread accumulation of glacially derived sediments (till and glaciofluvial meltwater deposits) which are currently being reworked on, off, and along the contemporary shoreline via winds, waves, tides and postglacial sea-level change.

7.112. Much of the present foreshore was inundated during the postglacial marine transgression when relative sea-levels were higher than those of present, resulting in the formation of raised beach sequences (HR Wallingford, 1997). As relative sea-level began to fall, as a result of isostatic readjustment of the Scottish coastline, large areas of intertidal sands dried out and subsequently were reworked onshore.

7.113. The coastline at Carnoustie, in the immediate area to the south of the proposed landfall location, is characterised by a wide (~15m) rock revetment coastal defence structure. Landward of the coastal defence is the Barry Links Special Area of Conservation (SAC) dune system which has developed on the extensive broad triangular foreland of Buddon Ness. The dune system comprises the following Annex 1 habitats:

- embryonic shifting dunes;
- shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes');
- fixed dunes with herbaceous vegetation ('grey dunes');
- Atlantic decalcified fixed dunes (*Calluno-Ulticetea*); and
- humid dune slacks.

7.114. At Buddon Ness there is a small sandy spit, which is highly dynamic and moves with the tidal and wave conditions. Some 500m east of Buddon Ness, and trending towards the north, there is a series of subtidal and intertidal sand bars called Gaa Sands.

7.115. Although operated by the Ministry of Defence (MoD) as a weapons range, Barry Links is also designated as a Site of Special Scientific Interest (SSSI) and is a Geological Conservation Review (GCR) site for the excellence of its coastal geomorphology.

7.116. The diversity of coastal landforms and their linkages with formative agents is of particular note, generally, along the eastern Scottish coastline of the study area. This geological variety is recognised locally, regionally, nationally and internationally in the array of geological features which contribute to the currently designated SSSI, SAC, Special Protection Area (SPA) and possible SAC (pSAC) within the near- and far-field study areas (see Chapter 9: Nature Conservation Designations of this ES). Where the ECR intersects the coastline the northern and southern extents of the proposed corridor fall within the boundaries, or are within close proximity (<5km) of the following designated sites, noted for their nature conservation importance:

- Firth of Tay and Eden Estuary SAC, SPA, Ramsar and SSSI; and
- Barry Links SAC and SSSI.

7.117. The Firth of Tay and Eden Estuary SAC, stretches for some 35km along the estuary from near Newburgh to the estuary mouth. For much of its length the main channel of the estuary lies close to the southern shore and the most extensive intertidal flats are on the north side, west of Dundee.

7.118. The Firth of Tay and Eden Estuary SAC represent two integral high-quality estuarine component areas within a large, geomorphologically complex single site that incorporates a mosaic of estuarine and coastal habitats. The Tay is the least-modified of the large east coast estuaries in Scotland, while the Eden Estuary represents a smaller 'pocket' estuary. The inner parts of the estuaries are largely sheltered from wave action, while outer areas, particularly of the Tay, are exposed to strong tidal streams, giving rise to a complex pattern of erosion and deposition of the sand bank feature at the firths' mouth. The sediments within the site support biotopes that reflect the gradients of exposure and salinity, and are typical of estuaries on the east coast of the UK. The abundance, distribution and composition of the associated plant and animal communities are ecologically representative of northern North Sea estuaries.

7.119. The Annex I habitats that are a primary reason for the selection of this site are estuaries. Additional Annex I habitats present as qualifying features are sand banks, which are slightly covered by seawater all the time and mudflats and sandflats not covered by seawater at low tide. The entire Firth of Tay and Eden Estuary is also designated as a SSSI.

7.120. The Annex I habitats that are a primary reason for the selection of Barry Links SAC are:

- embryonic shifting dunes;
- shifting dunes along the shoreline with Ammophila arenaria (`white dunes`);
- fixed dunes with herbaceous vegetation (`grey dunes`); and
- humid dune slacks.

7.121. According to SNH (2011), Barry Links can be conveniently subdivided into three units: the east sands from Carnoustie beach to Buddon Ness, the area of the Ness itself, and the western sands from the Ness to Monifieth. The east sands are composed of medium grade, non-calcareous sand with occasional patches of gravel. At the eastern extremity of the site, the foreshore at Carnoustie is a low-gradient sandy beach backed by a variety of erosion protection structures including some experimental concrete mats and discontinuous intertidal rip-rap breakwaters.

7.122. To the west of this beach, the northern 4km of the eastern sands of Barry Links is a low-gradient, east-facing beach, approximately 300m wide. At low tide and this beach is characterised by several shore-parallel intertidal sand bars, with intervening pools and runnels which are deflected southwards and extend the entire length of the foreshore, as far as Buddon Ness (SNH, 2011).

7.123. This coast has a recent history of severe erosion and the dune face is recorded to have retreated up to 10m in one year (Wright, 1981). In response, 0.5km of protective gabions and boulder rip-rap were constructed in 1978, extending from Carnoustie to the northern limit of the MoD range, just beyond the exit of Barry Burn. On account of a perceived erosional threat to the MoD firing ranges, sited in the dunes behind the eastern beach, the boulder rip-rap was further extended in 1992/ 3 from Barry Burn south along a 3km stretch of the east side of Buddon Ness and up to the full frontal dune height of 7-10m (SNH, 2011). As a result, the eastern sands now exist only as intertidal sand, with the upper beach above MHWS being entirely boulder rip-rap which now replaces the crest of the backing dune and its landward slope.

ASSESSMENT OF EFFECTS – SCENARIOS

7.124. Full details on the range of options being considered by Seagreen are provided in Chapter 5: Project Description of this ES. The assessment of potential changes on the physical environment from construction, operation and decommissioning of the Proposed Development was informed through the Seagreen Rochdale Envelope to determine the worst case design scenarios on the physical environment (as these potentially will influence hydrodynamics, seabed sediments, seabed morphology and coastal geomorphology).

7.125. The definition of the worst case was required for substructure/ foundations type and wind turbine array spacing for assessment purposes due to the large number of engineering variables inherent within the potential design (number, type, layout and dimensions of structures). The worst case scenario for substructure/ foundations types was discussed with Marine Scotland, who supported the assumptions made and conclusions drawn (see Appendix E1).

7.126. No pre-defined layouts are proposed for assessment purposes. The final layout of the Seagreen Project will be selected post consent. To ensure that the largest, or worst case, effects for any potential layout is assessed, the minimum WTG spacing of 5 times the rotor diameter has been assumed in any direction between adjacent turbines. The minimum rotor diameter within the Rochdale envelope is 122m and therefore the minimum spacing assessed is 610m between adjacent turbines within the array. If a greater spacing is utilised within the final constructed wind farm, then the anticipated effects will be less than the potential effect presented herein for this worst case.

7.127. The potential effects on hydrodynamics (waves and tides) associated with various potential substructure/ foundation options (including monopiles, tubular jackets with piles or suction piles, tripods with piles or suction piles, rectangular / square Gravity Base Structures and conical Gravity Base Structures) were discussed with Marine Scotland (see Appendix E1) to confirm that the worst case scenarios for changes to hydrodynamics (waves and tides) would generally be associated with the conical Gravity Base Structures (conical GBS). This is primarily because these structures have the largest seabed footprint and largest cross-sectional area within the water column compared to other potentially available substructure/ foundation types. It therefore represents the greatest potential physical blockage to hydrodynamic flow (waves and tides) and any consequential effects on sediment transport and morphology, when compared with the existing background hydrodynamic conditions (waves and tidal currents). The only exception is at the location of Offshore Platforms (OSP) where 100m x 75m rectangular GBS represents the worst case at up to 1 location and 40m x 40m square GBS represents the worst case at up to 4 locations (this type and sizes of substructure/ foundation is not considered for use other than for the OSP).

7.128. The potential effects in terms of maximum potential for scour (or conversely the maximum requirement for scour protection) and maximum requirement for sea bed preparation were also assessed for various potential substructure/ foundation options (see Appendix E4). This also confirmed that the conical GBS represented the worst case substructure/ foundation type in respect of these parameters, except for at the location of the OSP, where 100m x 75m rectangular GBS are considered at up to 1 location and 40m x 40m square GBS are considered at up to 4 locations.

7.129. In the context of the physical environment, the worst case substructure/ foundation details are described below and then summarised in Table 7.21. It is important to note that the number of structures assessed within this chapter of the ES is a function of the Rochdale Envelope development; Seagreen has confirmed that the maximum number of WTGs in either Project Alpha or Project Bravo will not exceed 75.

7.130. The worst case assessment has assumed that for WTGs a 72m baseplate diameter conical GBS will be used within Project Alpha and Project Bravo in areas of weak soils, assumed to be a maximum of 8 locations within each Project area. Elsewhere, in areas of average soils, a 52m baseplate diameter conical GBS will be considered as a worst case substructure/ foundation option. In reality, design optimisation will be undertaken to identify the substructure/ foundations s types that are best suited to the ground conditions and water depths that will be experienced at each WTG location. This is likely to mean that there will actually be relatively few locations across Project Alpha and Project Bravo where 72m baseplate conical GBS are required. It should be noted that the Rochdale envelope also includes jackets with piles and jackets with suction piles, which could also be used but would have considerably lesser effect on the physical environment.

7.131. For purposes of worst case assessment, it is further assumed that substructure/ foundations for meteorological masts will be the same as the worst case for the WTGs. There will be a maximum of three meteorological masts installed within each Project area in the worst case assessment, although in reality a maximum of three are likely to be distributed across the Seagreen Project.

7.132. Within the Transmission Asset Project a worst case is considered to include up to three OSP within Project Alpha and up to two OSP within Project Bravo (i.e. up to five collectively across the Transmission Asset Project). As previously discussed, the worst case substructure/ foundation for the OSP is a 100m x 75m rectangular GBS, with a baseplate thickness of 7.5m, at up to one location within Project Alpha and 40m x 40m square GBS, with a baseplate thickness of 7.5m, at up to four other locations.

Table 7.21 Summary of substructure / foundation details that define the worst case scenario, with respect to the physical environment

Description	Structure type	Dimensions (m)	
WTG substructure/ foundations for weak soils	Conical GBS	72m octagonal baseplate diameter	35.4m cone basal diameter
WTG and meteorological mast substructure/ foundations s for average soils	Conical GBS	52 m octagonal baseplate diameter	28.4m cone basal diameter
OSP (up to 1 location within Project Alpha)	Rectangular GBS	100m x 75m rectangular baseplate, 7.5m thickness	Six square columns each up to 15m x 15m aligned in 2 rows each containing 3 columns
OSP (up to 2 locations within Project Alpha and up to 2 locations within Project Bravo)	Square GBS	40m x 40m square baseplate, 7.5m thickness	Four square columns each up to 7.5m x 7.5m aligned in 2 rows each containing 2 columns

7.133. For these worst case substructure/ foundations types, empirical tools have been used to calculate scour hole development arising under different combinations of wave and current action, assuming a further worst case that no scour protection is provided. These assessments are presented in full in Appendix E4 and summarised in Table 7.22. In the case of the rectangular GBS, the individual columns have been grouped in the assessments to simulate their influence as a single, larger, complete surface-piercing unit, which is a highly conservative assumption.

7.134. GBSs would also require seabed preparation prior to installation, unlike some other substructure/ foundations options. For conical GBS, the worst case scenario assumes that this will be required to a maximum depth of up to 5m below existing bed level across the footprint of the structure at a maximum of 8 locations within each Project Area associated with the larger diameter GBSs, with any conical GBS used at other locations within each Project Area requiring sea bed preparation to a maximum depth of up to 3m. For the rectangular and square GBS used as a worst case for OSP, it has been assumed that seabed preparation of up to 5m will be required at each location. The worst case sea bed preparation volumes are summarised in Table 7.23.

Table 7.22 Worst case scour hole development

Substructure / Foundation	Water Depth	Scour Hole 1 in 1 year Event			Scour Hole 1 in 50 year Event			Method
		Area m^2	Depth m	Vol. m^3	Area m^2	Depth m	Vol. m^3	
Conical GBS (72m baseplate for use in areas of weak soils)	60m	5,150	1.75	924	6,671	3.92	4,877	Khalfin (2007) Soulsby & Clarke (2002)
Conical GBS (52m baseplate for use in areas of average soils)	50m	3,137	2.18	1,067	4,283	4.24	4,304	Khalfin (2007) Soulsby & Clarke (2002)
Rectangular GBS (100m x 75m) for use at up to 1 OSP location within Project Alpha	50m	1,174	5.21	2,038	1,850	6.54	4,032	Khalfin (1983) Bos (2002)
Square GBS (40m x 40m) for use at up to 2 OSP locations within each of Projects Alpha and Bravo	50m	137	1.78	81	518	3.46	597	Khalfin (1983) Bos (2002)

Table 7.23 Worst case seabed preparation volumes

Substructure / Foundation	Dimensions	Footprint	Maximum seabed preparation depth	Maximum volume of seabed preparation material
Conical GBS (72m baseplate for use in areas of weak soils)	72m baseplate diameter	4,295m^2	5m *	21,475m^3
Conical GBS (52m baseplate for use in areas of average soils)	52m baseplate diameter	2,240m^2	3m	6,720m^3
Rectangular GBS (100m x 75m) for use at up to 1 OSP location within Project Alpha	100m x 75m rectangular baseplate	7,500m^2	5m	37,500m^3
Square GBS (40m x 40m) for use at up to 2 OSP locations within Project Alpha and up to 2 OSP locations within Project Bravo	40m x 40m square baseplate	1,600m^2	5m	8,000m^3

*up to 5m depth to be used at a maximum of 8 locations within Project Alpha and a maximum of 8 locations within Project Bravo.

7.135. Establishing the worst case scenario from the full range under consideration (see Chapter 5: Project Description of this ES) ensures that the assessment is focused on the maximum potential adverse effect that could arise from the Seagreen Project.

7.136. The worst case scenarios for Project Alpha, Project Bravo and the Transmission Asset Project are defined in detail in Tables 7.24 to 7.26. As previously stated, the OSPs have been considered within the detailed assessments for Project Alpha and Project Bravo respectively. The outcome of the OSP assessments is then cross referenced where appropriate when describing the potential effects of the Transmission Asset Project.

Table 7.24 Worst case scenario for Project Alpha assessment (includes WTG arrays, OSPs, meteorological masts and array cables)

Effect	Worst case scenario	Justification / assumptions
Construction		
Effects on hydrodynamic regime (waves and tidal currents) due to construction activities.	Installation of up to 75 WTGs and up to 3 meteorological masts on conical GBSs at spacings of 610m. Installation of up to 1 OSP on rectangular (100m x 75m) GBS and up to 2 OSP on square (40m x 40m) GBS. Substructure / foundation installation to be complete within the 36 month offshore substructure and foundations activity programme, which runs from the 3rd Quarter 2016 to the 3rd Quarter 2019. Substructure / foundation installation via Heavy Lift Vessel (HLV) / 6-leg jack-up barge (each leg 4.5m x 4.5m square, with maximum seabed penetration of 2m at each leg). Anchoring of other installation support vessels is so insignificant that this does not form part of the worst case assessment.	Maximum potential number of WTGs and meteorological masts at closest possible spacings and using largest cross-sectional area substructure / foundation type. Maximum potential number of OSP using largest cross-sectional area substructure / foundation type. A minimum period of 6 months over each of 2 years will be required for foundation and substructure installation. Offshore working may be restricted to between April and September each year. Installation of up to 2 substructure / foundations simultaneously. Maximum total number of vessels at any one time is small, the presence of each anchor is temporary and the area of seabed potentially affected by each anchor is very small ($4m^2$).
Effects on sediments and sedimentary structures due to construction activities.	As above, with the following additional effects: Substructures / Foundations: Seabed preparation works across a seabed footprint area of $191,160m^2$ for conical GBS used for WTG and meteorological masts and $10,700m^2$ for rectangular/square GBS structures used for OSP. Total seabed footprint area of $201,860\ m^2$.	As above, with the following additional assumptions: Largest footprint area is associated with the conical GBS for WTG and meteorological masts and rectangular/square GBS for OSP. Assumes 72m diameter conical GBS at up to 8 sites within Project area and 52m diameter conical GBS at other locations, with total of 75 WTG and 3 met masts. Up to a further 1 OSP considered on 100m x 75m rectangular GBS and 2 OSPs considered on a 40m x 40m square GBS.

Effect	Worst case scenario	Justification / assumptions
Construction		
Effects on suspended sediment concentrations and transport due to construction activities.	As above, with the following additional effects: Substructures / Foundations: Release of up to 642,200m^3 of seabed material side-cast to seabed adjacent to substructure or returned to water column from dredger hopper during seabed preparation works for conical GBS used for WTG and meteorological masts. A further 53,500m^3 of seabed material similarly disposed during seabed preparation works for rectangular/square GBS used for OSPs. Array cables: 355km of array cabling buried to depths of between 0.5m and 2.1m across a 3m wide trench. Cable burial achieved using jetting ROV within the 36 month offshore cabling activity programme (from the 3rd Quarter 2016 to the 3rd Quarter 2019).	As above, with the following additional assumptions: Assumes 72m diameter conical GBS at up to 8 sites within Project area and 52m diameter conical GBS at other locations, with total of 75 WTG and 3 meteorological masts. 100m x 75m rectangular GBS used at up to 1 OSP location and 40m x 40m square GBS used at up to 2 OSP locations. No material re-use as ballast. Includes for potential use of suction cutter dredging. Maximum trench dimensions. Assumes an indicative installation rate using jetting of 237.5m/hr, which is slower than for cutter and plough. Jetting fluidises or liquefies the sediment, making it more readily re-suspended. Offshore working may be restricted to between April and September each year.
Operation		
Effects on hydrodynamic regime (waves and tidal currents) during the operation phase.	Presence of 75 WTGs and 3 meteorological masts on conical GBSs at spacings of 610m. Presence of up to 1 OSP on rectangular (100m x 75m) GBS and up to 2 OSPs on square (40m x 40m) GBS.	Maximum potential number of WTGs and meteorological masts at closest possible spacings and using largest cross-sectional area substructure / foundation type. Maximum potential number of OSP using largest cross-sectional area substructure / foundation type.
Effects on sediments and sedimentary structures during the operation phase.	As above, with the following additional effects: Substructure / Foundations: Scour hole formation on the seabed adjacent to each substructure under a 1 in 50 year storm. Total scour hole development covers a seabed area of 353,178m^2 at conical GBS. A further area of 2,886m^2 affected by rectangular / square GBS for OSP. Array cables: 355km of array cabling buried to depths of between 0.5m and 2.1m across a 3m wide trench. Cable burial achieved using jetting ROV within the 36 month offshore cabling activity programme (from the 3rd Quarter 2016 to the 3rd Quarter 2019).	As above, with the following additional assumptions: Assumes that no scour protection is provided. Conical GBS causes greatest scour areas of all substructure / foundation types during a 1 in 50 year storm condition due to combined wave and current action. Assumes 72m diameter conical GBS at up to 8 locations within Project area and 52m diameter elsewhere, with Maximum trench dimensions. Assumes an indicative installation rate using jetting of 237.5m/hr, which is slower than for cutter and plough. Jetting fluidises or liquefies the sediment, making it more readily re-suspended. Offshore working may be restricted to between April and September each year.

Effect	Worst case scenario	Justification / assumptions
Operation		
Effects on hydrodynamic regime (waves and tidal currents) during the operation phase.	Presence of 75 WTGs and 3 meteorological masts on conical GBSs at spacings of 610m. Presence of up to 1 OSP on rectangular (100m x 75m) GBS and up to 2 OSPs on square (40m x 40m) GBS.	Maximum potential number of WTGs and meteorological masts at closest possible spacings and using largest cross-sectional area substructure / foundation type. Maximum potential number of OSP using largest cross-sectional area substructure / foundation type.
Effects on sediments and sedimentary structures during the operation phase.	As above, with the following additional effects: Substructure / Foundations: Scour hole formation on the seabed adjacent to each substructure under a 1 in 50 year storm. Total scour hole development covers a seabed area of 353,178m^2 at conical GBS. A further area of 2,886m^2 affected by rectangular / square GBS for OSP. Array cables: Up to 35.5km of rock/mattress protection on array cables. Height not exceeding 1.0m above the seabed and width not exceeding 7m. Completed within cabling activity programme described above.	As above, with the following additional assumptions: Assumes that no scour protection is provided. Conical GBS causes greatest scour areas of all substructure / foundation types during a 1 in 50 year storm condition due to combined wave and current action. Assumes 72m diameter conical GBS at up to 8 locations within Project area and 52m diameter elsewhere, with total of 75 WTG and 3 meteorological masts. Rectangular (100m x 75m) GBS used at up to 1 OSP location and square (40m x 40m) GBS used at up to 2 OSP locations. Estimated maximum length of cable where target burial depth (0.5m minimum depth) is not practicably achievable.
Effects on suspended sediment concentrations and transport during the operation phase.	Scour hole formation on the seabed adjacent to each substructure under a 1 in 50 year storm. Total volume of material released from seabed due to scour hole development around conical GBS is 340,296m^3. A further 5,226m^3 released from scour around rectangular / square GBS. In the event that scour protection is provided, no scour will occur, but there will be the physical footprint on the seabed caused by the scour protection materials.	Assumes that no scour protection is provided. Conical GBS causes greatest scour volumes of all substructure / foundation types during a 1 in 50 year storm condition due to combined wave and current action. Assumes 72m diameter conical GBS at up to 8 locations within Project area and 52m diameter elsewhere, with total of 75 WTG and 3 meteorological masts. Rectangular (100m x 75m) GBS used at up to 1 OSP location and square (40m x 40m) GBS used at up to 2 OSP locations. Secondary scour around the limits of the scour protection will be insignificant.

Effect	Worst case scenario	Justification / assumptions
Decommissioning		
Effects on hydrodynamic regime (waves and tidal currents) due to decommissioning activities.	Removal of all WTG and meteorological mast substructures and foundations and array cables (based on the worst case assumptions detailed under the construction phase). Removal of all OSP substructure and foundations.	Arrangements associated with decommissioning will be determined prior to construction and a full Decommissioning Plan for the project will be drawn up and agreed with Marine Scotland. Until these arrangements have been clarified, the worst case scenario is that all structures and array cables will be removed.
Effects on sediments and sedimentary structures due to decommissioning activities.	As above.	As above.
Effects on suspended sediment concentrations and transport due to decommissioning activities.	As above.	As above.

Table 7.25 Worst case scenario for Project Bravo assessment (includes WTG arrays, OSPs, meteorological masts and array cables)

Effect	Worst case scenario	Justification / assumptions
Construction		
Effects on hydrodynamic regime (waves and tidal currents) due to construction activities.	As for Project Alpha, but with up to 2 OSP (instead of up to 3 OSP for Project Alpha) founded on square (40m x 40m) GBS.	As for Project Alpha, but with up to 2 OSP (instead of up to 3 OSP for Project Alpha) founded on square (40m x 40m) GBS.
Effects on sediments and sedimentary structures due to construction activities.	As for Project Alpha, but with seabed preparation works across a seabed footprint area of 191,160m^2 for conical GBS structures and 3,200m^2 for square (40m x 40m) GBS structures.	As for Project Alpha, but with up to 2 OSP considered on square (40m x 40m) GBS.
Effects on suspended sediment concentrations and transport due to construction activities.	As for Project Alpha, but with release of up to 642,200m^3 of seabed material side-cast to seabed adjacent to substructure or returned to water column from dredger hopper during seabed preparation works for conical GBS used for WTG and meteorological masts. A further 16,000m^3 of seabed material similarly disposed during seabed preparation works for square (40m x 40m) GBS.	As for Project Alpha, but with up to 2 OSP considered on square (40m x 40m) GBS.

Effect	Worst case scenario	Justification / assumptions
Operation		
Effects on hydrodynamic regime (waves and tidal currents) during the operation phase.	As for Project Alpha, but with up to 2 OSP (instead of up to 3 OSP for Project Alpha) founded on square (40m x 40m) GBS.	As for Project Alpha, but with up to 2 OSP (instead of up to 3 OSP for Project Alpha) founded on square (40m x 40m) GBS.
Effects on sediments and sedimentary structures during the operation phase.	As for Project Alpha, but with total scour hole development covering a seabed area of 353,178m^2 at conical GBS. A further area of 1,036m^2 affected by square (40m x 40m) GBS for OSP.	As for Project Alpha, but with up to 2 OSP considered on square (40m x 40m) GBS.
Effects on suspended sediment concentrations and transport during the operation phase.	As for Project Alpha, but with total volume of material released from seabed due to scour hole development around conical GBS of 340,296m^3. A further 1,194m^3 released from scour around square (40m x 40m) GBS.	As for Project Alpha, but with up to 2 OSP considered on square (40m x 40m) GBS.
Decommissioning		
Effects on hydrodynamic regime (waves and tidal currents) due to decommissioning activities.	As for Project Alpha, but with up to 2 OSP (instead of up to 3 OSP for Project Alpha) founded on square (40m x 40m) GBS.	As for Project Alpha, but with up to 2 OSP (instead of up to 3 OSP for Project Alpha) founded on square (40m x 40m) GBS.
Effects on sediments and sedimentary structures due to decommissioning activities.	As above.	As above.
Effects on suspended sediment concentrations and transport due to decommissioning activities.	As above.	As above.

Table 7.26 Worst case scenario for the Transmission Asset Project assessment (includes OSPs and export cables to landfall at Carnoustie)

Effect	Worst case scenario	Justification / assumptions
Construction		
Effects on hydrodynamic regime (waves and tidal currents) due to construction activities.	The installation of up to 1 OSP on rectangular (100m x 75m) GBS and up to 4 OSPs on square (40m x 40m) GBS has already been assessed in detail as part of the Project Alpha and Project Bravo assessments (where they have greatest potential for cumulative impact), but the findings are cross-referenced within this assessment because OSPs form part of the Transmissions Asset Project consent application. Substructure and foundation installation to be complete within the 36 month offshore substructure and foundations activity programme, which runs from the 3rd Quarter 2016 to the 3rd Quarter 2019. Substructure / foundation installation via Heavy Lift Vessel (HLV) / 6-leg jack-up barge (each leg 4.5m x 4.5m square, with maximum seabed penetration of 2m at each leg). Anchoring of other installation support vessels is so insignificant that this does not form part of the worst case assessment.	Maximum potential number of OSPs using worst case substructure / foundation for OSP. A minimum period of 6 months per year for two years will be required for substructure / foundation and OSP installation. Offshore working may be restricted to between April and September each year. Installation of up to 2 substructures / foundations simultaneously. Maximum total number of vessels at any one time is small, the presence of each anchor is temporary and the area of seabed potentially affected by each anchor is very small ($4m^2$).
Effects on sediments and sedimentary structures due to construction activities	As above, with the following additional effects: Substructure / Foundations: The seabed preparation works across a seabed footprint area of $13,900m^2$ has already been assessed in detail for OSPs as part of the Project Alpha and Project Bravo assessments (where they have greatest potential for cumulative impact), but the findings are cross-referenced within this assessment because OSPs form part of the Transmissions Asset Project consent application.	As above, with the following additional assumptions: Largest footprint area is associated with the installation of up to 1 OSP on rectangular (100m x 75m) GBS and up to 4 OSPs on square (40m x 40m) GBS, with seabed preparation for each type of GBS to a depth of up to 5m. No material re-use as ballast. Includes for potential use of suction cutter dredging. Up to six 275kv export cables (HVAC) to be installed.

Effect	Worst case scenario	Justification / assumptions
Construction		
Effects on suspended sediment concentrations and transport due to construction activities	As above, with the following additional effects: Substructure / Foundations: The release of up to 69,500m^3 of seabed material side-cast to the seabed adjacent to the substructure or returned to the water column from the dredger hopper during seabed preparation works has already been assessed in detail for OSPs as part of the Project Alpha and Project Bravo assessments (where they have greatest potential for cumulative impact), but the findings are cross-referenced within this assessment because OSPs form part of the Transmissions Asset Project consent application. Export cables: 530km of export cabling buried to depths of between 0.5m and 3m across a 3m wide trench. Cable burial achieved using jetting ROV within the 36 month offshore cabling activity programme (from the 3rd Quarter 2016 to the 3rd Quarter 2019). HDD to achieve burial at landfall at Carnoustie.	As above, with the following additional assumptions: Assumes the installation of up to 1 OSP on rectangular (100m x 75m) GBS and up to 4 OSPs on square (40m x 40m) GBS, with seabed preparation for each type of GBS to a depth of up to 5m. No material re-use as ballast. Includes for potential use of suction cutter dredging. Up to six 275kv export cables (HVAC) to be installed along an indicative 70km export cable corridor to landfall at Carnoustie. Maximum trench dimensions and buried cable length Assume an indicative installation rate using jetting of 237.5m/hr, which is slower than for cutter and plough. Jetting fluidises or liquefies the sediment, making it more readily re-suspended. Offshore working is restricted to between April and September each year.
Operation		
Effects on hydrodynamic regime (waves and tidal currents) during the operation phase	The operation phase of up to 1 OSP on rectangular (100m x 75m) GBS and up to 4 OSPs on square (40m x 40m) GBS has already been assessed in detail as part of the Project Alpha and Project Bravo assessments (where they have greatest potential for cumulative impact), but the findings are cross-referenced within this assessment because OSPs form part of the Transmissions Asset Project consent application.	Maximum potential number OSPs and using worst case substructure / foundation for OSPs.

Effect	Worst case scenario	Justification / assumptions
Operation		
Effects on sediments and sedimentary structures during the operation phase	As above, with the following additional effects: Substructure / Foundations: The scour hole formation on the seabed adjacent to each substructure under a 1 in 50 year storm has already been assessed in detail as part of the Project Alpha and Project Bravo assessments (where they have greatest potential for cumulative impact), but the findings are cross-referenced within this assessment because OSPs form part of the Transmissions Asset Project consent application. Total scour hole development covers a seabed area of 3,922m^2. Export cables: 26.5km of rock/mattress protection on export cables. Height not exceeding 1.2m above the seabed and width not exceeding 11m. Completed within cabling activity programme described above.	As above, with the following additional assumptions: Assumes the presence of up to 1 OSP on rectangular (100m x 75m) GBS and up to 4 OSPs on square (40m x 40m) GBS Assumes that no scour protection is provided around rectangular/square GBS. Maximum length of cable where target burial depth (0.5m minimum depth) is not practicably achievable.
Effects on suspended sediment concentrations and transport during the operation phase	The scour hole formation on the seabed adjacent to each substructure under a 1 in 50 year storm has already been assessed in detail as part of the Project Alpha and Project Bravo assessments (where they have greatest potential for cumulative impact), but the findings are cross-referenced within this assessment because OSPs form part of the Transmissions Asset Project consent application.. Total volume of material released from seabed due to scour hole development is 6,420m^3. In the event that scour protection is provided, no scour will occur, but there will be the physical footprint on the seabed caused by the scour protection materials.	Assumes the presence of up to 1 OSP on rectangular (100m x 75m) GBS and up to 4 OSPs on square (40m x 40m) GBS Assumes that no scour protection is provided around rectangular/square GBS. Secondary scour around the limits of the scour protection will be insignificant.

Effect	Worst case scenario	Justification / assumptions
Decommissioning		
Effects to hydrodynamic regime (waves and tidal currents) due to decommissioning activities.	Removal of all substructures and foundations, export cables and rock/mattress protection (based on worst case assumptions detailed under construction).	Arrangements associated with decommissioning will be determined prior to construction and a full Decommissioning Plan for the project will be drawn up and agreed with Marine Scotland. Until the arrangements have been clarified, the worst case scenario is that all structures and export cables will be removed.
Effects on sediments and sedimentary structures due to decommissioning activities.	As above.	As above.
Effects on suspended sediment concentrations and transport due to decommissioning activities.	As above.	As above.

ASSESSMENT OF EFFECTS – CONSTRUCTION PHASE

Project Alpha

Effects on hydrodynamic regime

- Changes to wave heights and periods and tidal current velocities (speed and direction) due to the installation of substructures/ foundations and the presence of installation or support vessels.

7.137. Potential changes to the wave and tidal climate during construction are associated with the presence of temporarily static structures associated with working plant used to install the substructures/ foundations and WTG, meteorological mast and OSP structures, such as the legs of jack-up barges or the hulls of anchored vessels.

7.138. Given the limited amount of time that jack-up barges or HLVs may be stationed at each WTG, meteorological mast or OSP location to install substructures/ foundations and the size of the jack-up legs compared to the wavelength of typical waves, the potential effects upon wave heights and periods are considered to be well within the range of natural variability.

7.139. Similarly, the potential effect on tidal current velocities will be small, temporary and highly localised, confined to the bifurcation on flow in the immediate vicinity of the obstacle presented by the jack-up legs or vessel hull.

7.140. This situation also applies to any temporarily anchored vessels used during construction in addition to, or instead of, jack-up plant where the hull of the vessel may have a small and highly localised temporary effect, but with no wider reaching consequences.

7.141. Even under a worst case scenario of two substructures/ foundations being installed simultaneously, the construction plant at each of the two locations would be sufficiently separated that no cumulative or in-combination effects from these activities would be noted.

7.142. The anticipated effect upon wave heights and periods and tidal current velocities from the construction phase is anticipated to be negligible, with only temporary and highly localised changes anticipated.

7.143. This conclusion is supported by the evidence from a review of twenty-eight Environmental Statements (ES) for OWF developments from around the UK and wider European waters (see Appendix E1), which did not identify any adverse effects on the hydrodynamic regime during the construction phase.

Mitigation

7.144. No mitigation is proposed. It is expected that the hydrodynamic regime shall return to its pre-construction state upon cessation of construction activities.

Residual Effects

7.145. None anticipated.

Effects on sediments and sedimentary structures

- Effects upon the seabed, sediment distribution patterns and mobile bedforms due to the installation of substructures/ foundations.

7.146. Potential changes to seabed, sediment distribution patterns and mobile bedforms are related to the disturbance of areas of the seabed during the construction operations. This may be caused by the temporary presence of construction plant or the preparation of the seabed in advance of substructure/ foundations installation.

7.147. If jack-up barges are used to install the substructures/ foundations, there will be a shallow depression caused in the seabed, of up to 2m in depth, at each location where a leg is placed. This would be confined to the immediate footprint of each leg and therefore cover an area at each substructure location of 4.5m x 4.5m x 6 legs = 121.5m^2. It is anticipated that over time the depression will become infilled with marine sand once the jack-up barge is removed, unless in areas with clay substrata and no or little sand veneer where a more permanent depression is likely to remain in the clay. This localised and, in many locations temporary, effect, is anticipated to cause a negligible effect even when scaled across the 81 locations in Project Alpha where jack-up barges may be required.

7.148. For anchored installation or support vessels, each anchor will impact an area of seabed of up to only 4m^2. With no more than six vessels anticipated within Project Alpha at any one time, and each anchored for a temporary period of time, this is anticipated to cause no change.

7.149. Removal or displacement of material from the seabed during installation of substructures/ foundations has the potential to damage or destroy mobile bedforms, if they are present in the area affected. The worst case scenario during the construction phase assumes the simultaneous installation of up to two GBS substructures. In terms of the material to be excavated from the seabed, the simultaneous installation of one rectangular (100m x 75m) GBS for OSP and one 72m diameter baseplate conical GBS would affect the greatest footprint area of seabed, with some 11,795m^2 affected in order to accommodate these substructures. However, if two square (40m x 40m) GBS were installed simultaneously, the combined footprint area affected would reduce to 3,200m^2.

7.150. For substructures/ foundations installed in, or within close proximity to, areas characterised by mobile bedforms (such as megaripples and sand waves) it is anticipated that the construction phase would result in a low magnitude adverse effect caused by the flattening of these features. Mobile bedforms are considered to be sensitive receptors in line with Seagreen's Position Paper to Marine Scotland on the Coastal and Seabed Impact Assessment (see Appendix E1). Any changes are likely to be of a temporary duration and will alter particular aspects of the local seabed character or distinctiveness rather than having further reaching effects. Furthermore, due to the mobility of the seabed in these areas, any effects are potentially reversible and natural processes would be likely to infill any depressions excavated in the seabed in these mobile sedimentary areas.

7.151. In areas of the seabed that are devoid of mobile bedforms, it is anticipated that the installation of substructures/ foundations would have negligible effect.

7.152. The potential associated effects upon benthic ecology and natural fisheries of effects upon the seabed, sediment distribution patterns and mobile bedforms are assessed for their significance in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resource of this ES respectively.

Mitigation

7.153. The assessment presented above represents a worst case which assumes the greatest footprint in terms of the required seabed preparation. Where these substructures / foundation are proposed within close proximity to mobile bedforms care should be taken to ensure that any damage to the features is minimised via the implementation of good practice marine construction methods.

7.154. Ongoing refinement of the WTG, meteorological mast and OSP positions will be undertaken to minimise the number of worst case substructures/ foundations that will be required. If 52m baseplate diameter conical GBS are used in preference to 72m baseplate diameter conical GBS, for example, the seabed preparation footprint area drops notably from 4,295m^2 per substructure to 2,240m^2 per substructure, and for different substructure/ foundation types that are being considered (e.g. jackets with piles or suction piles) negligible seabed preparation is required.

Residual Effects

7.155. Assuming the application of good practice to minimise the direct damage to mobile bedforms, low magnitude adverse residual effects are anticipated to remain in areas characterised by the presence of these features.

7.156. All other potential effects discussed above will remain at negligible effects or result in no change.

7.157. Should it be confirmed following site design optimisation that Project Alpha will have a large proportion of 52m baseplate diameter GBSs, then the effects on the seabed sediments and structures will be negligible when spread over a minimum 6 months annual construction period.

7.158. Should jackets with piles or suction piles be used, then there will be no change on sediment transport and deposition during construction.

Effects on suspended sediment concentrations and transport

- Effects upon suspended sediment concentrations and suspended sediment transport due to the installation of substructures/ foundations and array cables.

Substructures / Foundations

7.159. Suspended sediment concentrations may become elevated during the construction phase of the project due to the installation of substructures/ foundations. For the WTG and meteorological masts, the worst case is associated with the seabed preparation activities that may be required associated with the installation of conical GBSs in order to provide a sufficiently level area of seabed. This is because this activity has the potential to release the greatest volume of material into the water column or seabed. The scenario assumes that 72m baseplate diameter conical GBSs will require up to 5m depth of seabed preparation at up to 8 locations, and 52m baseplate diameter conical GBSs will be used elsewhere, requiring up to 3m depth preparation. For the OSP, the worst case involves installation of rectangular (100m x 75m) GBS at up to 1 location and square (40m x 40m) GBS at up to 2 locations.

7.160. At present, the exact volume of seabed preparation at each location and the precise methods to be used are not fully defined and remain subject to ongoing design optimisation. However, in many areas of seabed the approach is likely to involve the removal and immediate side-casting of material from under the direct footprint of the structure. Under this scenario, the material that is side-cast onto the seabed adjacent to the substructure location may become re-mobilised from the seabed, entrained as a plume and subsequently transported in suspension in the water column by tidal currents.

7.161. In a small number of locations, likely to be confined to where the greater, up to 5m, depths of seabed preparation are required, cutter suction dredging may be necessary. If using this approach, sediment plumes may arise from: (i) the action of the drag head on the seabed causing a physical disturbance; (ii) overflow from the hopper; and (iii) deliberate on-board screening of recovered sediments and their return to the sea. Collectively, these processes are likely to result in enhanced suspended sediment concentrations in the water column during the dredging operations and remaining until a short timescale thereafter.

7.162. Measurement of plumes generated by the drag head of cutter suction operations alone has shown that the volume of sediment lifted into suspension is negligible (John *et al.*, 2000), indicating that the principal contributors of sediment to the plume are the processes of overflow and deliberate screening. Where screening is not required (i.e. where all material is retained in the hopper and taken away from the dredge site), the volume of material discharged from the vessel is considerably smaller, and the effects of a sediment plume are usually confined to within the dredge area (Hitchcock & Bell, 2004; Newell *et al.*, 2004).

7.163. Any material released from the vessel will create a plume of sediment that comprises a dynamic plume and passive plume phase (Whiteside *et al.*, 1995). The dynamic plume is influenced by the rapid downward mode of release from the dredger, typically resulting in deposition of the vast majority of the material within a few hundred metres of the activity. The passive plume involves a smaller proportion of the sediment load that is either stripped from the dynamic plume or re-suspended from the seabed, but can have an influence over a wider seabed area as tidal currents transport the material further away until it settles.

7.164. Tillin *et al.* (2011) reported plume modelling, undertaken for multiple licence areas, that showed the highest suspended sediment concentrations would occur for a short time around high water and remain within the dredger tracks, not extending beyond the licensed dredging area. Plumes containing lower suspended sediment concentrations (e.g. typically enhancements of background concentrations by as little as 5-10mg/l) were predicted to extend across much greater distances, along the direction of the tidal flows, but these were barely distinguishable from background levels. These generally comprised the finest sediment fractions only, as coarser material became deposited on the seabed a relatively short distance from its point of release back into the water column.

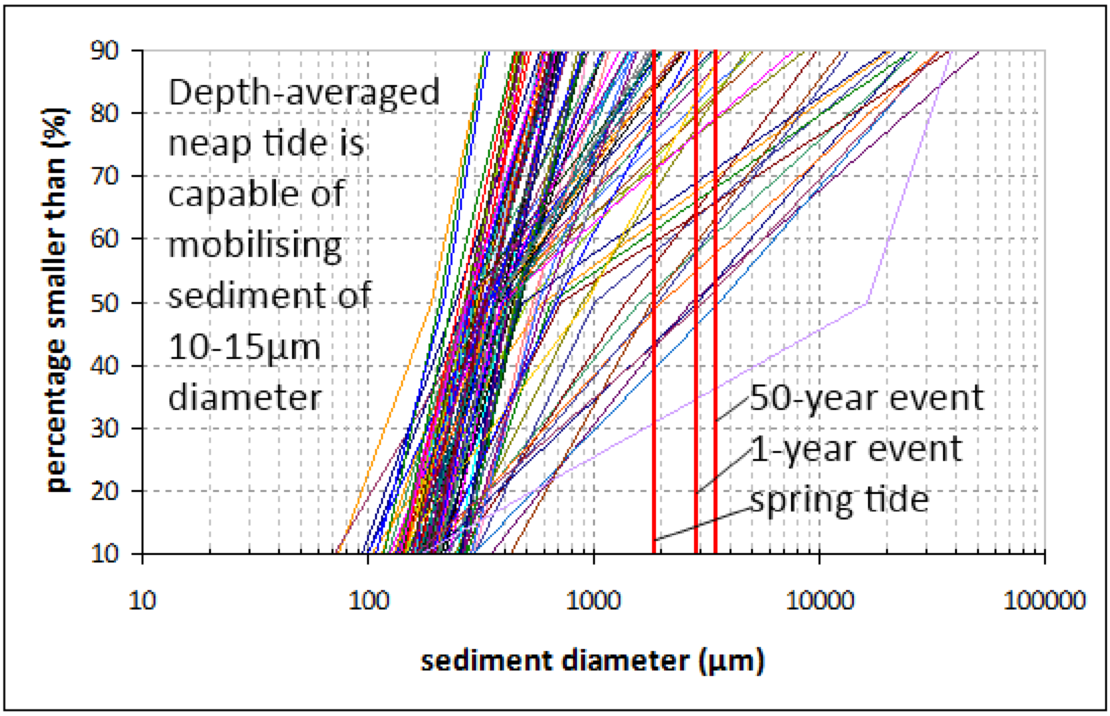
7.165. When considered across the whole of Project Alpha, some 642,200m^3 of material could cumulatively be excavated from the seabed and side-cast adjacent to the substructures or returned from a dredger to the water column if, as a worst case, 72m diameter baseplates GBS are used at up to 8 locations and 52m baseplate diameter elsewhere. An additional 53,500m^3 of material could cumulatively be released from installation of the OSP at up to three locations. However, up to only two substructures/foundations will be installed simultaneously over any three-day period across Project Alpha during the minimum 6 months annual construction period and therefore the release of this material during construction activities will be phased over time.

7.166. The effect that the release of material from seabed preparation will have on suspended sediment concentrations will depend on the mobility of the seabed, the transportation of sediment within a plume, and the presence, or absence, of any sensitive receptors.

7.167. For material released from the dredger (if used), the vast majority will fall to the seabed as part of a dynamic plume. Any material released as a passive plume will be in low concentrations and remain for a relatively short duration, becoming widely dispersed in the area of tidal currents. Once material is returned to the seabed from the dynamic plume (if a cutter suction dredger is used) or is side cast directly onto the seabed, it will remain in situ until the shear stresses acting on the sediment grains exceeds the threshold for motion of that particular grain size, whereupon sediment mobilisation will become initiated. The shear stresses are caused by tidal and wave-induced currents.

7.168. Sediment grading curves derived from the benthic survey (see Chapter 11: Benthic Ecology and Intertidal Ecology) are shown in Plot 7.10. Also plotted are three vertical lines (in red) which represent the sediment grain sizes at which critical thresholds for motion are exceeded at times of under peak flow during, from left to right: (i) mean spring tidal conditions; (ii) 1 in 1 year event conditions; and (iii) 1 in 50 year event conditions. Note that the critical threshold for motion at the peak of the neap tide is associated with a grain size of ~10-15µm.

Plot 7.10 Critical thresholds of motion for particular sediment grain sizes



7.169. This shows that under mean neap tide conditions no sediment with the characteristics of that sampled from Project Alpha can be mobilised from the seabed by current action. However, during mean spring tide conditions a larger proportion of sediment can become mobilised at times of peak flow and this proportion further increases under both 1 in 1 year and 1 in 50 year current events. It should be noted, in addition to tidal currents, that wave-stirring of bed sediment during storm events can also increase forces acting on the seabed and initiate motion, as previously shown in Plot 7.9.

7.170. Further, there is insufficient coarse sediment present to provide natural armouring of the seabed. Consequently, during the peak of a spring tide and during storm events, a proportion of the side cast material is likely to become re-mobilised from the seabed and dispersed by tidal currents until it drops from suspension and becomes re-deposited on the seabed at some distance away from its origin.

7.171. As material deposited during the dynamic plume phase from a cutter suction dredger (if used) or material that has been side-cast becomes mobilised, it will locally increase the turbidity of the water column. This process will be observed at times when the background suspended sediment concentration is naturally towards its highest values, although the metocean data demonstrate that suspended concentrations are generally relatively low. The greatest suspended sediment concentrations will likely be towards the seabed (rather than extensively through the water column right to the water surface) and deposition would occur when current speeds fall below the critical threshold for sediment transport. Due to this, there will be a low magnitude effect in terms of elevating suspended sediment concentrations, but this is likely to be a temporary duration and localised effect. The effect will also be phased over time as the substructures/ foundations are installed over a minimum 6 months annual construction period, with no more than two substructure/ foundations being installed simultaneously at any one time.

7.172. Once suspended in the water column, sediment will become transported by tidal currents until it settles. As shown in Figure 7.4, tidal current patterns at Site A and Site B within the ISA are generally aligned along a north-east to south-west axis.

7.173. Due to these tidal currents, suspended sediment will generally become transported along a north-east to south-west axis, with a general progressive residual transport towards the south-west.

7.174. However, since the critical threshold for motion is only exceeded for part of the spring-neap tidal cycle, sediment will not become widely dispersed in high concentrations. Rather there will be a tendency for successive periods of mobilisation and deposition with side cast material becoming indistinguishable from background sediment over a short timescale (order of days). Furthermore, whilst the cumulative volume of material released due to seabed preparation under the worst case is a relatively high value, its effect will be phased over time as the substructures/ foundations are installed over a minimum 6 month annual construction period, with no more than two substructures/ foundations being installed simultaneously at any one time. Consequently, there will be a low magnitude effect in terms of sediment transport and subsequent deposition on the seabed.

7.175. The consequences of this low magnitude effect on the physical environment upon ecological receptors (smothering of benthic fauna and flora and effects on fish) are assessed in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resources.

Mitigation

7.176. The assessment presented above represents a worst case for WTG and meteorological masts which assumes that substructures/ foundations at up to 8 locations are 72m diameter conical GBS, which has the greatest footprint in terms of the required seabed preparation, and elsewhere are 52m diameter conical GBS. It further assumes rectangular (100m x 75m) GBS at up to 1 location and square (40m x 40m GBS) at up to 2 locations for OSPs. Ongoing refinement of the location and type of substructures/ foundations will be undertaken to minimise the number of worst case structures that will be required. Furthermore, should jackets with piles or suction piles be used then negligible seabed preparation is required.

7.177. The assessment also includes the possibility of various seabed preparation methods to be used, including cutter suction dredging. In practice, site specific assessments will be made at each location to determine the preferred substructure/ foundations type and seabed preparation requirements and methods. If the need for seabed preparation is determined, a licence will be applied for under the Marine (Scotland) Act 2010 for Dredging and Deposit of Solid Waste in the Territorial Sea and UK Controlled Waters Adjacent to Scotland. This will necessarily consider details of the areas and materials to be dredged and a Best Practicable Environmental Option (BPEO) Assessment for deposit of the materials, including consideration of re-use of material as substructure/ foundations ballast, beneficial use and disposal at sea.

Residual Effects

7.178. Should it be confirmed following site design optimisation that Project Alpha will have fewer than the worst case numbers of substructures/ foundations, then the effects on suspended sediment transport and subsequent deposition on the seabed will be **negligible** when spread over a minimum 6 months annual construction period.

7.179. Should jackets with piles or suction piles be used, then there will be **negligible** effect on suspended sediment during construction since little or no seabed preparation will be required and the only effect will arise from minimal dispersal during drilling of piles, if this installation process is required.

Array cables

7.180. The assessment of sediment plume creation and dispersal of sediment from array cable burial follows the rationale above for substructure/ foundations assessments. Elevated concentrations of sediment will be short-term (days) and, assuming that the installation activities occur continuously across the seabed within Project Alpha, will only experience limited release of sediments.

7.181. The worst case scenario for array cable installation equates to some 355km of cable, installed using jetting to a depth of between 0.5m and 2.1m, along a trench of an estimated 3.0m width.

7.182. The total volume of seabed sediments that might be mobilised will be released in a phased approach dependent upon the rate of excavation and across a minimum 6 months annual construction period for 3 years. Furthermore, the jetting approach will fluidise or liquefy the seabed sediments and therefore they will remain near to the bed. Consequently, there will not be the bulk loading of sediment into the marine environment in significant quantities. Indeed, much of the sediment released by jetting within Project Alpha is likely to settle back in the immediate vicinity of its release due to its relatively coarse grain size. Any sediment that does remain in suspension will become dispersed by the prevailing tidal currents in low concentrations.

7.183. Due to this, the jetting of seabed sediments for array cabling will have a low magnitude effect upon suspended sediment concentrations. However, any effects are likely to be of a temporary duration and occur relatively locally to the source of material release.

7.184. This finding is supported by a Technical Report on a review of cabling techniques and environmental effects applicable to the offshore wind farm industry (BERR, 2008) which drew its conclusions from a review of findings from studies undertaken for a number of UK and wider European offshore wind farms. In these studies marginal, short term increases in background suspended sediment concentrations were noted, but most sediment was rapidly re-deposited on the seabed and suspended sediment concentrations reduced to background levels within a very short distance from the trenches. Finer-grained material, where released, was transported considerably further distances by tidal currents, but in very low concentrations and becoming widely dispersed.

7.185. The consequences of this low magnitude effect on the physical environment upon ecological receptors (smothering of benthic fauna and flora and effects on fish) are assessed in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resources.

Mitigation

7.186. The assessment presented above represents a worst case which assumes that all array cables will be trenched using jetting techniques. Should other approaches be used, then the effects on suspended sediment concentrations are likely to be lower than those presented above.

Residual Effects

7.187. Should alternative cable laying approaches be used to jetting, then there will be **negligible** effect on suspended sediment during construction.

Project Bravo

Effects on hydrodynamic regime

- Changes to wave heights and periods and tidal current velocities (speed and direction) due to the installation of substructures/ foundations and the presence of installation or support vessels.

7.188. The effects on the hydrodynamic regime during the construction phase for Project Bravo will be as described for Project Alpha. The presence of only 2 OSP (compared with 3 OSP in Project Alpha) on square (40m x 40m) GBS does not make a material difference in effect on the physical environment. The anticipated effect upon wave heights and periods and tidal current velocities from the construction phase is anticipated to be **negligible**, with only temporary and highly localised changes anticipated.

Mitigation

7.189. No mitigation is proposed. It is expected that the hydrodynamic regime shall return to its pre-construction state upon cessation of construction activities.

Residual Effects

7.190. None anticipated

Effects on sediments and sedimentary structures

- Effects upon the seabed, sediment distribution patterns and mobile bedforms due to the installation of substructures/ foundations.

7.191. The effects on sediments and sedimentary structures during the construction phase for Project Bravo will be as described for Project Alpha. The presence of only 2 OSPs (compared with 3 OSPs in Project Alpha) on square (40m x 40m) GBS does not make a material difference in effect on the physical environment. If jack-up barges are used to install the substructures/ foundations there will be a **negligible** effect. If anchored vessels are used there will be **no change**. For any substructures/ foundations installed in, or within close proximity to, areas characterised by mobile bedforms (such as megaripples and sand waves) it is anticipated that the construction phase would result in a temporary low magnitude adverse effect caused by the flattening of these features. In areas of seabed that are devoid of mobile bedforms, it is anticipated that the installation of substructures/ foundations would have **negligible** effect.

Mitigation

7.192. The mitigation of effects on sediments and sedimentary structures during the construction phase for Project Bravo will be as described for Project Alpha (i.e. implementation of best practice during construction and the on-going refinement of the layout to minimise effects on mobile bedforms).

Residual Effects

7.193. The residual effects on sediments and sedimentary structures following mitigation during the construction phase for Project Bravo will be as described for Project Alpha. At worst there will be low magnitude adverse effects if infrastructure is located in areas of mobile bedforms. If 52m baseplate diameter GBSs, jackets with piles or suction piles are used, these effects will reduce to **negligible**.

Effects on suspended sediment concentrations and transport

- Effects upon suspended sediment concentrations and suspended sediment transport due to the installation of substructures/ foundations and array cables.

7.194. The effects on suspended sediment concentrations and transport during the construction phase for Project Bravo will be as described for Project Alpha. The presence of only 2 OSP (compared with 3 OSP in Project Alpha) does not make a material difference in effect on the physical environment. Although the tidal ellipses across Project Bravo are slightly more north-south aligned (see Site B in Figure 7.4), the assessment of effects is similar. Therefore there will be a low magnitude effect on suspended sediment concentrations and transport from the installation of substructures/ foundations and array cables.

Mitigation

7.195. The mitigation of effects on suspended sediment concentrations and transport during the construction phase for Project Bravo will be as described for Project Alpha. If jackets with piles or suction piles are used then negligible seabed preparation is required. The assessment represents a worst case which assumes that all array cables will be trenched using jetting techniques. Should other approaches be used, then the effects on suspended sediment concentrations are likely to be lower than those presented above.

Residual Effects

7.196. The residual effects on suspended sediment concentrations and transport following mitigation during the construction phase for Project Bravo will be as described for Project Alpha. If 52m baseplate diameter GBSs, or jackets with piles or suction piles are used, these effects will reduce to **negligible**. Should alternative cable laying approaches be used to jetting, then there will be **negligible** effect on suspended sediment during construction

Transmission Asset Project

Effects on hydrodynamic regime

- Changes to wave heights and periods and tidal current velocities (speed and direction) due to the installation of substructures/ foundations and the presence of installation or support vessels.

7.197. The effects on the hydrodynamic regime during the OSP substructure/ foundations construction phase have already been determined as an integral part of the assessments for Projects Alpha and Bravo.

7.198. The worst case substructure/ foundations option for OSP is up to one rectangular (100m x 75m) and up to four square (40m x 40m) GBS. Their installation will have **negligible** effect on the hydrodynamic regime since changes will be temporary and highly localised and they represent only 5 structures in total.

7.199. There will be **no effect** on the hydrodynamic regime due to burial of the export cable or achieving its landfall using HDD techniques at Carnoustie.

Mitigation

7.200. No mitigation is proposed. It is expected that the hydrodynamic regime shall return to its pre-construction state upon cessation of construction activities.

Residual Effects

7.201. None anticipate.

Effects on sediments and sedimentary structures

- Effects upon the seabed, sediment distribution patterns and mobile bedforms due to the installation of substructures/ foundations.

7.202. The effects on sediments and sedimentary structures during the OSP substructure/ foundation construction phase have already been determined as an integral part of the assessments for Projects Alpha and Bravo. Across the Transmission Asset Project there is a requirement for OSP at up to a total of 5 locations. The effects upon the seabed, sediment distribution patterns and mobile bedforms of these 5 substructures will be localised and are considered as **negligible**.

7.203. The effect on sediments and sedimentary structures due to burial of the export cable offshore will be confined to a low magnitude effect in locations where mobile bedforms exist and could be damaged or destroyed by burial activities. Where cable protection is used in other sea bed area, there will be **no effect**. At the landfall, there are no identified sedimentary structures or mobile beforms and therefore HDD will have **no effect**.

Mitigation

7.204. The mitigation of effects from OSP on sediments and sedimentary structures during the construction phase for the Transmission Asset Project will be as described for Project Alpha and Project Bravo (i.e. implementation of best practice during construction and the on-going refinement of the layout to minimise effects on mobile bedforms).

7.205. Design optimisation will be undertaken in finalisation of the cable route to avoid, where practicable, areas of mobile bedforms.

Residual Effects

7.206. The residual effects from OSP substructure/ foundations installation on sediments and sedimentary structures during the construction phase for the Transmission Asset Project will remain **negligible**.

7.207. The residual effects from export cable installation on sediments and sedimentary structures in areas of mobile bedforms will reduce to **negligible** as a result of the export cable mitigation.

Effects on suspended sediment concentrations and transport

- Effects upon suspended sediment concentrations and suspended sediment transport due to the installation of substructures/ foundations and array cables.

Foundations

7.208. The effects on suspended sediment concentrations and transport during the OSP foundation construction phase of the Transmission Asset Project has already been undertaken as an integral part of the assessments for Projects Alpha and Bravo. Across the Transmission Asset Project there is a requirement for OSP at up to a total of 5 locations. This creates considerably less volume of sediment released into the water column or deposited on the sea bed due to preparation activities for OSP substructures/ foundations than has previously been assessed in total for Project Alpha and Project Bravo. Therefore the effects upon the seabed, sediment distribution patterns and mobile bedforms will be localised and are considered as **negligible**. It is unlikely that cutter suction dredging will be needed for installation of these substructures/ foundations, but the effect remains negligible even under such a scenario since most material will be returned through the water column immediately to the seabed.

Export cable

7.209. There will be potential construction effects associated with the sea bed burial and landfall of the export cable. The assessment of sediment plume creation and dispersal of sediment from export cable burial follows the rationale presented for array cable burial assessments.

7.210. The worst case scenario for export cable installation equates to some 530km of cable, installed using jetting to a depth of between 0.5m and 3.0m, along a trench of 3.0m width. Landfall will be achieved by means of HDD.

7.211. The total volume of seabed sediments that might be mobilised will be released in a phased approach dependent upon the rate of excavation and will extend across a minimum 6 months construction period. Furthermore, the jetting approach will fluidise or liquefy the seabed sediments and therefore they will remain near to the bed. Consequently, elevated concentrations of suspended sediment at each point of release along the ECR corridor will be short-term (days). Also, there will not be the bulk loading of sediment into the marine environment in significant quantities. Indeed, much of the sediment released by jetting within the ECR corridor is likely to settle back in the immediate vicinity of its release due to its relatively coarse grain size. Any sediment that does remain in suspension will become dispersed by the prevailing tidal currents in low concentrations. With progression between the Project Alpha Site or Project Bravo Site and the Carnoustie shore, the axis of the tidal ellipses changes (as shown in Figure 7.4), adopting a more shore-parallel axis closer to shore. Consequently any sediment released along the ECR corridor will become widely dispersed according to the tidal ellipses that prevail at the release point, rather than resulting in all released material becoming transported to a common destination.

7.212. Due to this, the jetting of seabed sediments for export cabling and achieving cable landfall at Carnoustie will have a low magnitude effect upon suspended sediment concentrations. However, any effects are likely to be of a temporary duration and occur relatively locally to the source of material release.

7.213. This finding is supported by a Technical Report on a review of cabling techniques and environmental effects applicable to the offshore wind farm industry (BERR, 2008) which drew its conclusions from a review of findings from studies undertaken for a number of UK and wider European offshore wind farms. In these studies marginal, short term increases in background suspended sediment concentrations were noted, but most sediment was rapidly re-deposited on the seabed and suspended sediment concentrations reduced to background levels within a very short distance from the trenches. Finer-grained material, where released, was transported considerably further distances by tidal currents, but in very low concentrations and became widely dispersed.

7.214. The consequences of this low magnitude effect on the physical environment upon ecological receptors (e.g. smothering of benthic fauna and flora and effects on fish) are assessed in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resources.

Mitigation

7.215. The mitigation of effects on suspended sediment concentrations and transport from seabed preparation for substructure/ foundations installation during the construction phase for the Transmission Asset Project will be largely as described for Project Alpha and Project Bravo.

7.216. In addition, the assessment presented above for export cable burial represents a worst case which assumes that all cables will be trenched using jetting techniques. Should other approaches be used, then the effects on suspended sediment concentrations are likely to be lower than those presented above.

Residual Effects

7.217. The residual effects on suspended sediment concentrations and transport from seabed preparation for substructure/ foundations installation during the construction phase for the Transmission Asset Project will be largely as described for Project Alpha and Project Bravo.

7.218. In addition, should alternative export cable laying approaches to jetting be used, there will be **negligible** effect on suspended sediment during construction.

ASSESSMENT OF EFFECTS – OPERATION PHASE

Project Alpha

Effects on hydrodynamic regime

- Changes to wave heights and periods and tidal current velocities (speed and direction) due to the presence of WTG, meteorological masts, OSP and their substructures/ foundations.

7.219. Operational effects on the hydrodynamic regime due to the presence of static structures within the marine environment could take the form of alterations to the wave regime, water levels or current velocities across the Immediate Study Area (ISA) and/ or Regional Study Area (RSA). Such effects could have implications for resultant sediment transport and seabed morphology.

7.220. Waves can potentially become disrupted by the presence of any static structure within the marine environment that creates an obstacle to the passage (propagation) of the waves. In particular, a wave may become partly reflected when it interacts with an obstacle which affects its incident path. Also, when the obstacle is large with respect to the length of the wave, the waves may bend around the obstacle; a process known as diffraction. Both of these wave scattering processes will result in partial loss of energy, creating a wake effect in the lee of the obstacle. The critical issue is whether the waves can re-group soon after passage around the obstacle, returning to background conditions within a short distance, or whether a wider scale effect may be noticed.

7.221. A comprehensive review of a number of Environmental Statements from OWF around the UK and wider Europe was undertaken, with a view to collating outputs from impact assessments relating to changes to the hydrodynamic regime, especially the wave climate, to inform this ES (see Appendix E1). These previous assessments were based on outputs from numerical modelling studies, empirical observations and analytical application of conventional coastal engineering wave theory.

7.222. It was concluded from these previous study findings that rectangular GBS, piled tripod, piled jacket, suction caisson tripod or suction caisson jacket substructures/ foundations (either alone or in any combinations) would result in only very minor interaction with wave propagation, with effects confined locally to each turbine (e.g. locally due to wave reflection).

7.223. In all cases where these substructure/ foundations types were considered, wave diffraction was not observed and wave trains re-grouped shortly after interaction with the structures so that background conditions were restored. Typical reductions in wave height due to the OWF developments considered were in the range <0.5% (e.g. Scarweather Sands) to 9% (e.g. Teesside), but more typically were of the order of approximately 5% within a short distance from the array, dropping to lower levels further afield. For rectangular GBS, the greatest effect was in shallower water depths, where the GBS occupies a greater relative proportion of the water column.

7.224. Predicted reductions towards the higher end of the range stated above tended to be derived from modelling studies that used an overly conservative approach to the blockage effects. In most cases, the magnitude of the predicted change in wave climate across the ISA was considered in the respective ES to be immeasurable due to the variability in the natural baseline.

7.225. Consequently, effects across the ISA from these previous assessments were generally defined within the relevant ES as negligible or low, with no substantial effects identified on the wave climate across the RSA.

7.226. These previous assessments also identified that, in terms of relative effect, monopiles would have least effect on the wave climate, followed by tripods/ jackets and with rectangular GBS having the greatest effect (although still small in magnitude) of the substructure/ foundations types considered on those developments.

7.227. These studies did not, however, generally consider conical GBS structures. Results derived from detailed mathematical modelling of the effects of conical GBS structures on hydrodynamic processes are available from Galloper OWF (ABPmer, 2011). These indicate that predicted changes for significant wave height were up to a maximum reduction of 9%, in line with the largest reductions as documented within Round 1 and Round 2 Environmental Statements.

7.228. It is therefore anticipated that the potential effects of Project Alpha on the wave climate would be greatest within the ISA, with the largest reductions confined to immediately in the vicinity of each substructure. Under all incident wave directions, small percentage reductions are anticipated to be noted locally (especially in a down-wave direction) upon wave height in association with the worst case conical GBSs, resulting in **negligible** effect on the wave climate within the Immediate Study Area.

7.229. Due to the spacing between adjacent turbines (minimum 610m), **no change** will be experienced across the RSA as waves will re-group beyond the project area.

7.230. There is a strong scientific base of knowledge derived from empirical wave theory, previous modelling studies and field observations to support such a conclusion (see Appendix E1).

7.231. The presence of static structures within the marine environment also has the potential to affect the tidal regime due to the interaction of tidal flows with these structures. Such effects may manifest as changes to tidal levels (water levels) and current speeds. Changes in tidal levels are not anticipated during the operation life of the scheme (no effect) due to the nature of the development, but localised changes in tidal flow would be anticipated in the vicinity of each structure. As the flow bifurcates around an obstacle in the marine environment, it accelerates around the sides of the structure and decelerates in its lee. This process can result in scour of the seabed adjacent to the substructures and therefore is considered a low magnitude effect on the tidal regime for the worst case of conical GBS. As the process is confined to within a short distance of the substructure, there will be **no change** to the tidal regime across the RSA.

7.232. The significance of these changes on the hydrodynamic regime upon other receptors (e.g. benthic fauna and flora and effects on fish) are assessed in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resources.

Mitigation

7.233. The assessment presented above represents a worst case which assumes that 72m diameter baseplate conical GBS will be used at up to 8 locations and elsewhere 52m diameter baseplate conical GBS will be used for WTG and meteorological masts, with a minimum spacing between substructures of 610m. OSP substructures/ foundations will be rectangular (100m x 75m) GBS at up to 1 location and square (40m x 40m) GBS at up to 2 locations. Design optimisation of Project Alpha will be undertaken to minimise the number of 72m baseplate diameter conical GBS structures that will be required and consider the optimum spacings between adjacent turbines.

Residual Effects

7.234. If fewer 72m baseplate diameter conical GBS are used, the effect on the hydrodynamic regime will be similar, but very slightly lower in magnitude, to that of the worst case.

7.235. If jackets with piles or suction piles are used, then the effect on the wave climate will be immeasurable (**no change**) and the effect on the tidal regime will be **negligible**.

7.236. As there is no identifiable effect on the RSA from the worst case, then increasing the spacing between adjacent turbines will not result in a different residual effect.

Effects on sediments and sedimentary structures

- Effects upon the seabed, sediment distribution patterns and mobile bedforms due to the presence of WTG, meteorological masts and OSP and their substructures/ foundations and the presence or protective materials on unburied lengths of array cabling.

7.237. The main effects during the operational phase on the seabed sediments and sedimentary structures (sand bars, sand waves and megaripples) relate to the development of scour holes around the base of the substructures/ foundations and the presence of protective rock or mattresses on unburied sections of array cable.

Substructures / Foundations

7.238. As discussed, the presence of a structure within the marine environment provides a local obstruction to flows which otherwise would not occur in the baseline scenario. The effect of the obstruction is to increase local turbulence in the flow regime. Theoretically, the head-on flow first slows down in front of the obstruction before bifurcating around it. The diverted flows join with the adjacent flow to lead to locally increased speeds, before recombining downstream of the obstruction to form a wake in a region where the flow speeds have been slowed. This effect continues through the tidal cycle and is most prominent at the peak of the tide (i.e. flood and ebb periods on a spring tide). This process is the fundamental mechanism which, in the absence of scour protection, would result in scour hole development in the seabed at each substructure/ foundations location.

7.239. The resulting area, depth and volume of scour in the seabed will depend on the physical conditions, the thickness of the mobile seabed layer and the cohesiveness of the substrate.

7.240. Empirical scour assessments have been undertaken on a number of turbine substructure/ foundation options to derive the worst case scenario for scour footprint areas for both 1 in 1 and 1 in 50 return periods. This has demonstrated that the greatest scour potential occurs under a 1 in 50 year return period wave event combined with tidal currents. These conditions have been applied to the 72m baseplate diameter conical GBS, the 52m baseplate diameter conical GBS, the rectangular (100m x 75m) GBS used for OSP and the square (40m x 40m) GBS used for OSP as part of the worst case assessments (see Appendix E4 for full details).

7.241. Under lesser return period events (including typical spring and neap conditions), the scour hole development is considerably less, but a 1 in 50 year event is taken as a worst case that may occur during the operational phase of Project Alpha. Similarly, for alternative substructure/ foundations options (especially jacket structures) the scour hole development is considerably less than for the worst case substructure/ foundations type and size scenario.

7.242. For the worst case substructure/ foundations type and dimensions, a scour hole footprint will occur under a 1 in 50 year event across 6,671m^2 of seabed adjacent to each of the 72m baseplate diameter conical GBS and across 4,283m^2 of seabed adjacent to each of the 52m baseplate diameter conical GBS. At the OSP locations, a scour hole footprint around the rectangular (100m x 75m) GBS will occupy up to 1,850m^2 of seabed under these conditions and around the square (40m x 40m) GBS up to 518m^2. When considered across the whole of Project Alpha, the cumulative seabed area affected by scour hole development during a 1 in 50 year event would be 356,044m^2. This represents <0.2% of the Project Alpha seabed area and following scour hole development during the event, the scour hole would become partially infilled during more quiescent conditions. Within this context, the effect is considered low magnitude.

7.243. The consequences of these low effects on seabed sediments and sedimentary structures due to formation of scour holes around substructures/ foundations upon benthic ecology and natural fisheries are assessed in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resources.

Array cables

7.244. The optimal aim is for the array cables to be fully buried below the seabed to depths of between 0.5m and 2.1m. In some locations, however, this may be impracticable due to the nature of the underlying geology. Consequently, it is estimated that up to 35.5km of array cabling may require protection installed at seabed level in the form of rock berms or concrete mattresses. These structures will not exceed 1m in height above the seabed or 7m in width at their base. Once installed, these protective measures may present an obstacle to sediment that is transported across the seabed until a sand ramp has built sufficiently on the updrift side that subsequent bypassing of the seabed obstruction is possible. The effect that these structures have will depend on their locations, lengths and orientations with respect to sensitive receptors.

7.245. Mobile bedforms (such as megaripples and sand waves) are considered to be sensitive receptors in line with Seagreen's Position Paper to Marine Scotland on the Coastal and Seabed Impact Assessment (see Appendix E1). Within close proximity to areas characterised by mobile bedforms it is anticipated that the operation phase would result in a low magnitude adverse effect due to the presence of the rock berms or concrete mattresses, especially if they are continuous over considerable lengths (several hundred meters with no gaps) or aligned parallel to the crests of mobile bedforms.

7.246. In areas of the seabed that are devoid of mobile bedforms, it is anticipated that the installation of array cables would have **negligible** effect.

7.247. The consequences of these low effects on seabed sediments and sedimentary structures due to the presence of cable protection in areas characterised by mobile bedforms upon benthic ecology and natural fisheries are assessed for their significance in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resources.

Mitigation

7.248. The assessment presented above of operational effects from substructures/ foundations represents a worst case which assumes that all WTG and meteorological mast substructures/ foundations are conical GBS and OSP foundations are rectangular (100m x 75m) GBS at up to 1 location and square (40m x 40m GBS) at up to 2 locations. The worst case further assumes that no scour protection measures will be provided. Design optimisation of Project Alpha will be undertaken to minimise the number of the larger, 72m baseplate diameter, conical GBS structures that will be required and consider the need for scour protection measures at all GBS locations. Where scour protection is adopted, as is highly likely for all GBS types to ensure structural stability, visual ROV, drop video or dive surveys or bathymetric surveys will be undertaken at selected locations within Project Alpha, to assess the effectiveness of scour protection approaches. Subsequent surveys will be planned depending on the results of initial monitoring. The requirement for visual or bathymetric surveys will be discussed with Marine Scotland and other key stakeholders and agreement reached to the detail on future monitoring requirements.

7.249. The assessment presented above, of operational effects from array cable protection measures, represents a worst case which assumes that up to 35.5km of cable requires protection. Design optimisation of Project Alpha will be undertaken to maximise the likelihood of achieving target cable burial and hence minimise the length of cable protection that is required.

Residual Effects

7.250. If scour protection is used around the GBSs, then there will remain a low magnitude effect on the seabed, but the nature of the effect will change from a scour hole developed in the seabed to scour protection material placed on, or below, the seabed. Secondary scour around the scour protection material is not expected to be significant.

7.251. The effect will reduce to **negligible** effect if jackets with piles or suction piles are used as substructures/ foundations.

7.252. If design optimisation ensures that all array cables achieve target burial depths, then there will be **no change** from baseline conditions during the operational phase from the array cables.

Effects on suspended sediment concentrations and transport

- Effects upon suspended sediment concentrations and suspended sediment transport due to the presence of WTG, meteorological masts and OSP and their substructures/ foundations.

7.253. In the absence of scour protection, the development of a scour hole adjacent to each turbine will result in a volume of material released from the seabed into the marine environment.

7.254. Using the empirical scour approaches described previously, assessments have been undertaken to derive the material volumes released by scour processes under worst case conditions of a 1 in 50 year return period wave event combined with tidal currents acting around a 72m conical base GBS at 8 locations and a 52m conical base GBS elsewhere for WTG and meteorological masts (see Appendix E4 for full details). Added to this is the volume released by scour around up to 1 rectangular (100m x 75m) and up to 2 square (40m x 40m) GBS at OSP locations.

7.255. Under lesser return period events (including typical spring and neap conditions), the material volume released by scour is considerably less, but a 1 in 50 year event is taken as a worst case that may occur during the operational phase of Project Alpha. Similarly, for alternative substructure/ foundations options (especially jacket structures) the material volume released by scour is considerably less than for the worst case GBS.

7.256. For the worst case substructure/ foundations type and dimensions, the material volume released by scour under a 1 in 50 year event is 4,877m^3 adjacent to each 72m baseplate diameter conical GBS and 4,304m^3 adjacent to each 52m baseplate diameter conical GBS for the WTG and meteorological masts. At the rectangular (100m x 75m) GBS for OSP, scour volumes of up to 4,032m^3 could be generated during these storm conditions and at each of the square (40m x 40m) GBS for OSP scour volumes could reach 597m^3 in the absence of scour protection. When considered across the whole of Project Alpha, the cumulative material volume released during a 1 in 50 year event would be 345,522m^3.

7.257. This represents a small volume in comparison to the worst case seabed preparation activities for substructure/ foundations installation. However, in contrast to the phased manner in which the substructures/ foundations will be installed, the scour volumes could, in the absence of scour protection, be released instantaneously across every substructure location within Project Alpha during a 1 in 50 year storm event.

7.258. The extent of scour is, however, confined spatially to an area localised to each substructure/ foundation. Whilst in theory the possibility exists for the coalescing of scour holes between adjacent turbines, the assessment performed indicates that this would not be possible between adjacent GBSs even with the worst case turbine spacing considered of 610m (see Appendix E4 for full details). Within this context, there is considered to be a low magnitude effect upon suspended sediment concentrations and suspended sediment transport associated with substructure/ foundations scour during the operational life of Project Alpha.

Mitigation

7.259. The assessment presented above of operational effects from substructures/ foundations represents a worst case which assumes that all WTG and meteorological mast substructures/ foundations are conical GBS and OSP substructures/ foundations are rectangular (100m x 75m) GBS at up to 1 location and square (40m x 40m) GBS at up to 2 locations. It further assumes that no scour protection measures will be provided. Design optimisation of Project Alpha will be undertaken to minimise the number of 72m baseplate diameter conical GBS structures that will be required at WTG and meteorological masts and consider the need for scour protection measures at all GBSs. Where scour protection does become used, as is highly likely for all GBS types to ensure structural stability, visual ROV, drop video or dive surveys or bathymetric surveys will be undertaken at selected locations within Project Alpha to assess the effectiveness of scour protection approaches. Subsequent surveys will be planned depending on the results of initial monitoring. The requirement for visual or bathymetric surveys will be discussed with Marine Scotland and other key stakeholders and agreement reached to the detail on future monitoring requirements.

Residual Effect

7.260. The effect will reduce to a **negligible** effect if jackets with piles or suction piles are used as substructures/ foundations, since scour volumes associated with these structures are significantly lower than for GBS.

7.261. If scour protection is used around the substructures/ foundations, then there will be **no effect** on the suspended sediment concentrations during the operational phase, irrespective of which substructures/ foundations are used, because scour processes will not develop. Secondary scour around the scour protection material is not expected to be significant.

Project Bravo

Effects on hydrodynamic regime

- Changes to wave heights and periods and tidal current velocities (speed and direction) due to the presence of WTG, meteorological masts and OSP and their substructures/ foundations.

7.262. The effects on the hydrodynamic regime during the operation phase for Project Bravo will be as described for Project Alpha. The presence of only 2 OSP (compared with 3 OSP in Project Alpha) on square (40m x 40m) GBS does not make a material difference in effect on the physical environment. It is anticipated that the potential effects of Project Bravo on the wave climate would be greatest within the Immediate Study Area, with the largest reductions confined to immediately in the vicinity of each substructure/ foundations. Under all incident wave directions, small percentage reductions are anticipated to be noted locally upon wave height in association with the worst case GBSs, resulting in **negligible** effect on the wave climate within the ISA. Due to the spacing between adjacent turbines (minimum 610m), **no change** will be experienced across the RSA as waves will re-group beyond the project area. It is considered that there will be a low magnitude effect on the tidal regime for the worst case of GBS within the ISA. As the process is confined to within a short distance of the substructure, there will be **no change** to the tidal regime across the RSA.

Mitigation

7.263. The mitigation of effects on the hydrodynamic regime during the construction phase for Project Bravo will be as described for Project Alpha (i.e. design optimisation of to minimise the number of 72m baseplate diameter conical GBS structures that will be required and consider the optimum spacings between adjacent turbines).

Residual Effects

7.264. The residual effects on the hydrodynamic regime following mitigation during the construction phase for Project Bravo will be as described for Project Alpha. If jackets with piles or suction piles are used, then the effect on the wave climate will be immeasurable (**no change**) and the effect on the tidal regime will be **negligible**. All effects will be confined to the ISA.

Effects on sediments and sedimentary structures

- Effects upon the seabed, sediment distribution patterns and mobile bedforms due to the presence of WTG, meteorological masts and OSP and their substructures/ foundations and the presence or protective materials on unburied lengths of array cabling.

7.265. The effects on sediments and sedimentary structures during the operation phase for Project Bravo will be as described for Project Alpha. The presence of only 2 OSP (compared with 3 OSP in Project Alpha) on square (40m x 40m) GBS does not make a material difference in effect on the physical environment. Scour effects from substructures/ foundations are therefore considered to be of low magnitude. Effects from array cables would occur where cable protection is required. There would be a low magnitude effect in areas of mobile bedforms and a **negligible** effect elsewhere.

Mitigation

7.266. The mitigation of effects on sediments and sedimentary structures during the construction phase for Project Bravo will be as described for Project Alpha. Reduction of effects is dependent upon the requirements for scour / cable protection, the size of substructures/ foundations and the location of the infrastructure and therefore optimization of the design.

Residual Effects

7.267. The residual effects on sediments and sedimentary structures following mitigation during the construction phase for Project Bravo will be as described for Project Alpha. There will remain a low magnitude effect for any size of GBS used; either with or without scour protection. This will reduce to **negligible** effect if jackets with piles or suction piles are used as substructures/ foundations. Secondary scour around the scour protection material is not expected to be significant. If design optimization ensures that all cables achieve target burial depths, then there will be **no change** from baseline conditions during the operational phase from the array cables.

Effects on suspended sediment concentrations and transport

- Effects upon suspended sediment concentrations and suspended sediment transport due to the presence of WTG, meteorological masts and OSP and their substructures/ foundations.

7.268. The effects on suspended sediment concentrations and transport during the operation phase for Project Bravo will be as described for Project Alpha. The presence of only 2 OSP (compared with 3 OSP in Project Alpha) on square (40m x 40m) GBS does not make a material difference in effect on the physical environment. Although the tidal ellipses across Project Bravo are slightly more north-south aligned, the assessment of effects is similar. Therefore it is considered that there will be a low magnitude effect upon suspended sediment concentrations and suspended sediment transport associated with substructure/ foundation scour during the operational life of Project Bravo

Mitigation

7.269. The mitigation of effects on suspended sediment concentrations and transport during the construction phase for Project Bravo will be as described for Project Alpha (i.e. minimising the use of 72m conical GBS and provision of scour protection materials for GBS, selecting substructure/ foundations type according to site conditions, etc.).

Residual Effects

7.270. The residual effects on suspended sediment concentrations and transport following mitigation during the construction phase for Project Bravo will be as described for Project Alpha. The effects on suspended sediment concentrations and suspended sediment transport will reduce to **negligible** effect if jackets with piles or suction piles are used as substructures/ foundations, even without scour protection, because scour volumes are significantly lower than for GBS. If scour protection is used around the substructures/ foundations, then there will be **no effect** on the suspended sediment concentrations during the operational phase, irrespective of which substructures/ foundations are used, because scour processes will not develop. Secondary scour around the scour protection material is not expected to be significant.

Transmission Asset Project

Effects on hydrodynamic regime

- Changes to wave heights and periods and tidal current velocities (speed and direction) due to the installation of substructures/ foundations and the presence of installation or support vessels.

7.271. The effects of OSP substructures/ foundations on the hydrodynamic regime during the operation phase for the Transmission Asset Project have already been assessed as an integral part of the assessments for Projects Alpha and Bravo. Across the Transmission Asset Project there is a requirement for OSP at up to a total of 5 locations and therefore the physical presence of these structures and their foundations within the marine environment will have **negligible** effect on the hydrodynamic regime since changes will be temporary and highly localised.

7.272. There will be no effect of the export cable on the hydrodynamic regime during the operational phase where it is buried below the sea bed. Where sections of cable require protection, there will be localised and small magnitude changes in the hydrodynamic regime, resulting in a **negligible** effect.

Mitigation

7.273. The mitigation of effects on the hydrodynamic regime during the construction phase for the Transmission Asset Project will be as described for Project Alpha and Project Bravo. Efforts will be made to optimize the length of cable that will achieve target burial depth and therefore the amount of cable protection required will be minimised.

Residual Effects

7.274. The residual effects on the hydrodynamic regime during the operational phase for the Transmission Asset Project will be **negligible**. Any effects will be confined to the ISA.

Effects on sediments and sedimentary structures

- Effects upon the seabed, sediment distribution patterns and mobile bedforms due to the installation of substructures/ foundations and export cables.

Substructures / Foundations

7.275. The effects of OSP substructures/ foundations on sediments and sedimentary structures during the operation phase have already been assessed as an integral part of the assessments for Projects Alpha and Bravo. Across the Transmission Asset Project there is a requirement for OSP at up to a total of 5 locations therefore the total area of seabed that may be affected by scour processes is small (3,922m^2) within the context of the Transmission Asset Project seabed area. Therefore, even if no scour protection was provided, the effects upon the seabed, sediment distribution patterns and mobile bedforms from scour hole development on the seabed around OSP substructures/ foundations will be **negligible**.

Export cables

7.276. The optimal aim is for the export cable to be fully buried below the seabed to depths of between 0.5m and 3.0m. In some locations, however, this may be impracticable due to the nature of the underlying geology. Consequently up to 26.5km of export cabling may require protection installed at seabed level in the form of rock berms or concrete mattresses. These structures will not exceed 1.2m in height above the seabed or 11m in width at their base. Once installed, these protective measures may present an obstacle to sediment that is transported across the seabed until a sand ramp has built sufficiently on the updrift side that subsequent bypassing of the seabed obstruction is possible. The effect that these structures have will depend on their locations, lengths and orientations with respect to sensitive receptors.

7.277. Should any rock berm or concrete mattress be required across the inter-tidal zone or the shallow (<7m chart datum) nearshore zone, there exists a high potential to interrupt sediment transport processes that generally operate from north to south along, or just offshore from, the shoreline between Carnoustie and Buddon Ness. Since this feed of sediment is important to the geomorphological interests along this shoreline, any reduction in drift potential would be considered to be a significant medium magnitude effect. The need for cable protection in this manner within the inter-tidal or nearshore zone, however, is unlikely due to the nature of the seabed sediments in this area.

7.278. In water depths around 7m below the Lowest Astronomical Tide (LAT), the seabed may occasionally be characterised by areas of mobile bedforms (such as megaripples and sand waves). These are considered to be sensitive receptors in line with Seagreen's Position Paper to Marine Scotland on the Coastal and Seabed Impact Assessment (see Appendix E1). Within close proximity to areas characterised by mobile bedforms it is anticipated that the operation phase would result in a low magnitude adverse effect due to the presence of the rock berms or concrete mattresses, especially if they are continuous over considerable lengths (several hundred meters with no gaps) or aligned parallel to the crests of mobile bedforms.

7.279. In areas of the seabed that are devoid of mobile bedforms in water depths below around 7m below LAT, it is anticipated that the installation of substructures/ foundations would have **negligible** effect.

7.280. The consequences of these effects on seabed sediments and sedimentary structures due to the presence of cable protection in areas characterised by mobile bedforms upon benthic ecology and natural fisheries are assessed for their significance in Chapter 11: Benthic Ecology and Intertidal Ecology and Chapter 12: Natural Fish and Shellfish Resources.

Mitigation

7.281. The key mitigation measure is the commitment from Seagreen that rock dumping and concrete mattresses will not be used to protect the cables in the nearshore (depths less than 7m and intertidal zone). The mitigation of substructures / foundation effects on sediments and sedimentary structures during the operation phase for the Transmission Asset Project will be as described for Project Alpha and Project Bravo. Reduction of effects is dependent upon the requirements for scour / cable protection, the size of substructures/ foundations and the location of the infrastructure and therefore optimisation of the design.

7.282. The assessment presented above of operational effects from export cable protection measures represents a worst case which assumes that up to 26.5km of cable requires protection. Design optimisation of the Transmission Asset Project will be undertaken to maximise the likelihood of achieving target cable burial and hence minimise the length of cable protection that is required. The need for cable protection within the inter-tidal or nearshore zone, where the effect would be greatest, is highly unlikely.

Residual Effects

7.283. The residual substructure/ foundations effects on sediments and sedimentary structures during the operation phase, for the Transmission Asset Project assuming mitigation measures are implemented will be **negligible**.

7.284. In addition, if design optimisation ensures that all export cables achieve target burial depths, then there will be **no change** from baseline conditions during the operational phase from the export cables.

Effects on suspended sediment concentrations and transport

- Effects upon suspended sediment concentrations and suspended sediment transport due to the installation of substructures/ foundations and export cables.

7.285. The effects on suspended sediment concentrations and transport during the operation phase have already been assessed as an integral part of the assessments for Projects Alpha and Bravo. Across the Transmission Asset Project there is a requirement for OSP at up to a total of 5 locations, therefore a small total volume of material (up to 6,420m^3) will be released due to the OSP substructures/ foundations. Due to this, the effects on suspended sediment concentrations form seabed material released by scour processes will be **negligible**.

7.286. There will be **no effect** on suspended sediment concentrations during the operational phase from the export cable since it will be either buried or protected on the surface.

Mitigation

7.287. The mitigation of effects on suspended sediment concentrations and transport from substructure/ foundations scour during the operation phase for the Transmission Asset Project will be largely as described for Project Alpha and Project Bravo (i.e. design optimisation and considering the use of scour protection materials).

Residual Effects

7.288. The residual effects on suspended sediment concentrations and transport during the operation phase for the Transmission Asset Project will remain **negligible**.

ASSESSMENT OF EFFECTS – DECOMMISSIONING PHASE

Project Alpha

Effects on hydrodynamic regime

Effects on sediments and sedimentary structures

Effects on suspended sediment concentrations and transport

7.289. Arrangements associated with decommissioning of Project Alpha will be determined prior to construction and a full Decommissioning Plan will be drawn up and agreed with Marine Scotland. Until these arrangements have been clarified, the worst case scenario is that all structures and array cables will be removed.

7.290. Decommissioning will involve the sequential removal of any structures or cables related to Project Alpha. This has the potential to cause effects on the hydrodynamic regime, sediments and sedimentary structures and suspended sediment concentrations and transport that will be similar in type and no greater in magnitude than those described for the construction phase. Therefore there will be temporary low magnitude effects at worst.

Project Bravo

Effects on hydrodynamic regime

Effects on sediments and sedimentary structures

Effects on suspended sediment concentrations and transport

7.291. The effects on the hydrodynamic regime, sediments and sedimentary structures and suspended sediment concentrations and transport during the decommissioning phase for Project Bravo will be as described for Project Alpha. Therefore there will be temporary low magnitude effects at worst.

Transmission Asset Project

Effects on hydrodynamic regime

Effects on sediments and sedimentary structures

Effects on suspended sediment concentrations and transport

7.292. The effects on the hydrodynamic regime, sediments and sedimentary structures and suspended sediment concentrations and transport during the decommissioning phase for the Transmission Asset Project will be largely as described for Project Alpha and Project Bravo for decommissioning of the OSP infrastructure.

7.293. In addition, decommissioning of the export cable has the potential to cause effects on the hydrodynamic regime, sediments and sedimentary structures and suspended sediment concentrations and transport that will be similar in type and no greater in magnitude than those described for its construction phase.

ASSESSMENT OF EFFECTS – CUMULATIVE AND IN-COMBINATION EFFECTS

7.294. Effects on the physical environment arising from Project Alpha are likely to occur cumulatively with those arising from Project Bravo and the Transmission Asset Project. However, since the construction, operational and decommissioning effects from each individually are not envisaged to be of high or medium effect and are likely to be local and, in many cases, short-duration, then no cumulative effect on the physical environment is envisaged.

7.295. If both Project Alpha and Project Bravo are consented, then there will be the requirement for only 3 meteorological masts across both sites, rather than 3 within each as currently assessed. This will not, however, materially reduce the effects assessed for each of Project Alpha and Project Bravo separately.

7.296. The Seagreen Project (Project Alpha, Project Bravo and the Transmission Asset Project) has the potential to cause effects cumulatively with both: (i) potential future phases of activity within the Firth of Forth Round 3 Zone and (ii) other relevant developments, including OWFs at Inch Cape and Neart na Gaoithe within Scottish Territorial Waters (STW). To further assess these issues, Seagreen has joined together with the developers of proposed Inch Cape and Neart na Gaoithe sites and The Crown Estate to form the Forth and Tay Offshore Wind Developers Group (FTOWDG).

7.297. As described in Chapter 6: EIA Process of this ES, the physical environment and sedimentary processes was one of the key topics highlighted as requiring detailed assessment for cumulative effects. Seagreen has adopted a very similar metocean survey approach to the STW developers in FTOWDG. However the STW developers have adopted a detailed numerical modelling approach to support the assessment of effects on the physical environment, including cumulative effects, whereas Seagreen has adopted an empirical approach.

7.298. The results from the assessments undertaken by the STW developers have been summarised in Chapter 9 of the Neart na Gaoithe OWF ES (Mainstream Renewable Power, 2012) and presented in full in its accompanying Appendix 9.3 Coastal Process Assessment for Neart na Gaoithe OWF (Intertek Metoc, 2011). This describes the numerical modelling undertaken to assess the effects on the tidal regime (using MIKE-HD), wave regime (using MIKE-SW) and suspended sediment transport regime (using MIKE-PT). This approach covered the construction, operation and decommissioning phases of development. The reported outputs from the modelling study provide a quantitative supporting justification for the conclusions drawn throughout this chapter relating to the assessment of effects on the physical environment arising from the Seagreen Project alone.

7.299. The numerical modelling approach was also adopted to assess the cumulative effects arising from the three OWF sites of Inch Cape, Neart na Gaoithe and the Firth of Forth Round 3 Zone. A ‘high impact’ layout was adopted for each site, comprising 328 turbines for each of Inch Cape and Neart na Gaoithe and 1,000 turbines for the Firth of Forth Round 3 Zone. In this ‘high impact’ development layout, the Firth of Forth Round 3 Zone was represented by the larger gravity base structures and these were positioned in the model as close to the Inch Cape and Neart na Gaoithe OWFs as possible given the minimum WTG spacings as defined in the Rochdale Envelope. The cumulative effect modelling is therefore highly over-conservative in all of its assumptions.

7.300. The results from the cumulative assessment presented in Chapter 9 of the Neart na Gaoithe OWF ES (Mainstream Renewable Power, 2012) show that cumulative effects on the physical environment and sedimentary processes are negligible or low and support the conclusion that no cumulative effect on the physical environment is envisaged, as confirmed in this section of this ES.

7.301. There are no pathways for potential effects on the physical environment arising from the Seagreen Project to occur in combination with any other known potential development due to the huge distances of geographical separation.

ENVIRONMENTAL STATEMENT LINKAGES

7.302. Table 7.27 presents Environmental Statement linkages in and between the physical environment and other key environmental parameters.

Table 7.27 ES Linkages

Inter-relationship	Relevant sections	Linked Chapter
Re-suspension of seabed sediments having potential to affect water and sediment quality	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 8 Water and Sediment Quality
Changes to far-field wave and hydrodynamic conditions having potential to affect designated habitats	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 9 Nature Conservation Designations
Changes to far-field wave and hydrodynamic conditions having potential to affect marine archaeological features	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 17 Archaeology and Cultural Heritage
Changes in coastal processes having potential to affect marine intertidal ecology	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 11 Benthic Ecology and Intertidal Ecology
Changes in coastal processes having potential to affect marine archaeological features	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 17 Archaeology and Cultural Heritage
Suspended sediments and changes in wave and tidal regime having potential to affect subtidal ecology	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 11 Benthic Ecology and Intertidal Ecology
Suspended sediments and changes in wave and tidal regime having potential to affect fish and shellfish resource	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 12 Natural Fish and Shellfish Resource
Suspended sediments and changes in wave and tidal regime having potential to affect marine archaeological features	Assessment of Effects – Construction Phase Assessment of Effects – Operation Phase Assessment of Effects – Decommissioning Phase	Chapter 17 Archaeology and Cultural Heritage

OUTLINE MONITORING

7.303. It is proposed that monitoring is undertaken if scour protection is used at the seabed adjacent to the substructures/ foundations to confirm its suitability in limiting scour and assess the development of any secondary scour.

SUMMARY

7.304. The effects of the construction, operation and decommissioning phases of Project Alpha, Project Bravo and the Transmission Asset Project has been assessed using a combination of analytical tools and techniques including, where appropriate and proportionate to the risks presented, review of previous schemes, historical trends analysis, expert geomorphological assessment, empirical formulae and numerical modelling.

7.305. Tables 7.28 and 7.29 show a summary of the effects and their potential mitigation measures and residual effects.

Table 7.28 Summary of Effects - Project Alpha and Project Bravo

Description of Effect	Worst Case Effect	Potential Mitigation Measures	Residual Effect
Project Alpha and Project Bravo - Construction Phase			
Effects on hydrodynamic regime	Negligible	None	N/ A
Effects on sediments and sedimentary structures	**Installation plant:** No change (anchored vessels) or negligible effect (jack-up barges)	None	N/ A
	Seabed preparation: Negligible effect in areas devoid of mobile bedforms, low effect in areas with mobile bedforms	Design optimisation to minimise the quantity of worst case substructures / foundations required and depths of seabed preparation required	Low effect in areas of mobile bedforms if only industry best practice guidance is used as mitigation, but if alternative foundation types are selected, the effect reduces to negligible (for other GBS) or no change (for jackets with piles or suction piles)
Effects on suspended sediment concentration and transport	**Substructures / Foundations:** Low effect	Design optimisation to minimise the quantity of worst case substructures / foundations required and depths of seabed preparation required	Negligible (for 52m baseplate diameter conical GBS) or negligible (for jackets with piles or suction piles)
	Array cables: Low effect	Design optimisation to select preferred cable trenching technique and minimise areas where jetting is used	Negligible (for ploughing or cutting)
Project Alpha and Project Bravo - Operation Phase			
Effects on hydrodynamic regime	**Waves:** Negligible **Tides:** Low	Design optimisation to minimise the quantity of worst case substructures / foundations required	**Waves:** N/ A **Tides:** Low (for 52m baseplate diameter conical GBS) or negligible (for jackets with piles or suction piles)

Description of Effect	Worst Case Effect	Potential Mitigation Measures	Residual Effect
Effects on sediments and sediment structures	**Substructures / Foundations:** Low effect **Array cables:** Negligible effect in areas devoid of mobile bedforms, low effect in areas with mobile bedforms	Design optimisation to minimise the quantity of worst case substructures / foundations required and scour protection likely to be needed to ensure integrity of substructures / foundations. Design optimisation to minimise the length of cable where protection is required	Low effect (conical GBS) or negligible effect (jackets) No change if all cable is buried to target depth.
Effects on suspended sediment concentration and transport	**Substructures / Foundations:** Low effect	Design optimisation to minimise the quantity of worst case substructures / foundations required and scour protection likely to be needed to ensure engineering integrity of substructures / foundations.	Low effect (conical GBS) or negligible effect (jackets). No change if scour protection used.
Project Alpha and Project Bravo - Decommissioning Phase			
Effects as for construction phase			

Table 7.29 Summary of Effects - Transmission Asset Project

Description of Effect	Effect	Potential Mitigation Measures / Monitoring	Residual Effect
Transmission Asset Project - Construction Phase			
Effects on hydrodynamic regime	Negligible	None / No monitoring	N/ A
Effects on sediments and sedimentary structures	**Installation plant:** No change (anchored vessels) or negligible effect (jack-up barges) **Substructures / Foundations:** Negligible effect **Export cable:** (offshore): Low effect in areas of mobile bedforms, no effect in areas devoid of mobile bedforms **Export cable** (landfall): No effect	None / No monitoring Design optimisation to minimise the seabed preparation depths required / No monitoring Design optimisation to minimise the length of cable where protection is required None / No monitoring	N/ A Negligible Negligible in areas of mobile bedforms, no effect elsewhere. No change if all cable is buried to target depth

Description of Effect	Effect	Potential Mitigation Measures / Monitoring	Residual Effect
Effects on suspended sediment concentration and transport	**Substructures / Foundations:** Negligible effect **Export cable (offshore & landfall):** Low effect	Design optimisation to minimise the seabed preparation depths required / No monitoring Design optimisation to select preferred cable trenching technique and minimise areas where jetting is used / No monitoring	Negligible Negligible (for ploughing or cutting or HDD)
Transmission Asset Project - Operation Phase			
Effects on hydrodynamic regime	Negligible effect	None / No monitoring	N/A
Effects on sediments and sediment structures	**Substructures / Foundations:** Negligible effect **Export cables:** Water depths > 7m chart datum: Negligible effect in areas devoid of mobile bedforms, low effect in areas with mobile bedforms Water depths < 7m chart datum: Potential medium effect	Design optimisation to minimise the quantity of worst case substructures / foundations required. Scour protection likely to ensure engineering integrity / Monitor scour protection Design optimisation to minimise the length of cable where protection is required / No monitoring if all cable is buried Design optimisation to ensure no cable protection is required in the inter-tidal or shallow nearshore zone	Negligible effect No change if all cable is buried to target depth No change if all cable is buried to target depth
Effects on suspended sediment concentration and transport	**Substructures / Foundations:** Negligible effect	Design optimisation to minimise the quantity of worst case substructures / foundations required and scour protection likely to be needed to ensure engineering integrity of substructures / foundations / Monitor scour protection	Negligible effect
Transmission Asset Project - Decommissioning Phase			
Effects as for construction phase			

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