Rampion 2 Wind Farm

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Environmental Statement

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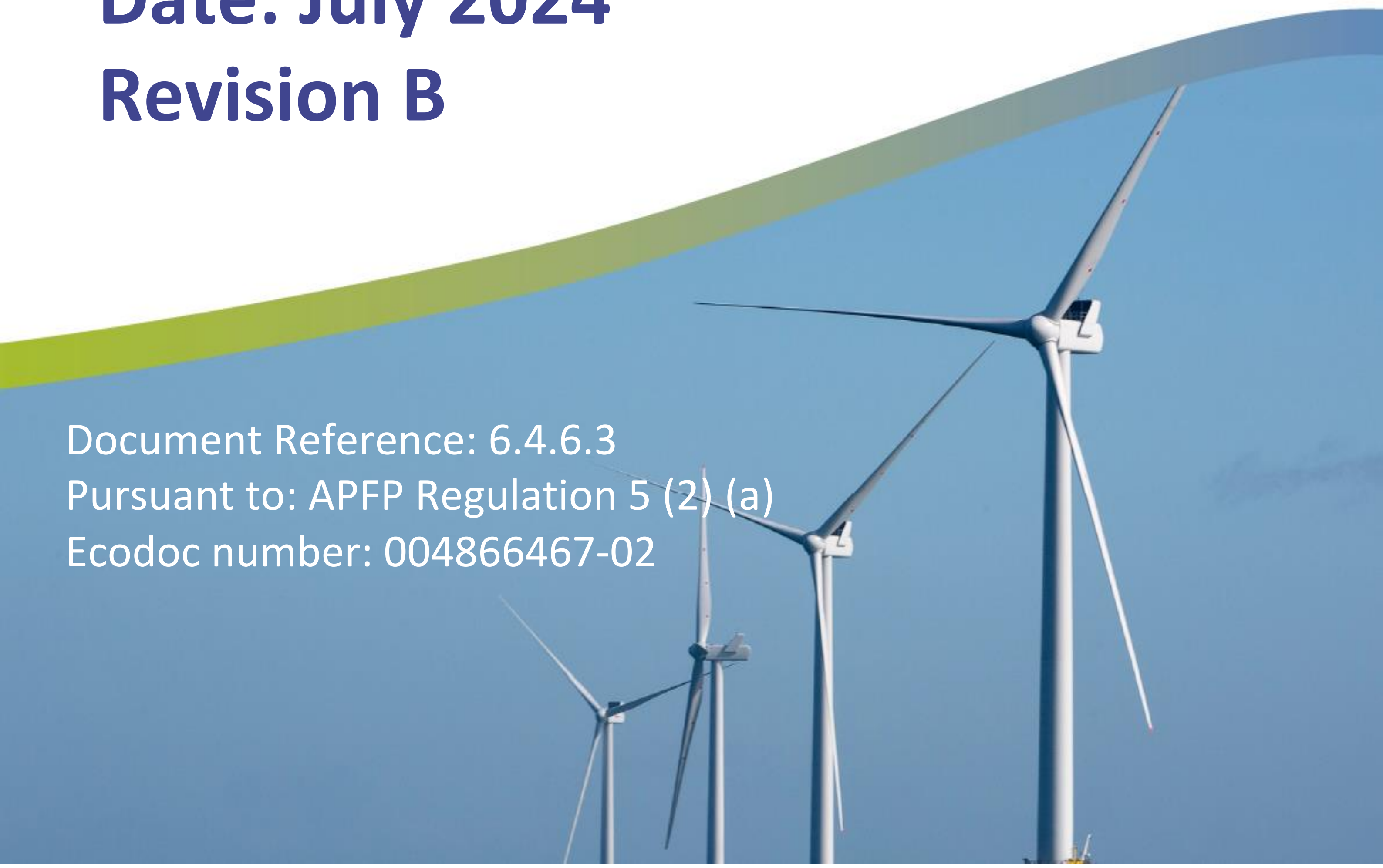

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Executive summary

Purpose of this report

This report has been produced to provide supporting technical information to underpin several of the significance of effect assessments set out in the Rampion 2 Coastal Processes Environmental Statement chapter. The assessment considers the effects on the offshore, nearshore and coastal processes. The following changes are considered:

- Changes to suspended sediment concentrations, bed levels and sediment type (**Section 2: Changes to suspended sediment concentrations, bed levels and sediment type**);
- Changes to the wave regime (**Section 2.9: Summary of changes to suspended sediment concentrations, bed levels and sediment type**);
- Changes to the tidal regime (**Section 4: Changes to the tidal regime);**
- Changes to the sediment transport regime (**Section 5: Changes to the sediment transport regime**); and
- Scour and seabed alteration (**Section 6: Assessment of scour and seabed alteration**).

The assessments draw upon a range of analytical techniques, including:

- The evidence base from existing operational projects, especially the adjacent Rampion 1 offshore wind farm;
- A new suite of numerical modelling scenarios for the wave regime;
- Consideration of existing and newly collected project-specific data of relevance to the assessment; and
- The use of standard empirical equations to quantify rates and scales of change.

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1. Introduction

1.1 Overview

1.1.1 ABPmer has been commissioned to deliver the Coastal Processes Environmental Impact Assessment (EIA) for the Rampion 2 Offshore Wind Farm. This appendix provides supporting technical analysis underpinning the offshore, nearshore and coastal processes assessments presented in **Chapter 6: Coastal processes, Volume 2** of the Environmental Statement (ES) (Document Reference 6.2.6) for the construction, operation and decommissioning of the Offshore Wind Farm. This appendix provides supporting analysis on the following effects assessments:

- changes to suspended sediment concentrations, bed levels and sediment type (**Section 2**);
- changes to the wave regime (**Section 3**);
- changes to the tidal regime (**Section 4**);
- changes to the sediment transport regime (**Section 5**); and
- scour and seabed alteration **(Section 6**).

1.1.2 The assessments presented in this technical annex have been informed by:

- the collation and analysis of baseline information (as set out in **Appendix 6.1: Coastal processes technical report: Baseline description, Volume 4** of the ES (Document Reference: 6.4.6.1)); and
- numerical wave modelling, the model build and validation of which is set out in **Appendix 6.2: Coastal processes model design and validation** of the ES (Document Reference: 6.4.6.2).

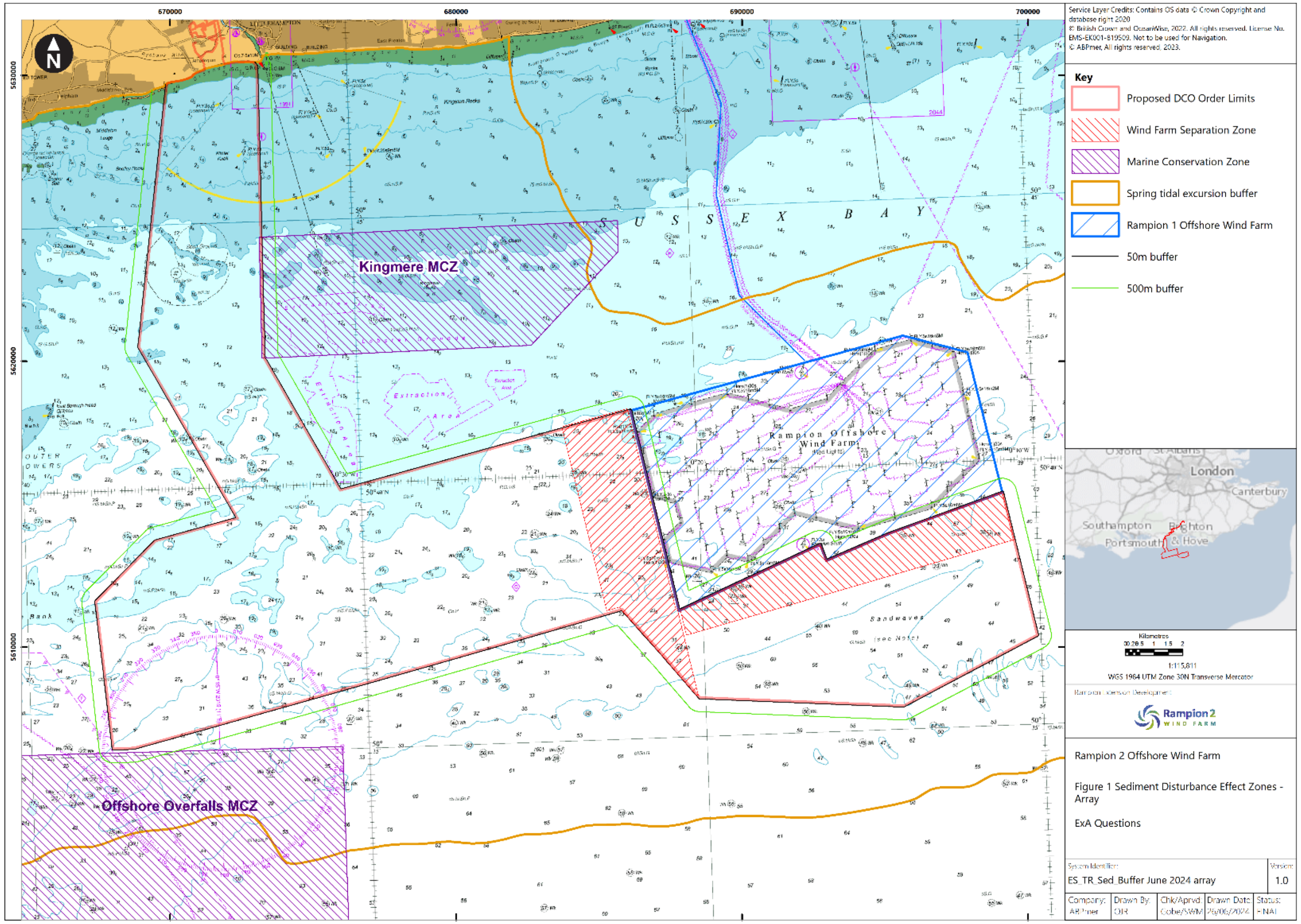
1.2 Approach

1.2.1 In order to assess the potential changes relative to the baseline (existing) coastal and marine environment within the study area (**Figure 1-1**), a combination of complementary approaches have been adopted for the Rampion 1 coastal processes assessment. These include the following.

- The assessments follow the source-pathway-receptor model for identifying potential cause and effect.
- The 'evidence base' containing monitoring data collected during the construction, and operation and maintenance of other comparable offshore wind farm developments. The evidence base also includes results from numerical modelling and desk-based analyses undertaken to support other offshore wind farm EIAs, especially that used to support the consenting processes for the adjacent operational Rampion 1 project.
- New numerical modelling to consider potential changes to waves in response to the construction, operation and decommissioning of Rampion 2.

- Analytical assessments of Rampion 2 project-specific data, including the use of rule based and spreadsheet based numerical models.
- Standard empirical equations describing the relationship between (for example) hydrodynamic forcing and sediment transport or settling and mobilisation characteristics of sediment particles released during construction activities (e.g. Soulsby, 1997).

Figure 1-1 Study Area (extract from Figure 6.3.1)



2. Changes to suspended sediment concentrations, bed levels and sediment type

2.1 Overview

2.1.1 This section outlines the assessment of potential changes to suspended sediment concentrations, seabed levels and sediment characteristics due to sediment disturbance caused by construction activities.

2.1.2 Local increases in suspended sediment concentration (SSC) may result from the disturbance of sediment by construction related activities, most notably due to:

- drilling of monopile foundations and pin piles for jacket foundations;
- seabed preparation by dredging prior to jacket suction bucket foundation installation;
- sandwave clearance (prior to cable burial);
- cable burial; and
- drilling fluid release during Horizontal Directional Drilling (HDD) at the landfall.

2.1.3 The mobilised material may be transported away from the disturbance location by the local tidal regime. According to the source-pathway-receptor model:

- disturbance and release of sediment is considered as the source of potential changes to SSC in the water column;
- tidal currents act as the pathway for transporting the suspended sediment; and
- the receptor is a feature potentially sensitive to any increase in suspended sediments and consequential deposition.

2.1.4 The magnitude, duration, rate of change and frequency of recurrence of changes to SSC and bed level are variable between operation types and in response to natural variability in the controlling environmental parameters.

2.2 Baseline conditions

2.2.1 A summary of the relevant baseline characteristics within and nearby to the Rampion 2 array area is summarised below, based on the review and analysis of available information set out in coastal processes baseline appendix (**Appendix 6.1: Coastal processes technical report: Baseline description, Volume 4** of the ES (Document Reference: 6.4.6.1)).

- Depth averaged mean spring currents within the Rampion 2 array area are in the approximate range 0.75 to 1.1m/s. Within the cable corridor, speeds reduce gradually from approximately 0.9m/s at the western offshore array area end, to 0.5m/s near to the landfall.

- Monthly averaged satellite imagery of suspended particulate matter (SPM, including sediment and other organic matter) suggests that within the Rampion 2 offshore array area average (surface) SPM typically ranges between 10 and 20mg/l during winter months and are generally less than 4mg/l during the summer period (Cefas, 2016). A similar range of values was observed directly by the metocean survey, nearbed within the offshore array area, during winter months. Higher values (potentially several hundred mg/l) are anticipated during more energetic periods (e.g., during spring tides and/or larger storm conditions), in areas with a greater fines content, and generally with relatively greater concentrations also encountered close to the bed.
- SSC will naturally vary with height in the water column. Sediment is naturally re-suspended by the action of currents and waves at the seabed and so SSC is naturally highest near to the seabed (potentially up to hundreds or thousands of mg/l during larger storm events). Once resuspended, sediment naturally settles downwards under gravity but is also re-suspended upwards by turbulence which is again greater nearer the seabed. This results in a non-linear (power-law) profile of SSC (i.e., rapidly decreasing with height above the seabed).
- Seabed sediments within and nearby to the Rampion 2 offshore array area and offshore export cable corridor are typically characterised by the presence of fine to coarse sands and gravels in varying proportion. A small proportion of fines (typically less than 5%) may be locally present in some areas.
- Extensive areas of Cretaceous chalk are covered by varying thicknesses of Tertiary marine sediments and Holocene sediments. The thickness of seabed surficial sediment cover is highly variable. Only a thin veneer (less than 0.5m) of sediment is present overlying chalk in most of the offshore export cable corridor and offshore array area. In the offshore array area, mobile sediment is present in greater thickness (several metres up to tens of metres), with mobile bedform features present.

2.3 Assessment methodology

2.3.1 Sediment disturbed and released into the water column during construction will settle downwards at a rate depending upon its grain size. During settling, the sediment plume will be advected away from the point of release by any currents that are present and will be dispersed laterally by turbulent diffusion. The horizontal advection distance will be related to the flow speed and the physical properties of the sediment. The maximum near-bed level of SSC is expected to be found where the main body of the settling plume of sediment reaches the seabed.

2.3.2 Coarse grained (for example sand and gravel) sediments will behave differently to fine grained (for example silt and clay) sediments when released into the water column. The disturbance of coarse grained or consolidated material is likely to give rise to high SSCs in the vicinity of the release location but is also likely to settle out of suspension quickly (in the order of seconds to minutes) so any sediment plumes are likely to be localised. In contrast, fine grained material will tend to remain in suspension for a longer period of time (in the order of hours to days), potentially resulting in an increase in SSC over a larger area, at a progressively reduced concentration, due to advection and dispersion from the original release location.

2.3.3 Similar differences are expected when considering any resulting changes in bed level due to resettlement of the material in suspension. Coarser material will tend to give rise to thicker but more localised changes in bed levels, whereas fine grained material may give rise to smaller changes in bed levels over a wider area. The exact pattern of sediment re-deposition to the seabed will depend on the actual combination of operational methods and environmental conditions at the time of the event which will be variable. The total volume of sediment disturbed is, however, known with greater certainty and a range of potential combinations of deposit shape, thickness and area (corresponding to the same total volume) can be more reliably provided, as a subset of all possible combinations.

2.3.4 In order to inform the assessment of potential changes to SSC and bed levels arising from construction related activities, a number of spreadsheet based numerical models have been developed for use. Similar models were developed and successfully used by ABPmer to inform the environmental impact assessments for similar activities at Burbo Bank Extension, Walney Extension, Navitus Bay, Thanet Extension and Hornsea Three offshore wind farms (DONG Energy, 2013a; 2013b; Navitus Bay Development Ltd, 2014; Vattenfall, 2018; and Ørsted, 2018, respectively). The spreadsheet based numerical models used here are based upon the following information, assumptions and principles.

- Re-suspended coarser sediments (sands and gravels) will settle relatively rapidly to the seabed and their dispersion can therefore be considered on the basis of a ‘snapshot’ of the ambient conditions which are unlikely to vary greatly between the times of sediment release and settlement to the seabed. Re-suspended finer sediments may persist in the water column for hours or longer and so their dispersion is considered instead according to the longer-term residual tidal current drift rate and direction, which vary both temporally and spatially in speed and direction.
- A representative current speed for the Rampion 2 offshore array area is 0.5m/s, which is representative of mid to higher tidal flow conditions occurring on most flood and ebb cycles for a range of spring and neap conditions. Assuming a higher value will increase dispersion, decrease SSC and reduce the thickness of subsequent deposits and vice versa.
- Lateral dispersion of SSC in the plume is controlled by the eddy diffusivity of sediment. The horizontal eddy dispersion coefficient, Ke, estimated as $Ke = \kappa u^* z$ (Soulsby, 1997), where z is the height above the seabed (a representative value of half the water depth is used), κ is the von Kármán coefficient ($\kappa = 0.4$) and u* is the friction velocity ($u^* = \sqrt{(\tau/\rho)}$). Where ρ is the density of seawater ($\rho = 1027kg/m^3$) and τ is the bed shear stress, calculated using the quadratic stress law ($\tau = \rho\ Cd\ U^2$, Soulsby, 1997) using a representative current speed for Rampion 2 ($U = 0.5m/s$) and a drag coefficient value for a rippled sandy seabed ($Cd = 0.006$).
- The interpreted geophysical data and sediment grab samples from within the proposed DCO Order Limits indicate that the seabed sediments are predominantly a mixture of sands and gravels in varying proportion. A small

proportion of fines (typically less than 5% muds and silts) may also be present in some locations. The distribution of seabed sediments is illustrated in **Figure 6.1.18** of **Appendix 6.1: Coastal processes technical report: Baseline description, Volume 4** of the ES (Document Reference: 6.4.6.1)).

- To estimate the time-scale in suspension, sediment is assumed to settle downwards at a calculated (theoretical) settling velocity for each grain size fraction (0.0001m/s for fines, 0.05m/s for (medium) sands and 0.5m/s for gravels and generally coarser sediments, including clastic drill arisings; the representative value for fines is at the lower end of the realistic range and provides an estimate of the longest likely duration and greatest spatial extent of any plume effects).

2.3.5 The numerical model for SSC resulting from the release of sands and gravels is constructed as follows.

- The time required for sediment to settle at the identified settling velocity through a representative range of total water depths is calculated, to yield the duration for settlement.
- The horizontal distance downstream that the plume is advected is found as the product of the representative ambient current speed and the duration for settlement.
- The horizontal footprint area of the plume at different water depths is calculated from the initial dispersion area, increasing at the horizontal dispersion rate over the elapsed time for the plume to reach that depth.
- The estimate of SSC at different elevations is found by dividing the sediment mass in suspension at a given water depth (the product of the sediment release rate and the duration of the impact, divided by the water depth) by the representative plume volume at that depth (horizontal footprint area at that depth times 1m).

2.3.6 The numerical model for sediment deposition thickness resulting from the release of sands and gravels is constructed as follows:

- The area over which sediment is deposited depends on the lateral spreading of the sediment plume footprint with depth, but also with tidal variation in current speed and direction, including the possibility of flow reversal. This is an important factor if the release occurs for more than tens of minutes as it affects the distance and direction which the plume is advected from the source.
- The width of the footprint of (instantaneous) deposition onto the seabed is estimated as the square root of the near-bed plume footprint area (calculated using the model for SSC above). For monopile foundations, the point of sediment release is likely to be static and so the width of deposition is characterised directly as the footprint of deposition. For jacket foundations, the point of sediment release is likely to move within an area equivalent to the size of the foundation or dredged area, in which case the overall width of deposition is characterised as the footprint of deposition plus the diameter of the suction bucket foundation.

- The length of the footprint of deposition onto the seabed over multiple tidal cycles is estimated as twice the advected distance of the plume at the representative current speed, representing the maximum length over consecutive flood and ebb tides. If the operation lasts less than 12.4 hours (one full tidal cycle), the length is reduced proportionally.
- The average seabed deposition thickness is calculated as the total volume of sediment released, divided by the footprint area (width times length) of deposition.
- This model provides an appropriately conservative estimate of deposition thickness as it assumes that the whole sediment volume is deposited locally in a relatively narrow corridor. In practice, the deposition footprint on the seabed will probably be normally wider and frequently longer than is assumed, and the proportion of all sediment deposited locally will vary with the distribution in grain size (leading to a greater area but a correspondingly smaller average thickness).

2.3.7 The numerical model for SSC resulting from dispersion of fine sediment is constructed as per the following example.

- The vessel is likely to be stationary during precision dredging operations so the water movement relative to the vessel is dominantly tidal (at the representative current speed 0.5m/s).
- Sediment is discharged at a representative rate (e.g., 30kg/s for dredging over-spill) into a minimum volume of water 100m^3 = 10m x 10m x 1m deep.
- This volume of water will be refreshed every 20 seconds (10m/0.5m/s).
- The total sediment input is 20s x 30kg/s = 600kg.
- The resulting initial concentration in the receiving water is 600kg/100m^3 = 6kg/m^3 = 6,000mg/l.
- The initial concentration will then be subject to turbulent dispersion both laterally and vertically. Given the starting mass of sediment and water volume above, levels of SSC will vary rapidly in proportion to the dilution of the same sediment mass as the plume dimensions and volume increase.
- Assuming a faster current speed, faster vessel motion or larger footprint of release will reduce the mass of sediment introduced to the fixed volume of the receiving waters (and so SSC) at the point of initial dispersion, and *vice versa*.

2.4 Drilling of monopile foundations and pin piles for jacket foundations

Overview

2.4.1 Monopile foundations and pin piles for jacket foundations will be installed into the seabed using standard piling techniques. In some locations, the particular geology may present some obstacle to piling, in which case, some or all of the seabed material might be drilled from within the pile footprint to assist in the piling process.

2.4.2 The impact of drilling operations mainly relates to the release of drilling spoil at or above the water surface which will put sediment into suspension and the subsequent re-deposition of that material to the seabed. The nature of this disturbance will be determined by the rate and total volume of material to be drilled, the seabed and subsoil material type, and the drilling method (affecting the texture and grain size distribution of the drill spoil). These changes are quantitatively characterised in this section using the spreadsheet based numerical models described in **Section 2.3: Assessment methodology**.

Evidence base

2.4.3 The evidence-base does not presently include many measurements of SSC resulting from drilling operations for monopile or pin pile installation. This is due to the relatively small number of occasions that such works have been necessary.

2.4.4 Limited evidence from the field is provided by the during- and post-construction monitoring of monopile installation using drill-drive methods into chalk at the Lynn and Inner Dowsing offshore wind farms (CREL, 2008). Although chalk is also present in the Rampion 2 offshore array area, it is recognised that the geological properties of the chalk, the foundation dimensions and drilling apparatus will differ to some degree. In the Rampion 2 offshore array area, it is also not yet known how the drilled sub-soils will disaggregate as a result of the final chosen tools and method for drilling if and where needed. All of the above factors limit the extent to which the Lynn and Inner Dowsing monitoring evidence can be considered to be indicative of the proposed construction activities for Rampion 2.

2.4.5 The installation of steel monopiles (4.7m diameter and up to 20m penetration depth) was assisted in some cases by a drill-drive methodology. The drill arisings were mainly in the form of rock (chalk) chippings that were released onto the seabed a short distance away in a controlled manner using a pumped riser. The particular concern in that case was the possibility of sub-surface chalk arisings leading to high levels of SSC of an atypical sediment type. The result of sediment trap monitoring (located as close as 100m from the operation) was that the chalk was not observed to collect in significant quantities. However, direct measurements of SSC were not possible at the time of the operation.

2.4.6 The dimensions of the chalk drill arisings deposit created was measured by geophysical survey and characterised as a conical mound, approximately 3m thick at the peak, extending laterally (from the peak to ambient bed level) up to 10m in what is assumed the downstream direction and 5m in the other. The volume of the deposit (measured as approximately 290m^3) was similar to the total volume of the drilled hole (347m^3) indicating that the majority of the total drill arisings volume had been deposited locally. The difference in volumes might be partially explained by different patterns of settling or transport leading to some material settling away from the main deposit location. It is also possible that the combination of drill and drive did not necessarily release a volume of material equivalent to 100% of the internal volume of the pile, or that the full burial depth may not have been achieved in this example. Seabed photographs indicate that the material in the deposit is clearly horizontally graded, with the largest clasts closer to the centroid of the deposit.

Assessment of change

2.4.7 The greatest SSC and thickness of sediment deposition associated with drilling activities is associated with Wind Turbine Generator (WTG) monopile installation. The single foundation Maximum Design Scenario (MDS) occurs as a result of fully drilling (100% of the volume of) a single monopile foundation for a larger WTG type, (13.5m drill diameter, 60m average depth, drilling rate 5m/hour). For the offshore array area as a whole, the MDS is represented by fully drilling (100% of the volume of) up to 50% of 65 monopile foundations for a larger WTG type, (13.5m drill diameter, 60m average depth, drilling rate 5m/hour, 1,130m minimum spacing), and up to three jacket foundations on pin piles for offshore substations (OSSs ,12 pin piles, 4.5m drill diameter, 60m average depth, drilling rate 5m/hour.

2.4.8 The distribution of grain/clast sizes in the drill arisings for individual WTG foundations is not known in advance, so results are provided separately for scenarios where 100% of the material is assumed to be either fines, (medium) sand or (coarse) gravel sized. In practice, depending on the actual ground conditions and drilling tools used, the distribution of grain/clast size in the spoil will be some variable mixture of these with a corresponding intermediate duration, extent and magnitude of change. The drilled subsoils may include variable lengths of quartz and clay mineral sediments, and carbonate (chalk) sediments.

Maximum design scenario

2.4.9 The MDS for sediment release by drilling activities is summarised in **Table 2-1**for WTG monopile foundations and in **Table 2-2** for OSS jacket foundations.

Table 2-1 Maximum design scenario for sediment release by drilling WTG monopiles

Parameter	Maximum Design Scenario[1]	Working and other assumptions
Maximum number of WTG monopiles to be drilled	33 WTG monopiles	Up to 50% of 65 WTG monopiles may be drilled to an average depth of 60m
Maximum drill diameter used for (larger WTG type) WTG monopile	13.5m	100% of the monopile internal area will be drilled
Total volume of drill arisings from one (larger WTG type) WTG monopile	8,588m³	13.5m drill diameter, 60m depth
Total volume of drill arisings for whole array (50% of array of 65 = 33 x	283,415m³	8,588m³ x 33 WTG foundations

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[1] Derivative values (e.g., area, volume, mass, etc.) are calculated with full precision from the basic design dimensions but are presented as rounded values in this table.

Parameter	Maximum Design Scenario[1]	Working and other assumptions
larger WTG type) WTG monopiles		
Sediment mineral density	2,650kg/m³	Assumed value for quartz sand (Soulsby, 1997). (In comparison, the mean density of chalk is 1,790kg.m^3).
Total mass of drill arisings from one (larger WTG type) WTG monopile	22,759,072kg	8,588m³ x 2,650kg/m³ Assuming the drilled material is fully consolidated with minimal voids. (The same volume of chalk would yield a smaller mass).
Total mass of drill arisings from all (50% of array of 65 = 33 x larger WTG type) WTG monopiles	751,049,364kg	283,415m³ x 2,650kg/m³ Assuming the drilled material is fully consolidated with minimal voids
Drilling rate	5m/hour	12 hours to drill 1 monopile (60m divided by 5m/hour)
Maximum sediment release rate whilst drilling	527kg/s	13.5m diameter, 5m/hour = 716m³/hr = 0.20m³/s x 2,650kg/m³ Assuming the drilled material is fully consolidated with minimal voids. (Chalk would yield a smaller release rate).
Consolidated packing density	0.6	Assumed value for a typical, medium sorted sand (Soulsby, 1997). (Chalk granules would consolidate in a similar manner).
Total (consolidated) volume of drill arisings from one (larger WTG type) WTG monopile	14,314m³	8,588m³ divided by 0.6.
Total (consolidated) volume of drill arisings from all (50% of array of 65 = 33 x larger WTG type) WTG monopiles	472,358m³	283,415m³ divided by 0.6
Area over which sediment is released at or above the	143m²	Assumed value – that sediment is released at or above the water surface in an area approximately

Parameter	Maximum Design Scenario[1]	Working and other assumptions
water surface (larger WTG type monopiles)		equal to the area of the drilled hole (13.5m diameter). Using a larger value will increase initial dispersion, decrease SSC and reduce the thickness of subsequent deposits and *vice versa*.

Table 2-2 Maximum design scenario for sediment release by drilling OSS jacket pin piles

Parameter	Maximum Design Scenario[2]	Working and other assumptions
Maximum number of OSS pin piles to be drilled	36 pin piles	3 OSSs 12 pin piles per OSS Average depth penetration depth of 60m
Maximum drill diameter used for pin pile installation	4.5m	100% of the pin pile internal area will be drilled
Total volume of drill arisings	954m^3 per pin pile 11,451m^3 per OSS 34,353m^3 all OSSs	4.5m drill diameter, 60m depth, 12 pin piles, 3 OSSs
Sediment mineral density	2,650kg/m^3	Assumed value for quartz sand (Soulsby, 1997). (In comparison, the mean density of chalk is 1,790kg.m^3).
Total mass of drill arisings from one pin pile	2,528,786kg	954m^3 x 2,650kg/m^3 Assuming the drilled material is fully consolidated with minimal voids. (The same volume of chalk would yield a smaller mass).
Drilling rate	5m/hour	12 hours to install 1 pin pile (60m divided by 5m/hour)
Maximum sediment release rate whilst drilling	58.5kg/s	4.5m diameter, 5m/hour = 80m^3/hr = 0.022m^3/s x 2,650kg/m^3 Assuming the drilled material is fully consolidated with minimal voids. (Chalk would yield a smaller release rate).

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[2] Derivative values (e.g., area, volume, mass, etc.) are calculated with full precision from the basic design dimensions but are presented as rounded values in this table.

Parameter	Maximum Design Scenario[2]	Working and other assumptions
Consolidated packing density	0.6	Assumed value for a typical, medium sorted sand (Soulsby, 1997). (Chalk granules would consolidate in a similar manner).
Total (consolidated) volume of drill arisings from one pin pile	1,590m^3 per pin pile 19,085m^3 per OSS 57,256m^3 all OSSs	954m^3 divided by 0.6 11,451m^3 divided by 0.6 34,353m^3 divided by 0.6
Area over which sediment is released at or above the water surface	20m^2	Assumed value – that sediment is released at or above the water surface in an area approximately 5m diameter. Using a larger value will increase initial dispersion, decrease SSC and reduce the thickness of subsequent deposits and *vice versa*.

Release of fines by drilling

2.4.10 Levels of SSC resulting from drilling of the different foundation types (with different rates of release) assuming 100% of the drill arisings are fines (including fluidised clay minerals or chalk) are shown in **Table 2-3** for the following range of dispersion scenarios:

- source concentration at the point of release (total mass evenly dispersed in a volume of water 10m wide, 10m length, 1m depth).
- vertical diffusion to 5m, 20m lateral spread in footprint dimensions (representative of approximately 30 seconds to one minute after release, 15 to 30m downstream).
- vertical diffusion to 15m (from surface to approximately half water depth), 50m lateral spread in footprint dimensions (five to ten minutes after release, 150m to 300m downstream).
- vertical diffusion to 30m (thus affecting the seabed in parts of the offshore array area with intermediate depth), 100m lateral spread in footprint dimensions (30 minutes after release, 900m downstream).

2.4.11 The approximate timeframe and distance downstream from the release point for each dispersion scenario is indicated, based on the representative rates of settling, lateral dispersion and current speeds previously described in **Section 2.3**.

Table 2-3 Suspended sediment concentration as a result of drilling 100% of the volume of one larger WTG type monopile foundation (100% drill arisings as fines)

Plume width (m)	Plume depth (m)	Plume section length (m)	Resulting SSC (mg/l)
10	1	10	105,366
20	5	10	10,537
50	15	10	1,405
100	30	10	351

* Inputs and assumptions: Rate of sediment release = 527kg/s; Total mass released into receiving water until refreshed = 10,537kg; Representative current speed = 0.5m/s.

2.4.12 The average thickness of fine sediment deposits resulting from drilling is realistically expected to be very small (less than millimetres locally, not measurable in practice) due to the expected wide dispersion and dilution of fine material over the longer timescales required for resettlement. Fines are expected to fully disperse to background turbidity concentrations within days of release and so will not result in any greater rate, type or thickness of accretion of fines than would be occurring naturally at any given location.

Release of sands and gravels by drilling

2.4.13 Levels of SSC and the estimated area and average thickness of sediment thickness resulting from drilling assuming 100% of the drill arisings are sands or gravels (including quartz mineral grains or chalk clasts) are shown in **Table 2-4** and **Table 2-5**, respectively, for a single larger WTG type monopile foundation.

Table 2-4 Suspended sediment concentration and sediment deposition as a result of drilling 100% of the volume of one larger WTG type monopile foundation (100% drill arisings as sand, settling rate 0.05m/s)

Water Depth (m)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)	Area of Seabed Deposition (m²)	Average Thickness of Seabed Deposition (m)*
13	260	130	136,976	3,406	4.20
30	600	300	316,098	14,776	0.97
45	900	450	474,147	31,315	0.46
65	1,300	650	684,879	62,859	0.23

* It is not realistically expected that deposits of thicknesses greater than 5 to 10m will be allowed to accumulate in practice (controlled by the applicable drilling activity protocols).

Water Depth (m)	Diameter of Midwater SSC Influence (m)	Area of Midwater SSC Influence (m²)	Midwater Average SSC (mg/l)	Diameter of Near-Bed SSC Influence (m)	Area of Near-Bed SSC Influence (m²)	Near-Bed Average SSC (mg/l)
13	12	118	89,165	15	183	57,490
30	22	372	28,312	29	648	16,272
45	30	714	14,756	41	1,293	8,151
65	41	1,342	7,853	56	2,497	4,221

Table 2-5 Suspended sediment concentration and sediment deposition as a result of drilling 100% of the volume of one larger WTG type monopile foundation (100% drill arisings as gravel, settling rate 0.5m/s)

Water Depth (m)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)	Area of Seabed Deposition* (m²)	Maximum (and Average) Thickness of Seabed Deposition (m)*
13	26	13	13,698	4,294	10 (3.3)
30	60	30	31,610	4,294	10 (3.3)
45	90	45	47,415	4,294	10 (3.3)
65	130	65	68,488	4,294	10 (3.3)

* Gravel and larger clasts will settle rapidly to the seabed and so have the potential to form concentrated local cone shaped deposits in excess of 10m high. It is not realistically expected that cone deposits of greater thicknesses (more than 5 to 10m) will be allowed to accumulate in practice (controlled by the applicable drilling activity protocols). The predicted area and thickness are based on a conical deposit of 14,314m^3 unconsolidated drill arisings, limited to 10m high at the central peak. Other possible scenarios are provided in **Table 2-6**.

Water Depth (m)	Diameter of Midwater SSC Influence (m)	Area of Midwater SSC Influence (m²)	Midwater Average SSC (mg/l)	Diameter of Near-Bed SSC Influence (m)	Area of Near-Bed SSC Influence (m²)	Near-Bed Average SSC (mg/l)
13	7	42	25,190	8	53	19,713
30	10	83	12,639	12	123	8,587
45	13	132	7,995	16	207	5,081
65	16	214	4,934	21	355	2,972

2.4.14 Estimates of the area and average thickness of sediment deposition are provided in the preceding tables based on the approximate footprint of the plume and tidal advection factors. The extent, thickness and shape of sediment deposits on the seabed will be highly variable in practice. However, given the total volume of sediment, a range of potential alternative combinations can be calculated. For a given volume of sediment, a smaller area of extent will correspond to a greater thickness of accumulation, and *vice versa*. A steeper sided cone shape deposit will have a greater thickness and a smaller area of change than a less steep sided cone or flat deposit shape. A range of possible value combinations are provided in **Table 2-6** for the larger WTG type foundation. The table demonstrates the changing spatial scale of the impact between two end members of: (i) maximum possible thickness (although also the smallest footprint or extent of impact); and (ii) the most extensive accumulation (to a smallest thickness of 0.05m).

2.4.15 More concentrated and localised deposits (associated with coarse gravels and large clastic materials) are assumed to deposit naturally into a cone shape where the maximum thickness is in the centre of the deposit and decreases linearly to zero at the edges. Operationally, very thick deposits may affect safe navigation or other engineering considerations and so will not be planned or allowed to occur. The greatest possible thickness (at the central point of the cone, also corresponding to the smallest possible area) is associated with a cone that has the steepest possible slope angle (the angle of repose for such loose sediments is 32 degrees). The height of cones with two and three times the extent of the steepest cone is provided for comparison. The largest possible areas impacted by uniformly distributed thicknesses of 0.5m, 0.3m and 0.05m (more likely associated with sand sized material) are also provided (making no assumptions regarding the shape of the area).

Table 2-6 Example range of potential extents and thicknesses of sediment deposition as a result of drilling 100% of the volume of one larger WTG type monopile foundation (100% drill arisings as sands or gravels)

Foundation Type/ Operation	Deposition Scenario	Nominal Diameter of Deposit (m)	Thickness of Deposit (m)*
Drilling of largest monopile (larger WTG type) (8,588m³ drill arisings per foundation; equivalent volume when deposited at seabed = 14,313m³ (based on a packing density of 0.6)).	Cone	74	10
	Cone	112	4.4
	Cone	168	1.9
	Uniform thickness	191	0.5
	Uniform thickness	246	0.3
	Uniform thickness	604	0.05

* Height of peak for cones and average uniform thickness. The dimensions of the steepest cone are provided here to indicate the smallest possible area that could be impacted. It is not realistically expected that cone deposits of greater thicknesses (more than 5 to 10m) will be allowed to accumulate in practice (controlled by the applicable dredging activity protocols). All value pairs are part of a continuous scale of possible outcomes.

Summary of results

Summary of potential SSC effects from drilling

2.4.16 The following summary observations, based on the spreadsheet based numerical model results set out in **Table 2-3** to **Table 2-6**, are consistent with similarly modelled patterns of change in assessments for other wind farms including that for Rampion 1 (E.ON Climate and Renewables, 2012) and the wider monitoring evidence base.

2.4.17 Assuming that the drill cuttings include a mixture of sediment grain sizes, the overall spatial pattern of change due to drilling of a single monopile foundation is summarised as follows.

- SSC will be increased by tens to hundreds of thousands of mg/l at the point of sediment release (for a period of seconds to a few minutes), which is at or near the water surface.
- SSC of low tens of mg/l will be present in a narrow plume (tens to a few hundreds of metres wide, up to one tidal excursion in length (up to approximately 11 to 16km on spring tides and approximately 5 to 8km on neap tides) aligned to the west-southwest to east-northeast tidal stream downstream from the source.
- If drilling occurs over more than one flood or ebb tidal period, the plume feature may be present in both downstream and upstream directions.

- Outside of the area up to one tidal excursion upstream and downstream of the foundation location, SSC less than 10mg/l may occur more widely due to ongoing dispersion and dilution of material.
- Sufficiently fine sediment may persist in suspension for hours to days or longer but will become diluted to very low concentrations (less than 5mg/l indistinguishable from natural background levels and variability) within timescales of around one day.
- Over longer timescales, net displacement of any fine-grained material persisting in suspension will generally be in an approximate easterly direction across from the offshore array area in accordance with the direction of longer-term net tidal current drift in this area.
- The maximum concentration and dimensions of the plume described above are equally applicable for quartz, clay and carbonate (chalk) minerals. The particular proportions and grain size distribution of each mineral type will affect the nature of the plume within the envelope described (from 100% relatively coarse and/or fast settling, to 100% relatively fine and/or slow settling material). The presence of chalk in suspension may also be visually and chemically different to baseline conditions, which may be relevant to the assessment of impacts in other topics.

Summary of potential deposition effects from drilling

2.4.18 Sediment deposition as a result of drilling for a single foundation installation are characterised as follows.

- Deposits of mainly coarse grained and clastic sediment deposits will be concentrated within an area in the order of approximately 10 to 100m downstream and upstream, and a few tens of metres wide from individual foundations, with an average thickness in the order of one to ten metres (limited to realistically likely values).
- Deposits of mainly sandy sediment deposits will be concentrated within an area (depending on the local water depth and current conditions at the time) in the order of approximately 150m to 650m downstream/upstream and tens to 100m wide from individual foundations, with an average thickness in the approximate order of tens of centimetres to approximately one metre.
- Fine grained material will be dispersed widely within the surrounding region and will not settle with measurable thickness.
- The absolute width, length, shape and thickness of local sediment deposition as a result of drilling is estimated above. It cannot, however, be predicted with certainty due to the varying composition of the drill spoil, the local water depth and the ambient environmental conditions during the drilling activity. Other possible combinations of shape, area and thickness of sediment deposition are provided in **Table 2-6**.
- The maximum concentration and dimensions of deposits described above are equally applicable for quartz, clay and carbonate (chalk) minerals. The particular proportions and grain size distribution of each mineral type will affect the nature of the deposit within the envelope described (from 100% relatively

coarse and/or fast settling, to 100% relatively fine and/or slow settling material). The presence of chalk clasts on the seabed may also be visually and chemically different to baseline conditions, which may be relevant to the assessment of impacts in other topics.

2.4.19 The local patterns of change to SSC and sediment deposition are described above, as a result of drilling activities for individual foundations of any type. In the offshore array area, up to 33 (50% of 65) larger WTG type monopile foundations for WTGs may be installed using drilling, and up to three OSSs on jacket foundations may require drilling for up to all pin piles. The total sediment volume potentially released by drilling 50% of all WTG foundations has also been assessed with respect to the total potential extent and thickness of sediment deposition, as summarised below.

2.4.20 The actual shape, width, length and thickness of local or regional sediment deposition as a result of drilling cannot be predicted with certainty and is likely to vary according to the final distribution of foundations, the local nature of the drill spoil, the local water depth and the ambient environmental conditions during the drilling activity. However, the maximum total compacted sediment volume that could theoretically be released from drilling 50% of all WTG foundations (33 monopiles), and three OSS jacket with pin pile foundations, is 317,757m^3 and it is found that:

- If the total volume of drill arisings from all foundations was distributed equally over the combined offshore array area (195.5km^2), the average increase in bed elevation will be approximately 0.0027m (approximately 3mm) (assuming a packing density of the deposited material of 0.6 as outlined in **Table 2-1** and **Table 2-2**);
- If the total volume of drill arisings from all foundations was distributed equally over only the part(s) of the Western (116.4km^2) and/or Eastern (43.2km^2) offshore array areas within the proposed DCO Order Limits locally used for WTG foundations, the average increase in bed elevation will be approximately double the values above (up to approximately 0.006m or 6mm) (assuming a packing density of the deposited material of 0.6); and
- A maximum area equal to approximately 5.4% of the combined offshore array areas (or up to 12% of only the area of WTGs in the Western or Eastern offshore array area within the proposed DCO Order Limits) could potentially be covered by an average thickness of 0.05m (50mm) of material (assuming a packing density of the deposited material of 0.6).

Discussion of potential for in-combination effects on SSC and sediment deposition

2.4.21 If one activity (for example drilling) occurs simultaneously with other construction activities (for example dredging or trenching for cables) and these activities are sufficiently nearby and aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition.

2.4.22 The effect on SSC in areas of overlap will be additive if the downstream activity occurs within the area of effect from upstream (when additional sediment is disturbed within the sediment plume from another activity occurring at a location upstream). The effect on SSC will not be additive (the effects will be as described for single occurrences only) if the areas of effect only meet or overlap downstream following advection or dispersion of the effects.

2.4.23 Effects of sediment deposition will be additive if and where the footprints of two or more sand and or gravel deposits overlap. Fines are not expected to be deposited in measurable thickness at any location, either due to single activity or cumulative effects.

2.4.24 Given that the minimum spacing between the WTG foundations is 950 to 1,130m (for the smaller and larger WTG type options, respectively), it is unlikely that coarse sands or gravels put into suspension will be dispersed far enough (between adjacent foundation locations) to cause any overlapping effects before being redeposited to the seabed. Only relatively fine sediment is likely to be advected far enough to potentially cause overlapping effects on SCC.

2.5 Seabed preparation by dredging prior to foundation and cable installation

Overview

2.5.1 To provide a stable footing for jacket foundations, standard dredging techniques may be used to remove or lower the level of the mobile seabed sediment veneer within a footprint slightly larger than the foundation base. Dredging may also be used to reduce the level of sandwaves where they are present in the footprint of foundations and in a narrow corridor where they intersect array, interconnector and export cable routes in the offshore array area. There are no sandwaves present in the offshore export cable corridor as evidenced in **Section 4.2** of **Appendix 6.1: Coastal processes technical report: Baseline description, Volume 4** of the ES (Document Reference: 6.4.6.1).

2.5.2 Dredging has the potential to cause elevated SSC by, sediment over-spill at the water surface during dredging and by the subsequent release of the dredged material from the dredger during spoil disposal at a nearby location. The subsequent settlement of the sediment disturbed by dredging will lead to sediment accumulation of varying thickness and extent on the seabed. These changes are quantitatively characterised in this section using spreadsheet based numerical models.

Evidence base

2.5.3 The evidence-base with regards to dredging and elevated levels of SSC is broad and well established through a variety of monitoring and numerical modelling studies. The following text from the UK Marine SAC Project is representative of the wider evidence base.

> *"Dredging activities often generate no more increased suspended sediments than commercial shipping operations, bottom fishing or generated during severe storms (Parr et al., 1998). Furthermore, natural events such as storms, floods and large tides can increase suspended sediments over much larger areas, for longer periods than dredging operations (Environment*

> *Canada, 1994). It is therefore often very difficult to distinguish the environmental effects of dredging from those resulting from natural processes or normal navigation activities (Pennekamp et al., 1996).*
>
> *…In general, the effects of suspended sediments and turbidity are generally short term (<1 week after activity) and near-field (<1 km from activity). There generally only needs to be concern if sensitive species are located in the vicinity of the maintained channel."*

2.5.4 Dredging for construction aggregates is a common marine activity on the south coast of UK. The total mass of aggregate recovered from each region is reported annually by the British Marine Aggregate Producers Association. It is reported that, in 2020, approximately 7.25 million tonnes (3.4 million m^3) of construction aggregate were dredged from a total permitted licensed tonnage of approximately 17.5 million (8.3 million m^3) in the combined 'South Coast' and 'East English Channel' regions (within approximately 15 separate license area locations within the wider study area, from just west of the Isle of Wight, to Beachy Head).

2.5.5 In comparison, the total volume of sediment that could potentially be dredged for foundation preparation in the Rampion 2 offshore array area is 343,125m^3 (60 x 60 x 1m for 90 x smaller WTG type jacket foundations and 85 x 75 x 1m for three OSS jacket foundations) over the whole duration of the construction period (equivalent to approximately 10% of the annual volume of aggregate material actually extracted from licenced areas in the South Coast and East English Channel regions). The total volume of sediment that could potentially be dredged as part of sandwave clearance or levelling in the Rampion 2 offshore array area is up to 1,375,000m^3 (including up to 475,000m^3 for foundations and up to 900,000m^3 for cables) over the whole duration of the construction period (equivalent to approximately 40% of the annual volume of aggregate material actually extracted from licenced areas in the South Coast and East English Channel regions).

2.5.6 It is also noted that sediment dredged as part of construction activities for Rampion 2 will all be returned to the seabed nearby to the dredging location, whereas sediment dredged as part of aggregate extraction is removed permanently from the seabed.

Assessment of change

2.5.7 The greatest SSC and thickness of sediment deposition as a result of bed preparation by dredging for a single WTG foundation is assessed for the jacket foundation type (same dimensions for both smaller and larger WTG types, up to 30m base side length, dredging up to 15m beyond the footprint of the foundation, to a depth of 1m); up to 90 x smaller WTG type jacket foundations might be installed within the Rampion 2 offshore array area with a minimum spacing of 950m.

2.5.8 The distribution of grain/clast sizes in the dredging over-spill and spoil release plumes is not known in advance, so results are provided separately for scenarios where 100% of the material is assumed to be either fines, (medium) sand or (coarse) gravel sized. In practice, depending on the actual ground conditions and dredging vessel used, the distribution of grain/clast size in the over-spill and spoil will be a variable mixture of these with a corresponding intermediate duration, extent and magnitude of change.

Maximum design scenario

2.5.9 The maximum adverse scenario for sediment release by ground preparation dredging for a single jacket foundation is characterised in **Table 2-7**.

Table 2-7 Maximum design scenario for sediment release by ground preparation dredging for a single, and for all WTG jacket foundations

Parameter	Maximum Design Scenario[3]	Working and Other Assumptions
Number of WTG jacket foundations to be dredged	65 larger WTG 90 smaller WTG	The volume of sediment disturbed by ground preparation dredging for a single WTG foundation is the same for both the smaller and larger WTG jacket foundations Up to 90 smaller WTG type jacket foundations may be installed: this represents the maximum adverse scenario for the array area as a whole
Dredged area for one WTG jacket foundation (larger and smaller)	4,900m²	Maximum WTG jacket dimensions at the seabed 45 x 45m. Dredging to 70 x 70m = 4,900m²
Average depth of dredged area	1m	-
Total volume of sediment to dredge for one WTG jacket foundation (larger and smaller)	4,900m³	4,900m² x 1m depth
Total volume of sediment to dredge from sandwaves for all foundations and cables in the offshore array area	1,375,000m³	Including up to 475,000m³ for foundations and up to 900,000m³ for cables.
Sediment mineral density	2,650kg/m³	Assumed value for quartz sand (Soulsby, 1997)

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[3] Derivative values (e.g., area, volume, mass, etc.) are calculated with full precision from the basic design dimensions but are presented as rounded values in this table.

Parameter	Maximum Design Scenario[3]	Working and Other Assumptions
Consolidated packing density	0.6	Assumed value for a typical, medium sorted sand (Soulsby, 1997)
Total mass of sediment to dredge for one WTG jacket foundation	7,791,000kg	4,900m^3 x 2,650kg/m^3 x 0.6
Dredger hopper capacity	11,000m^3	The dredging will be undertaken by a trailing suction hopper dredger (TSHD) with an assumed representative hopper capacity of 11,000m^3
Equivalent number of dredging cycles to dredge one larger WTG jacket foundation	<1 (0.45) cycle	4,900m^3 divided by 11,000m^3
Dredger sediment over-spill release rate	30kg/s	Assumed value
Time to fill dredger	4 hours	Assumed value
Total mass of over-spilled sediment from dredging one larger WTG jacket foundation	192,436kg	30kg/s x 0.45 cycles x 4 hours x 60min/hour x 60s/min
Total (consolidated) volume of over-spilled sediment from dredging one WTG larger jacket foundation	121m^3	192,436kg divided by 2,650kg/m^3 divided by 0.6
Equivalent number of dredging cycles to dredge all 90 smaller WTG and three OSS jacket foundations	31.2 cycles	(324,000m^3 + 19,125m^3) divided by 11,000m^3
Equivalent number of dredging cycles to dredge sandwaves for all foundations and cables in the offshore array area	125 cycles	Up to 1,375,000m^3 divided by 11,000m^3. No sandwaves in the offshore export cable corridor.

Parameter	Maximum Design Scenario[3]	Working and Other Assumptions
Area over which sediment is released at the water surface	100m²	Assumed value – sediment over-spill is released at the water surface in an area approximately 10m x 10m = 100m². Using a larger value will increase initial dispersion, decrease SSC and reduce the thickness of subsequent deposits and vice versa

2.5.10 The maximum adverse scenario for sediment spoil disposal by the dredger is characterised as follows.

- Dredge spoil will be returned to the seabed by the dredger at a nearby location within the proposed DCO Order Limits.
- The dredging will be undertaken by a TSHD with a split bottom release (allowing the fastest possible release of all sediment in the hopper). It is assumed that the full representative hopper capacity of 11,000m³ is released.
- The majority of the sediment load (up to 90% based on monitoring evidence from the aggregate industry) will descend to the seabed as a single unit, behaving as a density flow. This downward movement of material is termed the ‘dynamic phase’ of the plume. The rate of descent of the dynamic phase through the water column is rapid (in the order of several metres per second) relative to the normal settling rate for the individual grains that comprise it. The remaining 10% of the sediment volume released will form a more dispersed plume throughout the water column, termed the ‘passive phase’, that will settle at approximately the rate of the individual grains.
- The rate of sediment release by over-spill during dredging is determined by the performance of the specific dredging vessel but is conservatively estimated to be 30 kg/s.
- Spoil will be disposed of at the end of each dredging cycle from the base of the dredging vessel at a nearby location within the Rampion 2 offshore array area. During disposal, up to 11,000m³ of material will be released from the bottom of the vessel in a sudden event; 90% of the material will be deposited directly to the bed as a single mass, and 10% of the material will be resuspended as a plume of elevated SSC.

Release of fines as overspill

2.5.11 Levels of SSC as a result of overspill during dredging for any purpose, assuming 100% of the overspill are fines, are shown in **Table 2-8** for the following range of dispersion scenarios.

- Source concentration at the point of release (total mass evenly dispersed in a volume of water 10m wide, 10m length, 1m depth).

- Vertical diffusion to 5m, 20m lateral spread in footprint dimensions (representative of approximately 30 seconds to 1 minute after release, 15 to 30m downstream).
- Vertical diffusion to 15m (from surface to approximately half water depth), 50m lateral spread in footprint dimensions (five to ten minutes after release, 150 to 300m downstream).
- Vertical diffusion to 30m (so affecting the seabed in locations with intermediate water depth), 100m lateral spread in footprint dimensions (30 minutes after release, 900m downstream).

2.5.12 The approximate timeframe and distance downstream from the point of release for each dispersion scenario is indicated, based on the representative rates of lateral dispersion and current speeds previously described in **Section 2.3**:

Table 2-8 Suspended sediment concentration as a result of overspill during dredging (100% overspill as fines)

Plume width (m)	Plume depth (m)	Plume section length (m)	Resulting SSC (mg/l)
10	1	10	6,000
20	5	10	600
50	15	10	80
100	30	10	20

* Inputs and assumptions: Rate of sediment release = 30kg/s; Total mass released into receiving water until refreshed = 600kg; Representative current speed = 0.5m/s

Release of sands and gravels as overspill

2.5.13 Levels of SSC and thickness of sediment deposition as a result of overspill during dredging one WTG jacket foundation, assuming 100% of the overspill is either sands or gravels, are shown in **Table 2-9** and **Table 2-10**, respectively. Results are likely to be similar or less for local sections and areas of sandwave clearance.

Table 2-9 Suspended sediment concentration and sediment deposition thickness as a result of overspill during dredging one larger WTG jacket foundation (100% overspill as sand, settling rate 0.05m/s)

Water Depth (m)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)	Area of Seabed Deposition (m^2)	Average Thickness of Seabed Deposition (m)*
13	260	130	7,800	2,972	0.04
30	600	300	18,000	7,885	0.02

Water Depth (m)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)	Area of Seabed Deposition (m²)	Average Thickness of Seabed Deposition (m)*
45	900	450	27,000	13,187	0.01
65	1,300	650	39,000	21,665	0.01

Water Depth (m)	Diameter of Midwater SSC Influence (m)	Area of Midwater SSC Influence (m²)	Midwater Average SSC (mg/l)	Diameter of Near-Bed SSC Influence (m)	Area of Near-Bed SSC Influence (m²)	Near-Bed Average SSC (mg/l)
13	8	47	12,666	11	91	6,579
30	17	234	2,562	24	460	1,303
45	26	517	1,161	36	1,022	587
65	37	1,065	563	52	2,114	284

Table 2-10 Suspended sediment concentration and sediment deposition thickness as a result of overspill during dredging one larger WTG jacket foundation (100% overspill as gravel, settling rate 0.5m/s)

Water Depth (m)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)	Area of Seabed Deposition (m²)	Average Thickness of Seabed Deposition (m)*
13	26	13	780	274	0.44
30	60	30	1,800	665	0.18
45	90	45	2,700	1,040	0.12
65	130	65	3,900	1,585	0.08

Water Depth (m)	Diameter of Midwater SSC Influence (m)	Area of Midwater SSC Influence (m²)	Midwater Average SSC (mg/l)	Diameter of Near-Bed SSC Influence (m)	Area of Near-Bed SSC Influence (m²)	Near-Bed Average SSC (mg/l)
13	3	6	9,760	4	11	5,434
30	6	26	2,269	8	50	1,194
45	8	56	1,069	12	108	553
65	12	113	532	17	220	272

Release of fines during spoil disposal

2.5.14 Levels of SSC in the passive phase of the plume created during dredge spoil disposal (full hopper), assuming 100% of the material is fines, is shown in **Table 2-11.**

Table 2-11 Suspended sediment concentration as a result of the dredge spoil disposal plume passive phase only (100% overspill as fines)

Plume width (m)	Plume depth (m)	Plume section length (m)	Resulting SSC (mg/l)
10	30	10	583,000
100	30	100	5,830
1000	30	1000	58
2000	30	2000	15

* Total mass fine sediment released into passive phase 1,749,000kg (10% x 11,000m³ x 2,650kg/m³ x 0.6 solidity); sediment released uniformly by the active phase during descent from surface to seabed (water depth 30m).

Release of sands and gravels during spoil disposal

2.5.15 Levels of SSC in the passive phase of the plume created during disposal of a full hopper of dredge spoil, assuming 100% of the material is sands or gravels, are shown in **Table 2-12** and **Table 2-13**, respectively; the resulting estimated area and average thickness of sediment deposition thickness is also provided.

Table 2-12 Suspended sediment concentration and sediment deposition thickness as a result of the dredge spoil disposal plume passive phase only (100% as sand, settling rate 0.05m/s)

Water Depth (m)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)	Area of Seabed Deposition (m²)	Average Thickness of Seabed Deposition (m)*
13	260	130	1,749,000	2,483	0.44
30	600	300	1,749,000	12,875	0.09
45	900	450	1,749,000	28,770	0.04
65	1,300	650	1,749,000	59,770	0.02

Water Depth (m)	Diameter of Midwater SSC Influence (m)	Area of Midwater SSC Influence (m²)	Midwater Average SSC (mg/l)	Diameter of Near-Bed SSC Influence (m)	Area of Near-Bed SSC Influence (m²)	Near-Bed Average SSC (mg/l)
13	8	47	2,840,157	11	91	1,475,189
30	17	234	248,937	24	460	126,607
45	26	517	75,204	36	1,022	38,035
65	37	1,065	25,256	52	2,114	12,729

Table 2-13 Suspended sediment concentration and sediment deposition thickness as a result of the dredge spoil disposal plume passive phase only (100% as gravel, settling rate 0.5m/s)

Water Depth (m)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)	Area of Seabed Deposition (m²)	Average Thickness of Seabed Deposition (m)*
13	26	13	1,749,000	86	12.73
30	60	30	1,749,000	425	2.59
45	90	45	1,749,000	937	1.17
65	130	65	1,749,000	1,929	0.57

Water Depth (m)	Diameter of Midwater SSC Influence (m)	Area of Midwater SSC Influence (m²)	Midwater Average SSC (mg/l)	Diameter of Near-Bed SSC Influence (m)	Area of Near-Bed SSC Influence (m²)	Near-Bed Average SSC (mg/l)
13	3	6	21,884,357	4	11	12,184,353
30	6	26	2,204,666	8	50	1,160,155
45	8	56	692,441	12	108	358,535
65	12	113	238,360	17	220	122,146

2.5.16 Estimates of the area and average thickness of sediment deposition are provided in the preceding tables based on the approximate footprint of the plume and tidal advection factors. The extent, thickness and shape of sediment deposits on the seabed will be highly variable in practice. However, given the total volume of sediment, a range of potential alternative combinations can be calculated. A range of alternative possible value combinations are provided in **Table 2-14** for dredging overspill and in **Table 2-15** for the active and passive phases of the dredge spoil disposal plume. For more details about the basis of these tables, see the previous assessment for drilling (**Section 2.4: Drilling of monopile foundations and pin piles for jacket foundations**).

Table 2-14 Example range of potential extents and thicknesses of sediment deposition as a result of overspill during dredging for foundation bed preparation

Foundation Type/ Operation	Deposition Scenario	Maximum Area of Influence (m²)*	Average Thickness of Deposit (m)**
Total dredging overspill for 90 smaller WTG jacket foundations (@89m³) and 3 x OSS jacket (@157m³)	Uniform thickness	16,950 (0.01%)	0.50
	Uniform thickness	28,250 (0.01%)	0.30
	Uniform thickness	169,503 (0.09%)	0.05

* Maximum total area at the specified average thickness of deposit as a result of dredging overspill for all foundations (and as a proportion of the whole Rampion 2 offshore array areas, 195.5km²).

** All value pairs are part of a continuous scale of possible outcomes.

Table 2-15 Alternative potential extents and thicknesses of sediment deposition as a result of all foundation bed preparation dredging spoil disposal (active and passive phases)

Foundation Type/ Operation	Deposition Scenario	Maximum Area of Influence (m^2)*	Average Thickness of Deposit (m)**
Spoil disposal from the dredger, 31.2 events for all foundations (9,900m³ in active phase, 90% of 11,000m³).	Cone***	59,945 (0.03%)	Steepest
	Cone***	293,781 (0.12%)	2 x radius
	Cone***	539,507 (0.28%)	3 x radius
	Uniform thickness	617,625 (0.32%)	0.50
	Uniform thickness	1,029,375 (0.53%)	0.30
	Uniform thickness	6,176,250 (3.16%)	0.05
Spoil disposal from the dredger, 31.2 events for all foundations (1,100m³ in passive phase, 10% of 11,000m³).	Uniform thickness	68,625 (0.04%)	0.50
	Uniform thickness	114,375 (0.06%)	0.30
	Uniform thickness	686,250 (0.35%)	0.05

* Total area as a result of dredging overspill for all foundations (and the area of influence of all foundations as a proportion of the whole Rampion 2 offshore array areas, 195.5km²).
** Height of peak for cones and average uniform thickness. The dimensions of the steepest cone are provided here to indicate the smallest possible area that could be impacted. It is not realistically expected that cone deposits of greater thicknesses (more than 5 to 10m) will be allowed to accumulate in practice (controlled by the applicable dredging protocols). All value pairs are part of a continuous scale of possible outcomes.
*** Cone shaped deposits are only likely to result from the larger single mass of the active phase; the passive phase is relatively more dispersed.

Table 2-16 Alternative potential extents and thicknesses of sediment deposition as a result of all sandwave clearance dredging spoil disposal (active and passive phases)

Foundation Type/ Operation	Deposition Scenario	Maximum Area of Influence (m^2)*	Average Thickness of Deposit (m)**
Spoil disposal from the dredger, 125 events for all cables and foundations (9,900m³ in active	Cone***	240,218 (0.12%)	Steepest
	Cone***	960,870 (0.49%)	2 x radius
	Cone***	2,161,958 (1.11%)	3 x radius
	Uniform thickness	2,475,000 (1.27%)	0.50

Foundation Type/ Operation	Deposition Scenario	Maximum Area of Influence (m^2)*	Average Thickness of Deposit (m)**
phase, 90% of 11,000m^3).	Uniform thickness	4,125,000 (2.11%)	0.30
	Uniform thickness	24,750,000 (12.66%)	0.05
Spoil disposal from the dredger, 125 events for all cables and foundations (1,100m^3 in passive phase, 10% of 11,000m^3).	Uniform thickness	275,000 (0.14%)	0.50
	Uniform thickness	458,333 (0.23%)	0.30
	Uniform thickness	2,750,000 (1.41%)	0.05

* Total area as a result of dredging overspill for all foundations (and the area of influence of all foundations as a proportion of the whole Rampion 2 offshore array areas, 195.5km^2).
** Height of peak for cones and average uniform thickness. The dimensions of the steepest cone are provided here to indicate the smallest possible area that could be impacted. It is not realistically expected that cone deposits of greater thicknesses (more than 5 to 10m) will be allowed to accumulate in practice (controlled by the applicable dredging protocols). All value pairs are part of a continuous scale of possible outcomes.
*** Cone shaped deposits are only likely to result from the larger single mass of the active phase; the passive phase is relatively more dispersed.

Summary of results

Summary of potential SSC effects from dredging

2.5.17 In summary, the influence of dredging overspill and spoil disposal on increasing SSC above ambient levels is characterised as follows.

- SSC levels will be highest (potentially tens to hundreds of thousands of mg/l) at the point of sediment release, which is at or near the water surface during dredging overspill and distributed through the whole water column during dredge spoil disposal. This feature will only be present during (the relatively longer) periods of active dredging or during (the relatively short) dredge spoil disposal events.
- For fine material in dredging overspill, SSC levels will decrease rapidly through vertical and horizontal dispersion to low tens of mg/l within the order of hundreds of metres from the point of release.
- For fine material released into the passive plume phase during dredge spoil disposal, SSC levels will be initially higher than for overspill (due to the sudden nature of the sediment release). SSC levels will decrease through horizontal dispersion to a few thousand mg/l within the order of low hundreds of metres and a few tens of mg/l within the order of one thousand metres distance from the source.

- For sand and gravel material in dredging overspill, local SSC levels will decrease to low thousands or hundreds of mg/l locally (low tens of mg/l in a depth mean sense) through horizontal dispersion whilst settling to the seabed.
- For sand and gravel material released into the passive plume phase during dredge spoil disposal, local SSC levels will decrease from hundreds to tens of thousands of mg/l due to horizontal dispersion whilst settling to the seabed.
- Sands will deposit to the seabed within the order of hundreds of metres from the source (taking in the order of 5 to 15 minutes to settle from surface to seabed), and gravels likewise within tens of metres (0.5 to 1.5 minutes). The horizontal diameter of the main sand or gravel plume footprint within the water column and on the seabed is likely to be in the order of only tens of metres.
- Following cessation of dredging or spoil release, the influence of sands or gravels on SSC levels will reduce rapidly as described above and will end when the sediment is redeposited to the seabed (in the order of 0.5 to 15 minutes, depending on the grain size and water depth).
- Once redeposited to the seabed, the locally dredged overspill and spoil material are essentially the same as the local sediment type. The dredged material will therefore immediately re-join the natural sedimentary environment and will not contribute further to elevated SSC above naturally occurring levels.

Summary of potential deposition effects from dredging

2.5.18 In summary, sediment deposition as a result of dredging for foundation and cable installation is characterised as follows.

- Deposits of mainly gravel sized dredge overspill will be concentrated within a relatively small area in the order of tens of metres from the location of dredging, with an average thickness in the order of less than ten centimetres.
- Deposits of mainly sand sized dredge overspill sediment will be concentrated within an area in the order of 150 to 500m downstream/upstream and approximately tens to one hundred metres wide from individual foundations, with an average thickness in the order of less than a few centimetres.
- Spoil disposal will form more concentrated sediment deposits on the seabed. The main mass of sediment (90% of the total volume, falling as the active phase of the plume) will initially result in discrete mounds of sediment in the order of tens to hundreds of metres in diameter (depending on the pattern of settlement) and tens of centimetres to a few metres in local thickness. An area equivalent to a circle of 502m in diameter might be covered to an average depth of 0.05m. Any larger area of change will correspond to a smaller average thickness. It is possible that consecutive disposal events may overlap on the seabed, resulting in a greater local thickness of sediment but a smaller overall area of influence.
- The smaller mass of material (10% of the total volume) falling as the passive phase of the spoil disposal plume will result in a narrow deposit downstream either hundreds of metres in length and a few centimetres or less thick (for sands), or, tens of metres in length and up to tens of centimetres to a few metres thick (for gravels).

- Fine grained material released as overspill or as the passive phase of spoil disposal will be dispersed widely within the surrounding region and will not settle locally with measurable thickness. Fine grained material in the active phase of spoil disposal will remain bound in the main sediment mass and will not be differently dispersed to that described above.
- The material being deposited will have a very similar grain size distribution, and so the nature of the deposited seabed surface will not be very different, to that of the surrounding seabed. Following deposition, the displaced sediment will immediately re-join the local sedimentary system and will be subject to sediment transport at the ambient rate and direction. Local accumulations will be eroded over time due to local sediment transport and the development and migration of bedforms.

2.5.19 The assessments undertaken and the summaries above describe the influence of conservatively marginal scenarios where the material being dredged or disposed is entirely fines, sands or gravels. Based on these marginal cases, the following summary describes the overall influence of the same activities assuming that a mixture of sediment grain sizes is present:

- SSC of low tens of mg/l will be present in a narrow plume (tens to a few hundreds of metres wide, up to one tidal excursion in length (up to approximately 13km on spring tides and 7km on neap tides) aligned to the tidal stream downstream from the source.
- If dredging occurs over more than one flood or ebb tidal period, the plume feature may be present in both downstream and upstream directions.
- Outside of the area up to one tidal excursion upstream and downstream of the foundation location, SSC less than 10mg/l may occur more widely due to ongoing dispersion and dilution of material.
- The majority of gravel and sand sized sediment will be deposited to the seabed within tens to hundreds of metres from the source, respectively. A larger proportion of such material in the plume may result in SSC reducing more rapidly in this region and reducing the length or extent of the plume feature overall.
- Sufficiently fine sediment may persist in suspension for hours to days or longer but will become diluted to very low concentrations (indistinguishable from natural background levels and variability) within timescales of around one day.

Discussion of potential for in-combination effects on SSC and sediment deposition

2.5.20 If dredging, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC has previously been discussed in **Section 2.5: Seabed preparation by dredging prior to foundation and cable installations**.

2.6 Cable burial

Overview

2.6.1 The impact of cable burial operations mainly relates to a localised and temporary re-suspension and subsequent settling of sediments (BERR, 2008). The exact nature of this disturbance will be determined by the soil conditions within the Rampion 2 offshore array area and offshore cable corridor, the length of installed cable, the burial depth and burial method. These changes are quantitatively characterised in this section for export, array and substation interconnector cables using spreadsheet based numerical models.

2.6.2 The impact of dredging sandwaves as part of cable burial is assessed in **Section 2.5**. There are no sandwaves present in the offshore export cable corridor as evidenced in **Section 4.2 of Appendix 6.1: Coastal processed technical report: Baseline description, Volume 4** of the ES (Document Reference: 6.4.6.1).

Evidence base

2.6.3 The evidence base with respect to cable burial activities is broad and includes a range of theoretical, numerical modelling and monitoring studies considering a range of installation methodologies, sediment types, water depths and other environmental conditions. The evidence base is widely applicable as the dimensions of the cables, the installation techniques used and the target depths of burial do not vary significantly with the scale of the development (small or large wind farm arrays) or the type of cable being installed (wind farm export, array or inter-connector cables, or non-wind farm electrical and communications cables).

2.6.4 SSC monitoring during cable laying operations has been undertaken at Nysted Wind Farm (ABPmer et al., 2007; BERR, 2008). During the works, both jetting and trenching were used, where the latter method involves pre-trenching and back-filling using back-hoe dredgers. Superficial sediments within the site were predominantly medium sands, approximately 0.5m to 3m in thickness, underlain by clay. SSC was recorded at a distance of 200m from jetting and trenching activities and the following values were observed:

- trenching – mean (14mg/l) and max (75mg/l); and
- jetting – mean (2mg/l) and max (18mg/l).

2.6.5 The higher sediment concentrations from the trenching activities were considered to be a result of the larger volume of seabed strata disturbed during operations and the fact that the material disturbed during trenching was lifted to the surface for inspection. This meant that the sediment was transported through the full water column before being placed alongside the trench (BERR, 2008).

2.6.6 Cable laying monitoring also took place at Kentish Flats where ploughing methods were used to install three export cables (EMU Limited, 2005). Cefas agreed pre-defined threshold limits against which SSC monitoring would be compared. The monitoring 500m down-tide (where the concentrations would be greatest) of the cable laying activities showed:

- marginal, short-term increases in background levels (approximately nine times increase to the background concentrations); and
- peak concentrations occasionally reaching 140mg/l (equivalent to peaks in the naturally occurring background concentrations).

2.6.7 The observations at Nysted and Kentish Flats provide confidence that cable laying activities do not create a long-term, significant disruption to the background sediment concentrations. Furthermore, it also illustrates that there is little sediment dispersal, indicating that there is unlikely to be much deposition on the seabed other than immediately adjacent to the cable route.

2.6.8 Reach (2007) describes plume dispersion studies for a cable laying jetting operation in Hong Kong with an assumption that 20% of a trench cross-section of 1.75m^2 would be disturbed by the jetting process and the speed of the jetting machine would be 300m/hour (0.083m/s). ASA (2005) describes similar studies for a cable laying operation near Cape Cod in the USA and assumed that 30% of a trench cross-section of 3m^2 would be disturbed by the jetting process and the speed of the jetting machine would be 91m/hour (0.025m/s). This latter study also assumed that any sand particles would quickly return to the bed and only the fine sediment particles (particles with a diameter less than 63µm) would form a plume in the water column.

2.6.9 SeaScape Energy (2008) describes cable installation plume dispersion monitoring studies carried out at the Burbo offshore wind farm in Liverpool Bay, UK.

- three export cables were installed to a target depth of approximately 3m by vertical injector ploughing while array cables were installed to a similar depth by jetting assisted ploughing.
- the monitoring demonstrated clearly that both cable installation techniques had only small scale impacts on localised SSC. Changes were measurable to a few hundreds of metres only and suspended sediment levels were not elevated more than five times background. Suspended sediment levels never approached the threshold level (3,000mg/l) agreed with regulatory authorities beforehand, even in very close proximity to the works (less than 50m).
- local changes in SSC over a relatively fine sediment seabed area (most likely to lead to plume impacts) was in the region of 250 to 300mg/l within 200m of the operation, falling to the measured baseline level (100mg/l) by 700m downstream. It is assumed, therefore, that coarser sediments were associated with even lower levels.

2.6.10 The post-burial impacts of cable burial on sandy seabed morphology were also considered by BERR (2008) with reference to a wide range of desktop and monitoring studies. The report concludes that impacts will also be limited in terms of both the thickness of re-deposited sediments and the potential for affecting the surficial sediment type:

> "*The low levels of sediment that are mobilised during cable laying mean that there will be only low levels of deposition around the cable route. The finer material will generally remain in suspension for longer but will settle and remobilise on each tide with no measurable material left in place. Coarser sediments are expected to settle within a few metres of the cable route and*

following disturbance is likely to recover rapidly, given similar communities in the vicinity." (BERR, 2008).

Assessment of change

Overview

2.6.11 Export, array and interconnector cables may be installed by burial into the seabed. The Rampion 2 offshore export cable corridor runs north from the central northern edge of the western offshore array area to a landfall at Climping. The routing of array cables and interconnector cables will be dependent on the final chosen layout of foundations and offshore substations.

Maximum Design Scenario

2.6.12 For Rampion 2, the maximum design scenario for sediment release caused by cable burial is characterised in **Table 2-17**. The potential effects of sediment release due to cable burial are typically localised to the cable route or the active cable burial location. As such, the maximum adverse scenario information mainly considers local trench dimensions and rates of sediment disturbance. The total volume of sediment disturbance is not relevant to the assessment and so is not presented here.

2.6.13 Jetting and mass flow excavation methods have the greatest potential to energetically fluidise and eject material from the trench into suspension. By contrast, the other cable installation techniques (e.g., ploughing or cutting) are expected to re-suspend a smaller amount of material into the water column. Due to spatial variation in the geotechnical properties of the underlying geology within this region, it is possible that a combination of techniques may be used.

Table 2-17 Maximum design scenario for sediment release by cable trenching

Parameter	Maximum Design Scenario[4]	Working and Other Assumptions
Number of export cables	4 export cables x 19km each in offshore cable corridor 2 interconnector cables, total 40km in the offshore array area	Maximum number of cables/trenches
Minimum spacing between pairs of export cables	120m	-

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[4] Derivative values (e.g. area, volume, mass, etc) are calculated with full precision from the basic design dimensions, but are presented as rounded values in this table.

Parameter	Maximum Design Scenario[4]	Working and Other Assumptions
Total length of all export cables	170km	((19km x 4 cables) + contingency + (40km interconnector cables)) + contingency
Maximum rate of cable burial	300m/hr	Maximum for jetting in soft soils. Same for all cable types.
Total length of all inter-array cables	250km in the offshore array area	The total length of inter-array cables will be installed as multiple shorter lengths (number, length and routes to be determined as part of the cable burial design plan)
Methods of cable burial	Jetting and mass flow excavation	See notes above about jetting and mass flow excavation in comparison to other possible tools and methods
Dimensions of cable trench	Up to 2m wide with a ‘U’ shaped profile. 1.5m deep in the offshore export cable corridor. 1.0m deep in the offshore array area.	Jetting might be used at any location but in practice will only be used where surficial sediments are suitable. Target burial depth will be confirmed by the cable burial design plan
Volume of sediment disturbed per metre progress using vertical injection	$3m^3$/m in the offshore export cable corridor. $2m^3$/m in the offshore array area.	2m x 1.5m in the offshore export cable corridor. 2m x 1.0m in the offshore array area. Assumes up to 100% of material is ejected from the trench. In practice, the bed may rather be liquified by the tool and a large proportion of the sediment volume may be retained as sediment cover within the trench.

2.6.14 The jetting process fluidises an area of sediment within the seabed through which the cable is inserted. By design, the process is intended to bury the cable and so only a minimal proportion of the fluidised sediment is expected be actually ejected from the trench in this case. The exact proportion ejected may vary. Values of 20 to 30% have been used in previous investigations of this type (ASA, 2005). For the purposes of this investigation, it is conservatively assumed that 100% of the disturbed material is ejected.

2.6.15 An assessment of potential changes to SSC and bed levels has been undertaken using the spreadsheet based numerical models introduced in **Section 2.3**. A conservative assumption has been made that sub-soil material with a different grain size distribution to surficial sediments may also be re-suspended.

2.6.16 Within the offshore array area and along the offshore cable corridor, the majority of disturbed surficial sediment will be sand and gravels. A relatively small proportion of fines (less than 63µm, typically less than 5% content) may be present in some locations. Disturbance of the underlying sub-soils (chalk for instance) may also increase the proportion of fine grained material resuspended, depending on the degree of disaggregation.

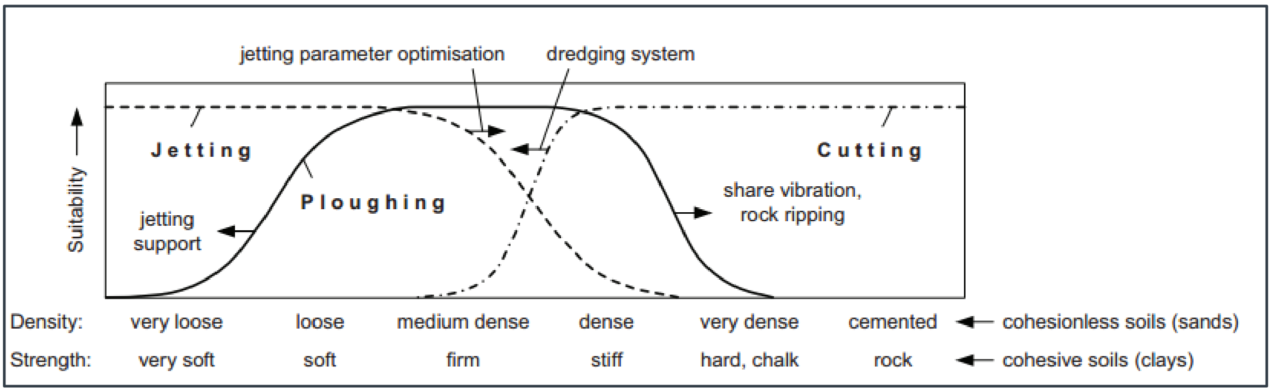
2.6.17 It is impractical to capture the full detail of sediment heterogeneity in detail within the context of this assessment, which instead considers a series of maximum adverse scenario 'end-member' scenarios. These are:

- jetting through 100% (coarse) gravel (15,000µm);
- jetting through 100% (medium) sand (375µm); and
- jetting through 100% (fine) silt (10µm).

2.6.18 These three scenarios represent the full potential range of change both in terms of the duration, spatial extent of changes to SSC, and maximum thicknesses of sediment deposition. In practice, a release comprising entirely fines is very unlikely.

2.6.19 Cable burial through the underlying sub-soils may result in the release of a range of sediment grain sizes, depending on the local nature of sub-soil and cable burial method used. In practice, these soil types are unlikely to disaggregate entirely into the finest possible constituent particle sizes due to the cable burial methods being assessed. This is particularly true for non-jetting installation methods such as ploughing which, given the density of the sub seabed sediment units along parts of the offshore export cable corridor, are more realistically expected to be used in these areas (DNV, 2014) (**Figure 2-1**). Also, even when fully disaggregated, the subcropping chalk present throughout the area will not necessarily disaggregate into 100% fine grained material. Ploughing will result in a much lower rate of sediment re-suspension, hence this method has not been explicitly assessed.

Figure 2-1 Indicative burial tool suitability in different ground conditions (DNV, 2014)



Cable burial

2.6.20 Results of the gravel release scenario assessment scenario outlined above is presented in **Table 2-18**.

2.6.21 Results of the sand and fines release scenario assessment scenario outlined above are presented in **Table 2-19**.

Table 2-18 Suspended sediment concentration and thickness of sediment deposition as a result of cable burial in 100% gravel (settling rate 0.5 m/s)

Representative Current Speed (m/s)	Height of Ejection Above Seabed (m)	Time for Resettlement (s)	Distance Plume Advected by Current (m)	Limited Length of Influence on SSC in Downstream Direction (m)	Limited Duration of Influence on SSC Locally (s)	Average SSC in the Limited Length/ Duration of Influence (mg/l)*	Average Thickness of Seabed Deposition (m)*
0.25	1	2	0.5	0.5	2.0	2,385,000	6.00
0.5	1	2	1.0	1.0	2.0	2,385,000	3.00
0.75	1	2	1.5	1.5	2.0	2,385,000	2.00
1	1	2	2.0	2.0	2.0	2,385,000	1.50
0.25	5	10	2.5	2.5	10.0	477,000	1.20
0.5	5	10	5.0	5.0	10.0	477,000	0.60
0.75	5	10	7.5	7.5	10.0	477,000	0.40
1	5	10	10.0	10.0	10.0	477,000	0.30
0.25	10	20	5.0	3.0	12.0	238,500	0.60
0.5	10	20	10.0	6.0	12.0	238,500	0.30
0.75	10	20	15.0	9.0	12.0	238,500	0.20
1	10	20	20.0	12.0	12.0	238,500	0.15

* Average thickness is based on the total volume of sediment released and the distance over which the plume is advected by the current; any resulting unrealistically high or steep deposits are expected to either be locally flattened by the trenching tool, or will slump locally under gravity to a stable shape. Each row of results is part of a continuous scale of possible outcomes.

Table 2-19 Suspended sediment concentration and thickness of sediment deposition as a result of cable burial in 100% sand (settling rate 0.05 m/s)

Representative Current Speed (m/s)	Height of Ejection Above Seabed (m)	Time for Resettlement (s)	Distance Plume Advected by Current (m)	Limited Length of Influence on SSC in Downstream Direction (m)	Limited Duration of Influence on SSC Locally (s)	Average SSC in the Limited Length/ Duration of Influence (mg/l)*	Average Thickness of Seabed Deposition (m)*
0.25	1	20	5.0	3.0	12.0	2,385,000	0.60
0.5	1	20	10.0	6.0	12.0	2,385,000	0.30
0.75	1	20	15.0	9.0	12.0	2,385,000	0.20
1	1	20	20.0	12.0	12.0	2,385,000	0.15
0.25	5	100	25.0	3.0	12.0	477,000	0.12
0.5	5	100	50.0	6.0	12.0	477,000	0.06
0.75	5	100	75.0	9.0	12.0	477,000	0.04
1	5	100	100.0	12.0	12.0	477,000	0.03
0.25	10	200	50.0	3.0	12.0	238,500	0.06
0.5	10	200	100.0	6.0	12.0	238,500	0.03

Representative Current Speed (m/s)	Height of Ejection Above Seabed (m)	Time for Resettlement (s)	Distance Plume Advected by Current (m)	Limited Length of Influence on SSC in Downstream Direction (m)	Limited Duration of Influence on SSC Locally (s)	Average SSC in the Limited Length/ Duration of Influence (mg/l)*	Average Thickness of Seabed Deposition (m)*
0.75	10	200	150.0	9.0	12.0	238,500	0.02
1	10	200	200.0	12.0	12.0	238,500	0.02

* Average thickness is based on the total volume of sediment released and the distance over which the plume is advected by the current. Each row of results is part of a continuous scale of possible outcomes.

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2.6.22 Results are presented for a range of representative current speeds, noting that cable burial will continue through all states of the tide, including current speeds lower than the highest locally possible (peak) value. Because of the uncertainty with regards to how high into the water column from the bed material may be ejected or re-suspended, results are provided for a realistic range of heights (one, five and ten metres). A greater height of ejection will lead to a potentially longer plume duration and a greater distance of influence, but also a corresponding reduction in SSC and deposition thickness. Because the cable burial tool moves relatively quickly (up to 300m/hr), any influence of the plume experienced downstream will be similarly limited in duration to approximately 12 seconds, after which time, the plume will have been advected downstream past the location of the receptor or will be instead affecting an area of seabed elsewhere.

2.6.23 Following the same principles, changes associated with cable burial into 100% fine grained sediment will be similar to that described for sand in **Table 2-19** for the predicated actual plume length in a downstream direction (3 to 12m), the duration of change to SSC locally (12 seconds) and the average level of SSC (hundreds of thousands of mg/l) will be the same for fines in areas near to active cable burial. Fine sediment may however persist in suspension for longer than sands (order of days) but the plume will be subject to significant dispersion in that time, reducing any change to SSC to tens of mg/l or less in the same timeframe. As a result of dispersion, no measurable thickness of deposit or accumulation of fine sediment is expected.

Summary of results

Summary of potential SSC and deposition effects from cable burial

2.6.24 The main findings of the assessment can be summarised as follows.

- Medium to coarse sand and gravels are likely to result in a temporally and spatially limited plume affecting SSC levels (and settling out of suspension) in close proximity to the point of release. SSC will be locally elevated within the plume close to active cable burial up to tens or hundreds of thousands of mg/l. However, the change will only be present for a very short time locally, in the order of seconds to tens of seconds for sand or gravel, before the material resettles to the seabed. Depending on the height to which the material is ejected and the current speed at the time of release, changes in SSC and deposition will be spatially limited to within metres (up to 20m) downstream of the cable for gravels and within tens of metres (up to a few hundred metres) for sands.
- Finer material will be advected away from the release location by the prevailing tidal current. High initial concentrations (similar to sands and gravels) are to be expected but will be subject to rapid dispersion, both laterally and vertically, to near-background levels (tens of mg/l) within hundreds to a few thousands of metres of the point of release. In practice, only a small proportion (typically less than 1 to 2%, occasionally up to 5%) of the material disturbed is expected to be fines, with a corresponding reduction in the expected levels of SSC.
- Irrespective of sediment type, the volumes of sediment being displaced and deposited locally are relatively limited (up to 3m³ per metre of cable burial)

which also limits the combinations of sediment deposition thickness and extent that might realistically occur. Fundamentally, the maximum distance from each metre of cable trench over which 3m³ of sediment can be spread to an average thickness of (for example) 0.05m is 60m (or to 0.15m is 20m); any larger distance will correspond to a smaller average thickness. The assessment suggests that the extent and so the area of deposition will normally be much smaller for sands and gravels (although leading to a greater average thickness of deposition in the order of tens of centimetres, up to around one metre) and that fine material will be distributed much more widely, becoming so dispersed that it is unlikely to settle in measurable thickness locally.

- The material being deposited will have a very similar grain size distribution, and so the nature of the deposited seabed surface will not be very different, to that of the surrounding seabed. Following deposition, the displaced sediment will immediately re-join the local sedimentary system and will be subsequently mobilised at the ambient rate and direction. Local accumulations will be eroded, and local depressions will be infilled over time due to local sediment transport and migration of bedforms.

Discussion of potential for in-combination effects on SSC and sediment deposition

2.6.25 If cable burial, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in **Section 2.4**.

2.7 Drilling fluid release during HDD at the landfall

Overview

2.7.1 HDD is the preferred option to transition the Rampion 2 export cable to the onshore grid at a landfall at Climping. The drill punch-out location will be around (at or below) the lowest astronomical tidal water level. The drill length may be up to approximately 1,000m, with a diameter of up to 0.63m for each of up to four HDD conduits.

2.7.2 The release of drilling fluid (a suspension of natural bentonite clay in water) into the coastal waters at the punch-out location may cause a sediment plume in the nearshore area.

2.7.3 Drilling fluid is a composite made of bentonite and water with the following functions:

- to remove cuttings from in front of the drill bit;
- power the mud motor;
- to transport cuttings from the drill face through the annular space towards the surface;
- lubricate the drill string during drilling phases and HDPE strings during pull back;

- cooling the reamers (cutting tools);
- hole stabilisation; and
- creation of a filter cake against the wall of the hole to minimize the risk of loss of drilling fluid or influx of groundwater penetration into the borehole.

2.7.4 The drilling fluid typically consists of a low concentration bentonite – water mixture. Depending on the formation to be drilled through, the concentration is typically between 13 litres (30kg) and 35 litres (80kg) of dry bentonite clay per m^3 of water (30,000 to 80,000mg/l).

2.7.5 The use of bentonite has limited potential to cause environmental impacts:

- it is a natural material, so has no chemical constituents;
- it is recyclable;
- it is on the OSPAR List of Substances Used and Discharged Offshore which Are Considered to Pose Little or No Risk to the Environment (PLONOR); and
- owing to the large diameter pipe and long length, the total volume of fluid used may be relatively large, but, owing to the low concentration, the total amount of bentonite used is limited.

Assessment of change

Maximum Design Scenario

2.7.6 Based on the range of expected HDD lengths and maximum diameter, the maximum volume of drilling mud contained in one HDD conduit is estimated to be between 93 and 312m^3. Several stages of drilling (pilot hole drilling and stages of reaming may result in multiple (up to approximately five) smaller release events (up to 25m^3) separated in time. The installation of the duct may result in a larger release of fluid from the HDD conduit (up to the total volume), however, the fluid present at this stage may have been replaced or otherwise reduced to a concentration lower than required for drilling.

2.7.7 The MDS considered is a release of full concentration drilling mud (80,000mg/l), up to the total volume of the conduit (312m^3), in a relatively short period of time (minutes to hours), at up to four HDD punch out locations for the four export cables. The releases will not happen simultaneously, with a sufficiently long time gap between events that no overlapping or cumulative changes to SSC are expected. The following assessment considers the change caused for one cable.

Table 2-20 Maximum design scenario for a single bentonite sediment release event during HDD

Parameter	Maximum Design Scenario[5]	Working and other assumptions
Number of export cables/HDD conduits	4 export cables	Maximum number of cables/ HDD conduits
Maximum dimensions of one HDD conduit	Length 1,000m Diameter 0.63m	
Maximum volume of drill fluid in one HDD conduit	312m^3	Maximum conduit volume = 1,000m x π x $(0.63/2)^2$.
Maximum concentration bentonite in drill fluid	80,000mg/l	Assumed value 80kg/m^3
Maximum total mass bentonite in one HDD conduit	24,960kg	312m^3 x 80kg/m^3

Drilling fluid release during HDD at the landfall

2.7.8 The initial plume will have a very high SSC of bentonite but will have a correspondingly small footprint. The plume will subsequently be advected in the general direction and speed of the ambient currents at the time of the release and will be gradually dispersed both horizontally and vertically by the natural processes of diffusion. The maximum mass of bentonite in the whole plume is finite (24,960kg) and so SSC within the plume will become diluted and reduced in proportion to the increase in the overall volume of the plume. The spreadsheet model results in **Table 2-21** shows that concentrations of bentonite will be reduced to naturally occurring background levels when the plume has dispersed to only a relatively small footprint in the order of 500m across. A larger extent will correspond to a small SSC.

Table 2-21 Suspended sediment concentration as a result of bentonite drill fluid release during HDD

Plume width (m)	Plume depth (m)	Plume section length (m)	Resulting SSC (mg/l)
10	1	10	80,000 *
50	5	10	3,200 *
100	5	10	1,600 *

---

[5] Derivative values (e.g. area, volume, mass, etc) are calculated with full precision from the basic design dimensions, but are presented as rounded values in this table.

Plume width (m)	Plume depth (m)	Plume section length (m)	Resulting SSC (mg/l)
500	5	10	320 *
500	5	500	20 **

* 10m long section through a plume subject to progressive lateral and vertical dispersion up to a representative limited nearshore depth (5m). Initial concentration the same as the undiluted drilling mud (80,000mg/l).
** single plume containing the maximum total mass of bentonite from one HDD conduit, dispersed to a 500 x 500m footprint and full representative nearshore water depth.

2.7.9 The time required to achieve such dispersion cannot be calculated with certainty but is estimated to be in the order of hours based on normal tidally induced turbulence. If waves are active at the time of the release, wave induced turbulence at the seabed and wave breaking nearshore will result in much higher rates of dispersion.

2.7.10 The mass of bentonite is assumed to remain unchanged in this model, which is realistic as the bentonite is a fine-grained clay suspension that is expected take at least hours, if not days or longer to settle out of suspension under suitable conditions. If any bentonite does settle out of suspension more rapidly, then SSC in the plume will be reduced accordingly. If the released drilling fluid does behave as a more dense fluid for any reason, some or all may accumulate in the exit pit (possibly becoming locally consolidated over days to weeks but more likely reworked and dispersed to not-measurable thicknesses over time) and/or some or all may move over the adjacent seabed downslope under gravity, i.e. in an offshore direction and away from the nearshore areas.

2.7.11 It is noted that the HDD exit point will be approximately 500m or more offshore of the upper beach. The currents advecting the plume are aligned parallel to the coast and so it is reasonable to assume that the plume will largely remain a similar distance offshore and therefore may not overlap the nearby (nearshore) bathing water areas at all. If the plume experiences sufficient lateral diffusion to reach the adjacent shoreline, then **Table 2-21** demonstrates that the corresponding SSC will be relatively low (within the range of naturally occurring values in a nearshore area subject to wave action).

2.7.12 The effects of the plume will also be of very short duration and temporary at any given location, limited to the time over which the release occurs (not presently known but estimated to be in the order of hours and less than one day).

Summary of results

Summary of potential SSC and sediment deposition effects from drilling fluid release

2.7.13 The results show that the release of bentonite and drill cuttings in the form of drilling fluid from the planned HDD operations will result in a localised and temporary plume of elevated bentonite SSC. Where the plume has measurable SSC that might be of concern (e.g. to bathing water quality), the duration and footprint of the plume will be small in absolute and relative terms (in the order of less than 10mg/l over footprints larger than 500m over a period of days; or, order of tens to low hundreds of mg/l over footprints less than 500m over a period of minutes to one hour).

2.7.14 In any case, the HDD exit point is located approximately 500m or further offshore of the beach. Any plume will be advected in the direction of the ambient tidal currents, which are aligned parallel to the coast and therefore will remain a similar distance offshore. The largest anticipated plume will be dispersed to relatively low concentrations within hours of release and to background concentrations within a few tidal cycles.

2.7.15 The bentonite in the drilling fluid is expected to remain in suspension for at least hours or days and will be widely dispersed before settling. Therefore, bentonite is not expected to accumulate anywhere in measurable thicknesses. If, however, bentonite and/or drill cuttings did accumulate in or around the HDD exit pit, the volume of the pit is theoretically sufficient to contain the full volume of that material and any accumulated material is expected to be reworked and redistributed to not-measurable concentrations and thicknesses in time by wave and tidal action.

2.7.16 The bentonite in the drilling fluid is expected to behave (advect, mix and disperse) in a similar manner to seawater. If the drilling fluid behaves as a more dense fluid, it will either accumulate in the HDD exit pit or move over the adjacent seabed downslope under gravity, namely, in an offshore direction and away from nearshore areas.

Discussion of potential for in-combination effects on SSC and sediment deposition

2.7.17 If release of HDD drilling fluid, or any other activity causing sediment disturbance, is undertaken simultaneously at two or more locations that are aligned in relation to the ambient tidal streams, then there is potential for overlap between the areas of effect on SSC and sediment deposition. The potential for in-combination effects on SSC and sediment deposition are discussed in **Section 2.4**.

2.8 Cumulative changes

Overview

2.8.1 A Cumulative Effects Assessment (CEA) has been undertaken to consider the impact associated with Rampion 2 together with other projects and plans. Each project on the CEA long list (see **Chapter 6: Coastal processes, Volume 2** (Document Reference: 6.2.6) and **Appendix 5.4: Cumulative effects assessment shortlisted developments, Volume 4** of the ES (Document Reference: 6.4.5.4)) has been considered on a case-by-case basis for scoping in or out of the coastal processes chapter, based upon data confidence, effect-receptor pathways and the spatial/temporal scales involved.

2.8.2 In terms of the potential for cumulative changes to SSC, bed levels and sediment type, the screening approach described above was informed using modelled spring tidal excursion ellipses. This is because meaningful sediment plume interaction generally only has the potential to occur if the activities generating the sediment plumes are located within one spring tidal excursion ellipse from one another and occur at the same time.

2.8.3 Given the length and orientation of tidal excursion ellipses in the vicinity of Rampion 2 (**Figure 2-2**), it is the case that the potential for sediment plume interaction will be limited to instances in which Rampion 2 construction activities occur simultaneously with:

- dredge disposal activities associated with the Aquind interconnector; and
- aggregation extraction operations.

2.8.4 It is considered unlikely that activities causing sediment disturbance will occur in the adjacent operational Rampion 1 offshore wind farm, in a manner that would cause cumulative impacts, during the installation phase of Rampion 2. Rampion 1 is already constructed, so will not foreseeably require large scale dredging, drilling or trenching works; minor repairs and maintenance do not disturb large volumes of sediment; it is also unlikely that activities in the Rampion 1 and Rampion 2 sites would be sufficiently closely aligned with respect to the tidal axis, and close enough in distance for overlapping plumes to occur. If such overlapping or interacting plumes should occur, they will be similar in nature or magnitude to that described above for other cumulative scenarios. The potential for cumulative change is discussed in this section.

Rampion 2 and other dredge disposal activities

2.8.5 The potential Aquind interconnector cable corridor crosses the seabed at the south-western end of the Rampion 2 western offshore array area. If and when the project proceeds, the corridor will potentially be a licenced dredge disposal site (‘Aquind Cable Site A’). In addition to initial cable burial, it is possible that future Aquind cable reburial activities may require disposal of material at this site. Should Rampion 2 construction activities be occurring at the same time as dredge disposal activities at this site, there could be the potential for cumulative changes in SSC and bed levels.

2.8.6 The interaction between sediment plumes generated by Rampion 2 cable of foundation installation activities and those from nearby dredge disposal operations could occur in two ways:

- where plumes generated from the two different activities meet and coalesce to form one larger plume; or
- where a vessel or barge is disposing of material within the plume generated by Rampion 2 construction activities (or vice versa).

2.8.7 Given the very close proximity of the two activities, it is considered that both types of plume interaction could potentially occur. However, it is noted that in line with UNCLOS, (The United Nations Convention on the Law of the Sea), cable installation vessels typically request a one nautical mile (approximately 1.85km) vessel safety zone when installing or handling cables. Accordingly, whilst plume interaction may still occur, the potential for much higher concentration and/or more persistent plumes than that previously described in the project-alone assessments of SSC is considered to be small.

2.8.8 Cumulative increases in bed level could also theoretically occur although the potential for this to occur is expected to be very, given the expected separation distance of the vessels.

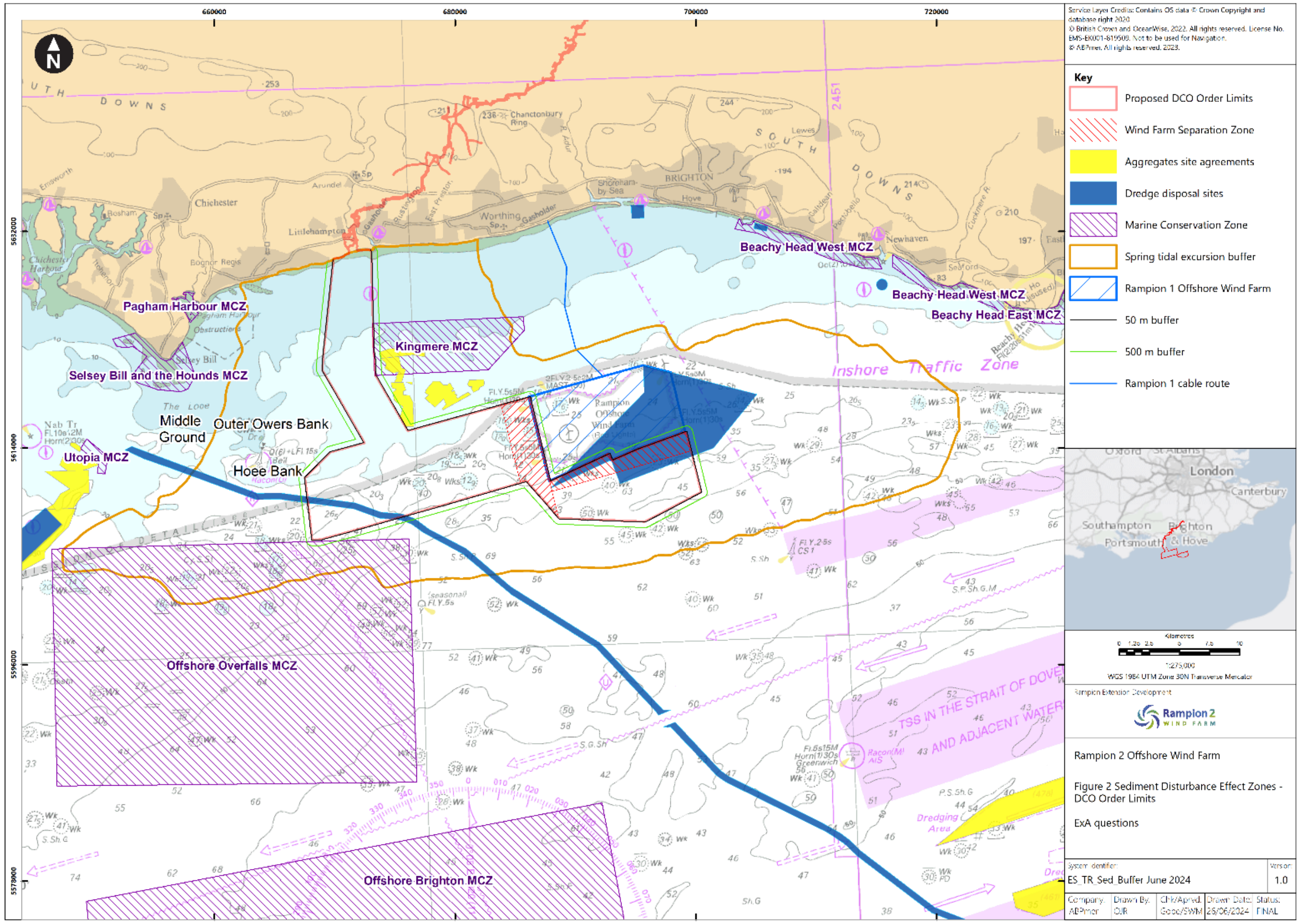
Rampion 2 and other aggregate dredging activities

2.8.9 Only a small number of active aggregate dredging license areas (namely: Inner Owers; Inner Owers North; and Inner Owers Extension) are sufficiently close to the Rampion 2 project (within one tidal excursion distance) that an overlapping plume effect is at all likely.

2.8.10 The aggregate dredging sites are located immediately to the north-west of the offshore array area and immediately to the east of the offshore export cable corridor. The orientation of the tidal axis means that interaction between plumes created by aggregate dredging and activities in the offshore array area are very unlikely. Some overlap of plumes might occur in relation to export cable burial in the offshore end of the Offshore Export cable corridor only, however, as assessed in **Section 2.6: Cable burial**, the extent and duration of sediment plumes from cable burial are very limited.

2.8.11 Any cumulative increase in either the spatial footprint or peak concentration of sediment plumes are therefore likely to be indistinguishable from background levels. Any associated cumulative changes in bed level (different to that already assessed for Rampion 2 alone) are also unlikely to be measurable in practice.

Figure 2-2 Projects considered within the cumulative effects assessment (extract from Figure 6.3.3)



2.9 Summary of changes to suspended sediment concentrations, bed levels and sediment type

2.9.1 The previous sections provide detailed tabulated results describing realistically possible combinations of magnitude and extent of impact for local increases in suspended sediment concentration (SSC) and seabed deposition, most notably due to:

- drilling of monopile foundations and pin piles for jacket foundations;
- seabed preparation by dredging prior to jacket suction bucket foundation installation;
- sandwave clearance (prior to cable burial);
- cable burial; and
- drilling fluid release during HDD at the landfall.

2.9.2 The actual magnitude and extent of such impacts will depend in practice on a range of factors, such as the actual total volumes and rates of sediment disturbance, the local water depth and current speed at the time of the activity, the local sediment type and grain size distribution, the local seabed topography and slopes, etc. There will be a wide range of possible combinations of these factors and so it is not possible to predict specific dimensions with complete certainty. To provide a robust assessment, a range of realistic combinations is provided, based on conservatively representative location (environmental) and project (MDS) specific information. Results are then provided for a range of water depths, or heights of ejection, or sediment types.

2.9.3 This wider range of results can be summarised broadly in terms of four main zones of effect, based on the distance from the activity causing sediment disturbance:

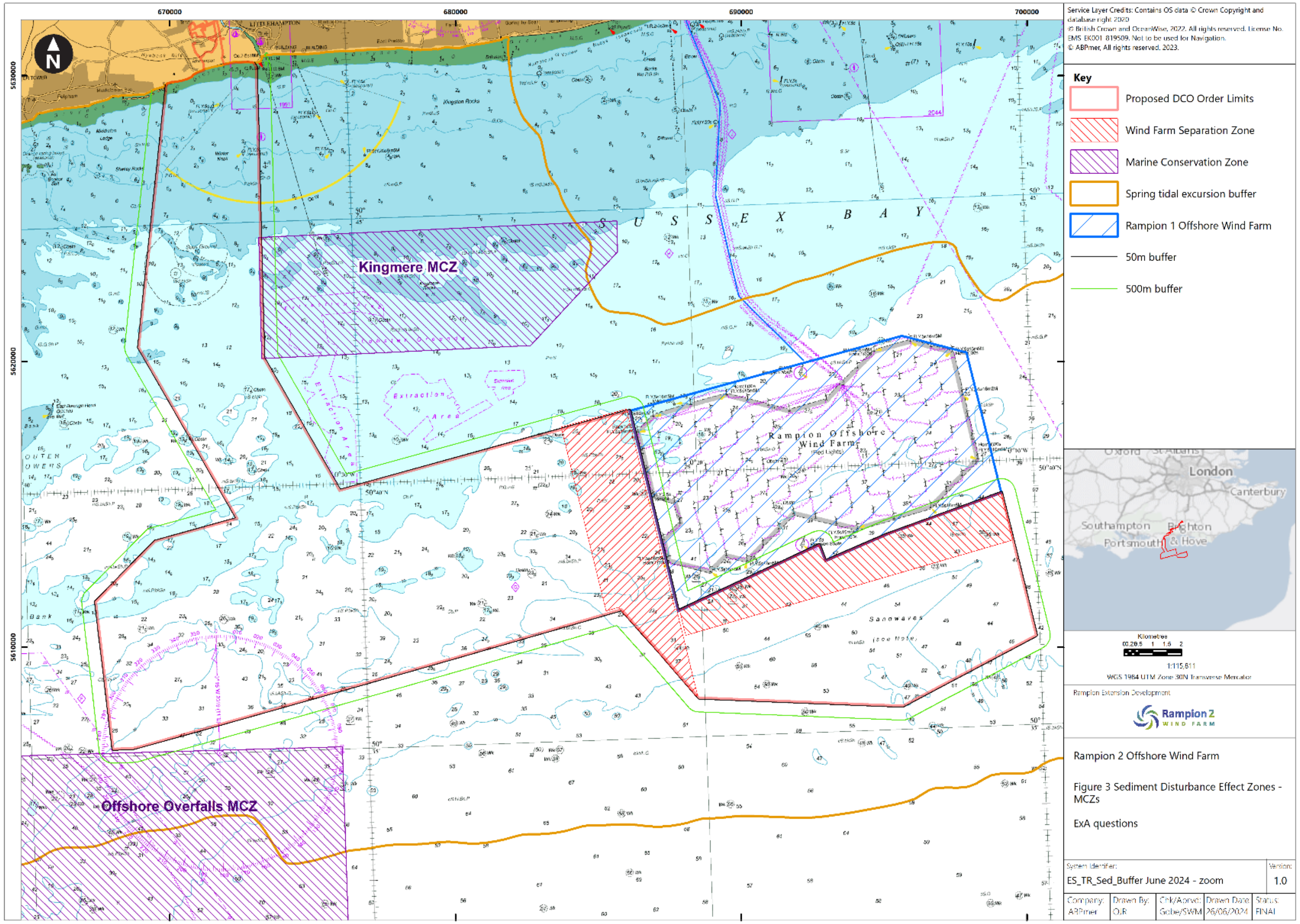
- 0 to 50m – zone of highest SSC increase and greatest likely thickness of deposition. All gravel sized sediment likely deposited in this zone, also a large proportion of sands that are not resuspended high into the water column, and also most or all dredge spoil in the active phase. Plume dimensions and SSC, and deposit extent and thickness, are primarily controlled by the volume of sediment released and the manner in which the deposit settles.
  - At the time of active disturbance - very high SSC increase (tens to hundreds of thousands of mg/l) lasting for the duration of active disturbance plus up to 30 minutes following end of disturbance; sands and gravels may deposit in local thicknesses of tens of centimetres to several metres; fine sediment is unlikely to deposit in measurable thickness.
  - More than one hour after the end of active disturbance – no change to SSC; no measurable ongoing deposition.
- 50 to 500m – zone of measurable SSC increase and measurable but lesser thickness of deposition. Mainly sands that are released or resuspended higher in the water column and resettling to the seabed whilst being advected by ambient tidal currents. Plume dimensions and SSC, and deposit extent and

thickness, are primarily controlled by the volume of sediment released, the height of resuspension or release above the seabed, and the ambient current speed and direction at the time.

  - At the time of active disturbance - high SSC increase (hundreds to low thousands of mg/l) lasting for the duration of active disturbance plus up to 30 minutes following end of disturbance; sands and gravels may deposit in local thicknesses of up to tens of centimetres; fine sediment is unlikely to deposit in measurable thickness.
  - More than one hour after end of active disturbance – no change to SSC; no measurable ongoing deposition.
- 500m to the tidal excursion buffer distance – zone of lesser but measurable SSC increase and no measurable thickness of deposition. Mainly fines that are maintained in suspension for more than one tidal cycle and are advected by ambient tidal currents. Plume dimensions and SSC are primarily controlled by the volume of sediment released, the patterns of current speed and direction at the place and time of release and where the plume moves to over the following 24 hours.
  - At the time of active disturbance – low to intermediate SSC increase (tens to low hundreds of mg/l) as a result of any remaining fines in suspension, only within a narrow plume (tens to a few hundreds of metres wide, SSC decreasing rapidly by dispersion to ambient values within one day after the end of active disturbance; fine sediment is unlikely to deposit in measurable thickness.
  - One to six hours after end of active disturbance – decreasing to low SSC increase (tens of mg/l); fine sediment is unlikely to deposit in measurable thickness.
  - Six to 24 hours after end of active disturbance – decreasing gradually through dispersion to background SSC (no measurable local increase); fine sediment is unlikely to deposit in measurable thickness. No measurable change from baseline SSC after 24 to 48 hours following cessation of activities.
- Beyond the tidal excursion buffer distance or anywhere not tidally aligned to the active sediment disturbance activity – there is no expected impact or change to SSC nor a measurable sediment deposition.

2.9.4 **Figure 2-3** provides a summary of the spatial extent of these zones in relation to Rampion 2 and selected receptors in the surrounding area. The figure clearly illustrates that the only anticipated effect with respect to SSC and sediment deposition is to a discrete area on the northern boundary of the Offshore Overfalls MCZ. No impacts to the Kingmere MCZ are expected.

Figure 2-3 Sediment Disturbance Effect Zones (extract from Figure 6.3.4)



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3. Changes to the wave regime

This section sets out the assessment of changes to the wave regime within the study area, based on spectral wave modelling of the maximum design scenario for blockage within the Rampion 2 array.

3.1 Wave model design and validation

3.1.1 The wave model has been built using the MIKE21FM Spectral Wave (SW) module, which simulates the development, propagation and dispersion of wave energy throughout the model domain.

3.1.2 More detailed information about the design and validation of the wave model may be found in **Appendix 6.2: Coastal processes model design and validation, Volume 4** of the ES (Document Reference: 6.4.6.2).

3.2 Wave conditions tested

3.2.1 The wave model creates discrete simulations of wave height, period and direction throughout the domain, for a representative range of selected everyday and extreme wave conditions (return periods and directions).

3.2.2 The wave condition scenarios considered by the model for the assessment are:

- wave coming directions (southwest, south-southwest, south, south-southeast, southeast); and
- return periods (50% non-exceedance, 0.1-year; 1-year; 10-year; 50-year; 100-year).

3.2.3 The details of each condition as defined in a central location, approximately 5km south of Rampion 2, are presented in **Table 3-1**. Plots showing the spatial distribution of wave height and direction for each of the baseline wave conditions are shown in **Annex A** (**Figure A-1** to **Figure A-5**).

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Table 3-1 Wave and wind boundary conditions for each of the directional return period sea state conditions tested

Directional Sector	Case (Return Period)	Significant Wave Height (m)	Peak Wave Period (Tp, s)	Mean Wave Direction (°N)	Wind Speed @10m (m/s)	Wind Direction (°N)
Southwest	50% no exc	1.4	5.8	225	9.3	225
	0.1-year RP	3.4	7.6	225	16	225
	1-year RP	5.2	9.5	225	21	225
	10-year RP	7.4	11.3	225	27	225
	50-year RP	8.4	12	225	26	225
	100-year RP	8.7	12.2	225	28	225
South-Southwest	50% no exc	1.2	4.8	205	8.5	205
	0.1-year RP	2.6	6.2	205	14	205
	1-year RP	4.6	8.1	205	19	205
	10-year RP	7.3	10.3	205	26	205
	50-year RP	8.4	11.1	205	26	205
	100-year RP	8.7	11.3	205	28	205
South	50% no exc	0.9	4.2	180	6.7	180
	0.1-year RP	1.6	4.9	180	9	180
	1-year RP	3.3	7	180	16	180

Directional Sector	Case (Return Period)	Significant Wave Height (m)	Peak Wave Period (Tp, s)	Mean Wave Direction (°N)	Wind Speed @10m (m/s)	Wind Direction (°N)
	10-year RP	6.3	9.7	180	23	180
	50-year RP	7.4	10.5	180	24	180
	100-year RP	7.7	10.7	180	26	180
South-Southeast	50% no exc	0.8	4.1	167	5.8	167
	0.1-year RP	1.3	4.6	167	7	167
	1-year RP	2	5.7	167	12	167
	10-year RP	4.2	8.2	167	18	167
	50-year RP	5.3	9.2	167	20	167
	100-year RP	5.6	9.5	167	22	167
Southeast	50% no exc	0.7	3.9	135	5.1	135
	0.1-year RP	1.1	4.2	135	6	135
	1-year RP	1.7	5.2	135	9	135
	10-year RP	3.4	7.4	135	16	135
	50-year RP	4.1	8.1	135	17	135
	100-year RP	4.3	8.3	135	18	135

3.3 Maximum Design Scenarios

Rampion 2 foundation type and number

3.3.1 The Rampion 2 design envelope includes a range of WTG and OSS foundation types, numbers and dimensions. The MDS is identified as the combination of options leading to the greatest total potential blockage to waves passing through the offshore array area.

3.3.2 The MDS for Rampion 2 is:

- 65 larger type WTGs on jacket foundations with suction buckets:
  - four legs, 5.0m diameter;
  - cross bracing, up to 3.0m diameter;
  - four suction buckets, 15m diameter, 10m high;
  - base dimensions at seabed 40m x 40m;
  - scour protection 3m high, 15m beyond foundation perimeter at seabed; and
  - combined equivalent blockage width 49.2m per foundation.
- three OSSs on jacket foundations with pin piles:
  - six legs, 5.0m diameter;
  - cross bracing, up to 3.0m diameter;
  - base dimensions at seabed 55m x 45m;
  - scour protection 3m high, 15m beyond foundation perimeter at seabed; and
  - combined equivalent blockage width 66.9m per foundation.

3.3.3 Any other combination of foundation type and number (including the larger number of smaller type WTG foundations) will result in a smaller total blockage.

Rampion 1 foundation type and number

3.3.4 WTG and OSS foundation details for the existing operational Rampion 1 offshore wind farm are as follows:

- 116 WTGs on monopile foundations:
  - 6.5m diameter;
  - scour protection 1m high, 15m diameter; and
  - combined equivalent blockage width 6.8m per foundation.
- One OSS on jacket foundation:
  - four legs, 2.5m diameter;
  - cross bracing, 1.5m diameter;

- base dimensions at seabed 30m x 30m;
- scour protection 1m high, 15m beyond foundation perimeter at seabed; and
- combined equivalent blockage width 23.3m per foundation.

Foundation layout

3.3.5 The MDS layout for a given wave direction and receptor will be the distribution of foundations that presents the greatest continuous distance of wind farm array area through which waves must pass (causing the greatest combined reduction in wave energy by the point waves exit the array) and then the smallest distance from the array to the receptor (leaving the least opportunity for recovery). The worst case in this respect may therefore vary depending on the wave direction and the receptor being assessed.

3.3.6 The actual location of all foundations in Rampion 1 are known and fixed in all scenarios.

3.3.7 For Rampion 2, an indicative layout pattern for the smaller WTG type and areas of likely locations for the OSSs are used to identify three MDS layouts for the MDS type and number of foundations (shown in **Figure 3-1** to **Figure 3-3**). These layouts group the maximum total number of foundations and blockage, at the minimum likely spacing, in different parts of the whole potential offshore array area, as close to potential (adjacent coastlines and sandbank) receptors as possible. These layouts are considered to be realistically and conservatively representative of any that might be eventually considered.

Figure 3-1 Rampion 2 MDS foundation layout 1

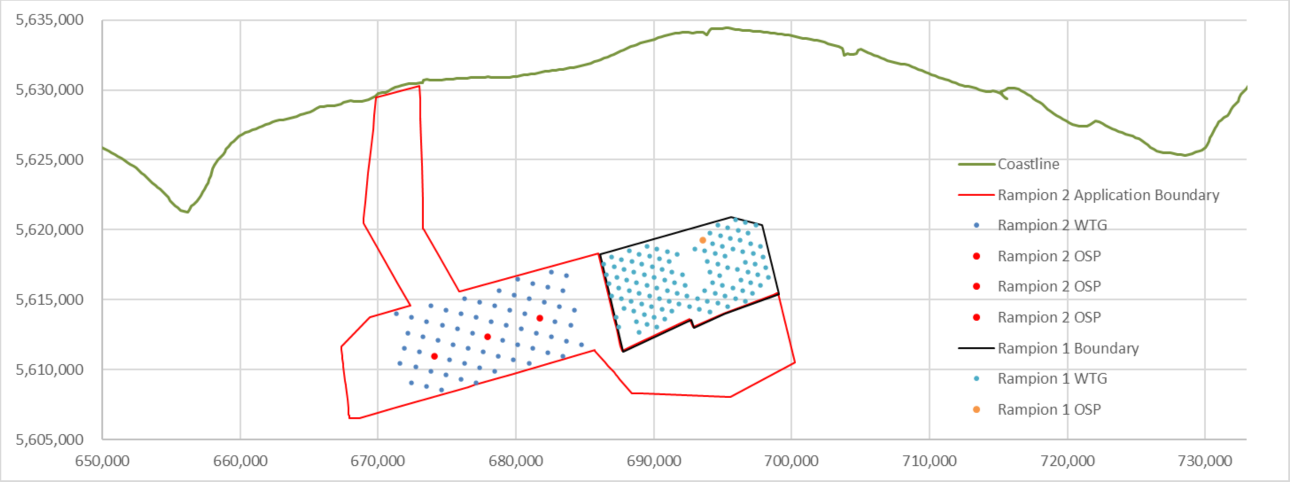


Figure 3-2 Rampion 2 MDS foundation layout 2

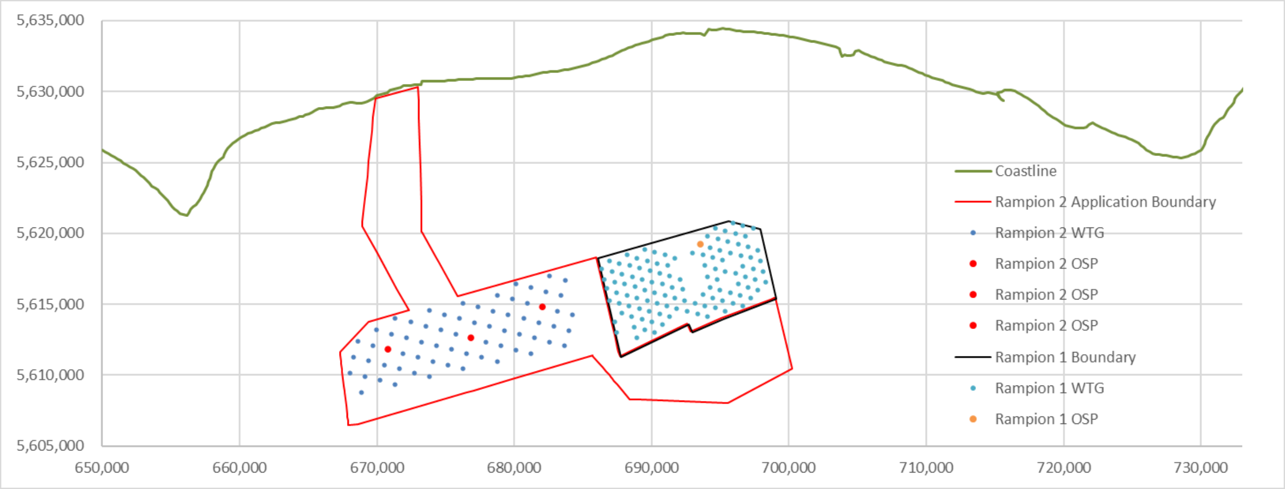
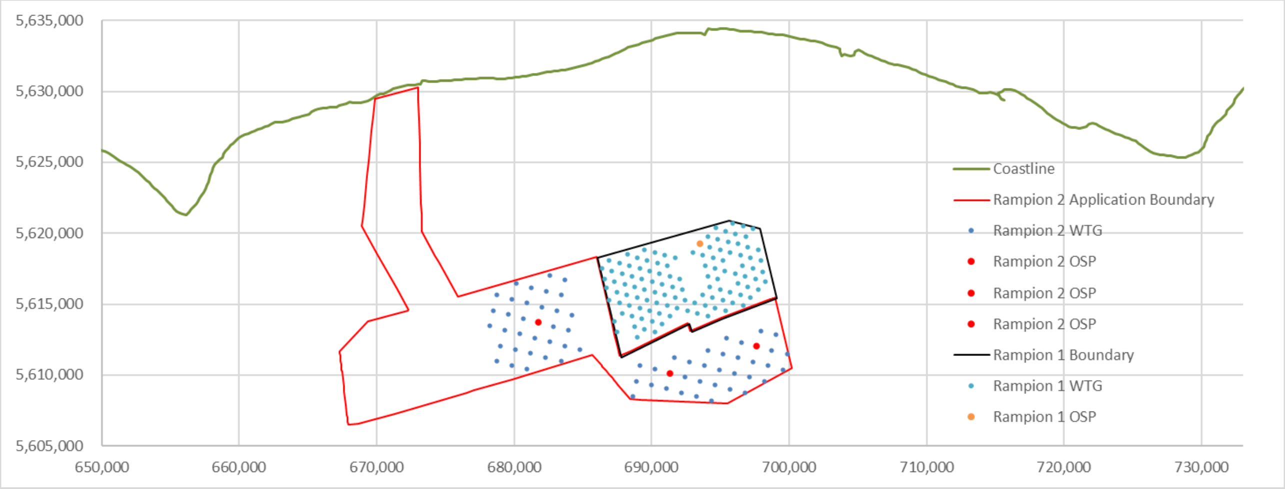


Figure 3-3 Rampion 2 MDS foundation layout 3



3.4 Assessment of change

Changes to the wave regime

3.4.1 Plots showing the spatial distribution of changes to wave height for each of the baseline wave conditions and the three MDS foundation layouts of Rampion 2, and Rampion 1 as built, are shown in **Annex A** (**Figure A-6** to **Figure A-10** for Layout 1; **Figure A-11** to **Figure A-15** for Layout 2; **Figure A-16** to **Figure A-20** for Layout 3).

3.4.2 Changes less than 5% of the baseline wave height will be indistinguishable from natural variability both within the sea state (difference between individual waves) and compared to normal rates of change (over timescales of one hour or less); such small differences will not be measurable in practice. Changes less than 2.5% are also less than the reasonably expected accuracy of the model and so are excluded from the colour scale.

3.4.3 The baseline wave condition model scenarios and plots exclude the presence of any wind farm infrastructure (Rampion 1 and Rampion 2). A separate set of results for a baseline condition including the presence of the built Rampion 1 wind farm (not shown) demonstrates that the change in wave height caused by the relatively small number of slender monopile foundations actually built is very small in absolute and relative terms (less than 2.5%); there is also no corresponding measurable change to wave period (less than 0.1s) and wave direction (less than three degrees). The small changes that do occur are limited in extent to within a very short distance of the downwind edge of the Rampion 1 offshore array area. The baseline images shown are therefore equally valid for a baseline that either includes or excludes Rampion 1.

3.4.4 The resulting patterns of difference in wave conditions for the three MDS layouts of Rampion 2 (together with the built design of Rampion 1), compared to the baseline condition excluding all wind farms, are similar and are collectively described below.

3.4.5 As shown in the results figures in **Annex A**, the wind farm infrastructure generally causes a local reduction in wave height at each foundation, and an array scale reduction in wave height in proportion to the overall blockage density presented by the WTG and substation foundations. The array scale change in wave height gradually increases with distance downwind from the upwind edge through the offshore array area. The change then extends downwind of the array, gradually recovering to background values with distance. In practice, a very localised area of wave shadowing might occur immediately behind individual foundations, but wave heights are expected to recover rapidly (within a few tens of metres of the foundation) due to normal lateral spreading of the ambient wave energy.

3.4.6 The same simulations (not shown in the figures) also show that associated changes to wave period and direction are not measurable (i.e. less than approximately 0.1s and three degrees, respectively); where present, the small scale of change follows a similar spatial pattern and footprint as that shown in the figures for wave height, recovering to baseline conditions with distance downwind from the array.

3.4.7 In a separate simulation (not shown in the figures) the relatively slender monopiles and jacket OSS installed in Rampion 1 alone cause little to no change in wave height: changes greater than 2.5% of the baseline condition are largely absent, both locally around each foundation, and at an array scale. A very localised change of between 2.5 and 5% is occasionally visible at the location of the Rampion 1 OSS.

3.4.8 The greatest relative change arising from Rampion 2 and Rampion 1 together is between 5 and 10% of the baseline wave height, within and immediately downwind of the Rampion 2 offshore array area, associated with the 50% exceedance return period scenario, for each of the wave directions tested. The change reduces to less than 5% within a short distance (3 to 4km) downwind of the offshore array area. Even the smallest potentially measurable changes in wave height (more than 2.5 to 5%) do not extend to any of the adjacent coastlines.

3.4.9 The relative change is greatest for the 50% exceedance return period scenario (the lowest energy wave height condition considered), and progressively decreases through higher return period scenarios for all of the wave directions tested. This occurs because wave energy is proportional to the product of the wave height and the square of the wave period. A reduction in wave energy at higher energy levels will therefore result in a smaller proportional reduction in wave height. For a given return period, the relative scale of change is similar for the range of wave directions simulated.

Changes to the wave regime at offshore sandbanks

3.4.10 The model results show that waves will not be measurably changed (less than 5% of wave height, 0.1 seconds for wave period and three degrees in wave direction) at the location of East Bank or the northern part of the Outer Owers Bank, due to the presence of MDS foundations in Rampion 2 (and Rampion 1). This is partly due to the small scale of change, but also due to the very limited number of wave directions where any change might extend to this particular location.

3.4.11 The southern part of the Outer Owers Bank (also called Hooe Bank) is closer to and slightly overlaps the far north-western end of the offshore array area. Within a relatively narrow corridor extending a few hundred metres downwind of individual WTG foundations sufficiently close to these banks, a local change (reduction) in wave height of up to 5 to 7.5% (but no associated measurable change in wave period or direction) might occur.

3.4.12 Outside the narrow downwind corridor, and as a result of more diffuse array scale effects, waves will not be measurably changed (less than 2.5 to 5% in wave height, 0.1 seconds in wave period and three degrees in wave direction).

3.4.13 The potential for any interaction is naturally limited by the location of the banks relative to the proposed DCO Order Limits Offshore Array Areas. Interaction between MDS foundation and any of the sandbanks around Selsey Bill are only likely to occur if the foundations are located in the far western end of the offshore array area, and sufficiently close to the banks for a measurable change in waves to extend that far.

3.4.14 The predominant wave climate controlling the evolution of the sandbanks around Selsey Bill (waves from the southwest and south-southwest, occurring approximately 60% of the time) will not pass through the offshore array areas within the proposed DCO Order Limits and so will not be changed at all in any case. Realistically, only waves coming from the southeast or east-southeast (occurring approximately 12% of the time) have the potential to interact with the windfarm infrastructure and then with the various sandbanks around Selsey Bill.

Changes to the wave regime at adjacent coastlines and recreational surfing venues

3.4.15 The model results show that wave height, period and direction (for a wide range of typical everyday to severe storm conditions) will not be measurably changed at any coastal locations, including recreational surfing venues, due to the presence of MDS foundations in Rampion 2, and Rampion 1.

3.4.16 It is noted that wave direction is naturally variable over time and only locations directly downwind of the Rampion 2 offshore array area will have any potential to experience any change under a particular wave condition; therefore, any such change at a given location will also only ever be intermittent over time. The model results show that the array scale changes extending outside of the offshore array area are relatively dispersed and do not lead to a focussed effect at any particular location.

3.4.17 The degree to which an individual wave will interact with an obstacle of finite width depends on the ratio of the obstacle width and the wavelength. A wave that is long in comparison to the width of the obstacle will experience relatively little resistance other than some surface friction as the water within the wave moves against the surface of the foundation; in this case, energy loss is minimal and the wave will experience little to no change to its height, period or direction. A wave that is short in comparison to the width of the obstacle is more likely to result in the wave breaking or being reflected from the face of the obstacle, resulting in partial to total wave energy blockage within the cross-sectional width of the obstacle; however, such short waves are typically created continuously and by local winds and so any local loss of energy will be quickly dispersed and replenished.

3.4.18 As such, the numerical model used here provides a conservative estimate of the changes to longer length waves (important for coastal processes and higher quality surfing waves), which are actually less likely to interact with or be fully blocked by the foundations.

4. Changes to the tidal regime

4.1 Overview

4.1.1 This section sets out the assessment of changes to the tidal regime within the study area, based on the maximum design scenario for blockage within the Rampion 2 array.

4.1.2 The interaction between the tidal regime and the foundations of the wind farm infrastructure will result in a general reduction in current speed and an increase in levels of turbulence locally due to frictional drag and the shape of the structure. Resistance posed by the array (due to the sum of all foundation drag) to the passage of water at a large scale may distort the progression of the tidal wave, also potentially affecting the phase and height of tidal water levels.

4.1.3 Changes to the tidal regime may potentially influence seabed morphology in a number of ways. In particular, a causal relationship between flow speed and bedform type can be expected (Belderson et al., 1982) and thus any changes to flows have the potential to alter seabed morphology over the lifetime of the Proposed Development. More generally, changes in flow may alter the balance between sediment erosion and deposition as well as the rate and direction of sediment transport. These potential changes to the sediment transport regime are discussed separately in **Section 5**.

4.2 Baseline conditions

4.2.1 A summary of the baseline water level and flow characteristics within and nearby to the proposed DCO Order Limits are provided below, based on the project-specific oceanographic survey data and existing publicly available information.

- The largest astronomical tidal range and mean spring tidal range can be described as macro-tidal (greater than 4m) conditions, whereas the mean neap tidal range can be described as meso-tidal (2 to 4m).
- Depth averaged mean spring currents within the offshore array areas of the proposed DCO Order Limits vary from approximately 0.75m/s to 1.1m/s depth averaged mean neap currents vary from approximately 0.4m/s to 0.7m/s.
- Flows are slightly stronger in the western side of the offshore array areas and are associated with a slightly larger tidal range.
- The axis of tidal flows in the offshore array areas is aligned approximately east (flood) to west (ebb) and is approximately parallel to the adjacent coastlines.
- Surge related influences are a frequent occurrence and may provide both positive and negative variations to the normal tidal elevation. Local wind stress may also cause slight modification to current speed and direction at the water surface and in the upper water column.

4.3 Evidence base

4.3.1 On the basis of: (i) post construction monitoring of wake fields (e.g. from Burbo and Lincs offshore wind farms (ABPmer et al., 2010); and (ii) numerical modelling results available from numerous other offshore wind farm project Environmental Statements, it is apparent that changes to flow speeds as a result of flow blockage are greatest in the immediate vicinity of the foundation structures, reducing quickly in magnitude with increased distance from the foundations. As such, the largest changes in flow speed are anticipated to occur within the offshore array areas, within the proposed DCO Order Limits. Outside of this, changes in flow speed are typically confined to within the order of hundreds of metres of individual WTGs and therefore also largely within the proposed DCO Order Limits.

4.3.2 Direct flow measurements undertaken at Burbo Bank (ABPmer, 2011) in the lee of a 4.7m diameter monopile indicated that the mean current speed within the wake recovers to within 10% of the ambient value approximately 200m downstream of the origin (i.e., ambient flows are effectively recovered at 40 diameters). This evidence helped validate the earlier assertions of effects which were modelled for the corresponding EIA.

4.3.3 Wake features have also been assessed at the Donghai Bridge offshore wind farm in the East China Sea using sea surface backscatter from TerraSAR-X (TS-X) Synthetic Aperture Radar (SAR) (Li et al., 2014). This wind farm comprises of 34 monopile foundations which have a 15m diameter concrete cap at the water surface (to mitigate ice loads). The tidal current interacts with these cylindrical piles and induces water turbulence, which dampens the surface Bragg waves, and therefore modulates the sea surface roughness and consequently is imaged by TS-X as wakes downstream. Approximately 1.2km away from the pile, the backscatter signal became comparable to the mean upstream value, indicating that the wake length in this case was approximately 80 diameters in length.

4.4 Assessment of change

4.4.1 The presence of the foundations will interfere with passage of tidal currents as a consequence of local drag and blockage effects, which lead to a reduction in flow speed behind the structure and the development of a wake. For slender round structures, the nature of the wake is clearly described by fluid dynamics theory. The magnitude and nature of the change is dependent on the diameter of the obstacle presented to the oncoming flow, the drag coefficient of the structure, the properties of the fluid (density and viscosity) and the current speed (American Petroleum Institute, 2014). For obstacles at the scale of the wind farm foundations (monopiles and jacket members), the ambient flow separates to pass around the obstacle, leading to local flow recirculation patterns within one to two diameters downstream, and the creation of eddies that are shed to form a narrow wake. The properties of the modified flow within the wake are a (slight) decrease in time mean current speed, and an increase in turbulence intensity due to the presence of the (relatively small) eddies, relative to the ambient current condition.

4.4.2 In an array of multiple structures, the array scale effect is the simultaneous presence of multiple individual effects, unless there are measurable interaction between adjacent wakes or structures, however, due to the relatively large separations between foundations (950 to 1,130m between WTGs), and the relatively small structures under consideration, such interactions are not expected to occur, nor have they ever been notably observed or found to cause indirect impacts in any constructed offshore wind farm to date.

Maximum design scenario

4.4.3 The MDS foundation option has been determined as 65 larger WTG type jacket foundations on suction buckets with scour protection at a minimum spacing of 1,130m, and three OSS jacket foundations on pin piles with scour protection, which are the combination of all options that presents the greatest total blockage cross section.

Change to tidal currents due to presence of foundations

4.4.4 The maximum leg spacing for each jacket foundation is 40m, narrowing to 30m at LAT. Primary leg members are up to 5.0m diameter and secondary bracing members are up to 3.0m. Currents passing through the structure in the middle and upper part of the water column will encounter local blockage effects from (up to) four primary members and eight secondary members. The estimated solidity ratio (A/Af) of the WTG jacket framework in the middle and upper part of the water column is 0.40, meaning that 40% of the total frontal area (Af) is solid structure (A, comprising the individual legs and cross-members).

4.4.5 The suction buckets and scour protection will present a more continuous blockage nearbed and in the lower water column, where current speed is lower. The depth average total blockage width for the structure (including all members on all faces, suction buckets and scour protection) is conservatively calculated for 30m water depth to be 49.2m (representative of a combination of narrow and wider individual blockage elements).

4.4.6 In contrast and similar to many recently built offshore wind farms, Rampion 1 uses (116) monopile foundations with a diameter of 6.5m, in a grid pattern with a spacing of approximately 750m.

4.4.7 In comparison to the monopiles used in Rampion 1, the MDS jacket foundation option will create a potentially less locally intense but broader wake (a combination of small local wakes effects from relatively smaller individual obstacles, across the slightly larger (20 to 40m) overall width of the structure.

4.4.8 As discussed in **Section 6**, without appropriate seabed protection, the modified flow field in the wake is a primary cause of normal and predictable ‘local’ and ‘global’ scour effects (scour locally associated with the structure as a whole, rather than an individual element).

4.4.9 The lateral dimensions of the wake are likely to be initially similar to the width of the structure (40m). This is likely to increase (widen) with distance downstream due to diffusion and dispersion of the effect; this is also the normal and natural mechanism for the recovery of time mean current speed and turbulence towards ambient conditions. Conservatively using a maximum leg spacing of 40m for the WTG jacket foundation (similar to the estimated total depth mean blockage cross section) and estimating the maximum measurable wake length as 80 diameters, then the likely extent of a measurable/detectable wake is estimated to be in the order of 3.2km, orientated along the local flood or ebb tidal current axis. This wake length distance is less than the corresponding tidal excursion distance in the offshore array area (11 to 16km, the distance over which water is displaced during each flood or ebb tide).

4.4.10 If these changes described above occurred from the outer limits of the proposed development area, then they are in such a direction that they will not overlap, or will remain too short to reach:

- the adjacent coastlines; and
- no more than a very small number of other foundations in the adjacent Rampion 1 array area, and only then where two foundations are closely aligned on the local tidal axis.

Changes to tidal water levels due to presence of foundations

4.4.11 As described above, the Rampion 2 foundations can be considered too small and widely dispersed to affect the movement of water at the array scale and therefore will have no measurable effect on the progression of the tidal wave or on associated water levels (tidal or residual surge) at either the local or regional scale. There is no evidence from other operational offshore wind farms to suggest a measurable array scale change to water levels.

4.4.12 This assertion is entirely consistent with numerical modelling undertaken to inform Round Three developments (e.g., East Anglia Offshore Wind, 2012; Moray Offshore Renewables Ltd, 2012, Navitus Bay Development Ltd, 2014).

4.5 Cumulative changes

4.5.1 Interaction between separate wind farms only has the potential to occur if the extent of the turbulent wake features from one location overlaps with that from the other. Wind farms that are not aligned in relation to the ambient tidal streams or located more than one wake length (or at most one spring tidal excursion distance) from one another, are very unlikely to cause cumulative changes.

4.5.2 If the changes described above in **Section 4.4: Assessment of change** occurred from the outer edges of the Rampion 2 offshore array area, then they are in such a direction that they will not overlap, or will remain too short to reach more than a very small number of other foundations in the adjacent Rampion 1 array area, and only then where two foundations are closely aligned on the local tidal axis.

4.5.3 No other wind farms or developments presenting blockage are present within one spring tidal excursion distance of Rampion 2.

5. Changes to the sediment transport regime

5.1 Overview

5.1.1 This section sets out the assessment of changes to the sediment transport regime within the study area, based on the maximum design scenario for blockage within the Rampion 2 array.

5.1.2 Potential changes to the sediment transport regime could occur in response to the presence of:

- WTG foundations and sub-stations; and
- cable protection measures.

5.1.3 Infrastructure installations may present a direct blockage to the transport of sediment. Interaction between the naturally present tidal and wave regimes and the WTG foundations could potentially result in a reduction in normal current speed and wave energy. However, elevated turbulence may also be present in the wake behind foundations, potentially enhancing the potential sediment transport rate (e.g. Butt et al., 2004, Gyr and Hoyer, 2006), as evidenced by its contribution to the formation of scour (considered in **Section 6**). Persistent changes to wave and currents over larger areas could potentially cause changes over time to patterns of net sediment transport (rates and directions) with resulting changes to sedimentary bedform morphology and general seabed bathymetry (considered in this **Section 5**).

5.1.4 The sensitivity of morphological features to these patterns of change will depend upon the relative importance of currents and/or waves, the magnitude and extent of any change to them and the degree to which the system is presently in balance. The potential for such changes to occur is assessed in this section, with the influence of foundation infrastructure and cable protection measures considered separately.

5.2 Baseline conditions

5.2.1 Baseline characteristics of the sediment transport regime are briefly summarised below.

- The seabed across the array and offshore export cable corridor is dominated by the presence of coarse-grained sediments (sands and gravels) with outcropping bedrock in places. Holocene deposits are widespread across central and eastern parts of the Rampion 2 offshore array area whereas in western parts, hard substrate is at or close to the surface in most areas.
- Sediments across the Rampion 2 offshore array area are characteristics of two very different depositional environments. The Holocene seabed sediments generally consist of sand, gravelly sand and sandy gravel and have been

reworked and deposited by marine processes. The sediments associated with the paleochannels are also sands and gravels but have a fluvial origin, deposited in a terrestrial setting.

- The available evidence suggests that (bedload) material is being transported east-northeast further towards the eastern English Channel. In the offshore environment, tidal currents are the primary agent for mobilising sediment through bedload and suspended load transport. As wave conditions alone are not normally large enough to mobilise large sediment volumes for transport.
- Within the proposed DCO Order Limits of the offshore array areas, suspended sediment concentrations are typically 10 to 20mg/l during winter and less than 4mg/l during summer (Cefas, 2016). However, during stormier conditions, the influence of waves stirring of the seabed can cause a short-term increase in sediment transport rate and SSC. Coarser sediments may be transported a short distance in the direction of ambient flow or down-slope under gravity before being deposited. Finer material that persists in suspension will eventually be transported in the direction of net tidal residual flow (to the east-northeast).

5.3 Evidence base

5.3.1 Cefas (2005) describe the results of post-construction monitoring at Scroby Sands offshore wind farm which was undertaken to investigate the impacts of monopiles on coastal processes. It was found that at Scroby Sands, the impacts on sediment transport appear limited to local scour pits and scour wakes. Any related bathymetric impacts are probably limited to the order of 100m around each monopile. It was further noted that, given the spacing between monopiles at Scroby Sands is greater than 300m, such morphological or sediment transport impacts are unlikely to be cumulative between monopiles and across the WTG array.

5.4 Assessment of change

Maximum Design Scenario

5.4.1 The MDS for each change type considered below is presented in the relevant supporting assessments (e.g. changes to waves or currents).

Change in alongshore and cross-shore transport due to change in wave regime at adjacent coastlines

5.4.2 On the basis of the quantitative analysis of potential changes to the wave regime (**Section 3.4: Assessment of change**), it is found that there will be no measurable reduction in wave height at adjacent coastlines in response to the presence of the WTG foundations since reductions in wave height along the downwind margin of the offshore array area will be less than approximately 2.5%. Changes in wave height of this magnitude are small in both absolute and relative terms. Such small differences are not measurable in practice and will be indistinguishable from normal short term natural variability in wave height (both for individual wave heights and in terms of the overall sea state). Accordingly, these changes are not predicted to have any measurable influence on alongshore or cross-shore sediment transport.

Change in patterns of bed load transport due to change in wave and tidal regimes

5.4.3 Within the offshore array areas and deeper offshore sections of the offshore cable corridor, within the proposed DCO Order Limits, sediment transport is dominated by the action and asymmetry of tidal currents. Potential changes to currents have previously been described in **Section 4.4**. The primary change is that time average current speed will be reduced but turbulence intensity will also be increased in a narrow wake extending downstream from each foundation. The net effect on bedload sediment transport is a balance of the decrease in overall flow speed and increase in flow turbulence. Very close to the foundation, time mean flow is most reduced, however, the additional turbulence dominates, causing an increase in local sediment transport rate, contributing to local scour (described in **Section 6**).

5.4.4 Time mean current speed may potentially also be increased (typically by only a few centimetres per second) between rows of foundations if the final grid layout is aligned to the tidal axis. However, the difference is very small in absolute and relative terms, within the range of natural variability and not measurable in practice. Little to no net difference in the total flow rate of water through the offshore array area is expected. No measurable associated changes to sediment transport patterns are expected or have been reported at any other wind farm.

5.4.5 The extent to which these persistent but localised changes in flow speed could influence overall rates of bedload transport within and nearby to the offshore array area will depend upon the magnitude of change relative to sediment mobilisation thresholds. In places, it is possible that localised flow reductions will slightly reduce the frequency with which sediment particles are mobilised and therefore rates of transport may also be similarly reduced. Conversely, marginally greater rates of sediment transport may be experienced where localised flow accelerations or elevated turbulence are found. The overall result of these slight changes in flow speed could potentially be a very small reduction in the net volume of material transported as bedload through the offshore array area. The reduction will likely not be measurable in practice and will be within the range of natural variability in sediment transport rates.

Change in patterns of suspended sediment transport due to change in wave and tidal regimes

5.4.6 As discussed in **Section 4.4**, changes to tidal currents (which primarily control the rate and direction in which suspended sediment is transported) due to the operational presence of the offshore array area are assessed to be very limited in absolute magnitude and spatially restricted to the offshore array area plus a small distance downstream in the main flood and ebb directions.

5.4.7 During large storm events, waves may stir the seabed within shallower parts of the offshore array area, naturally causing an additional short-term contribution to SSC levels locally. As discussed in **Section 3.4**, the MDS array of foundations will potentially cause a small reduction in wave heights within and nearby to the offshore array area and it is therefore possible that there will be a corresponding small reduction in the rate at which sediment is locally re-suspended from the seabed.

5.4.8 The change described above will only be apparent during larger storm events (if at all) and will potentially slightly reduce SSC from that which would have occurred in the baseline condition. However, levels of SSC will remain dominated by regional scale inputs that are not affected by the presence of the wind farm. No measurable changes to SSC outside the range of natural variability are expected to occur within or nearby to the offshore array area.

Change in sediment transport patterns due to cable protection

5.4.9 Installation of cable protection could result in a locally raised obstacle up to 1.0m above the present-day seabed level. Cable protection will be placed onto the seabed surface above the cable and could therefore directly trap or block sediment in transport, locally impacting down-drift locations. The spatial extent and location of the cable protection is to be confirmed.

5.4.10 The presence of cable protection could potentially influence sandy sediments which are being transported as bedload, including 'saltation', 'rolling' and 'sliding'.

- Saltation is the process by which sands are moved up into the water column. These suspended sands are expected to move relatively freely over the top of the armour although to begin with will regularly be deposited upon it, filling void spaces. Once any void spaces have been infilled, saltation is expected to be largely unaffected by the presence of the cable protection such that existing transport process (including bed form migration) will remain unaffected.
- Rolling and sliding is the process by which sands move while still in contact with the seabed. Transport via these mechanisms will be temporarily intercepted until such time that the armour is sufficiently covered by sand that the slope gradient has been reduced in response to the accumulation of a sediment wedge with stable slope angles (approximately 30 degrees). Following this, bedload will continue freely at the ambient rate and direction because the slope angle presented by sections of protected cable is within the naturally present range of bed slope angles (associated with bed forms for example).

5.4.11 Following installation and under favourable conditions, an initial period of sediment accumulation may be expected to occur. The largest likely volume of sediment that could accumulate is associated with the filling any open surface voids and the creation of a smooth stable sediment slope against or over the cable protection. Given the relatively high potential sediment transport rates within the study area, this process of accumulation may take place over a period as short as a few weeks to months, depending on the net rate of sediment transport onto (less any scour or erosion from) the cable protection.

5.4.12 Accordingly, for all areas in which cable protection is used (including where sandwaves are present), it is not expected that the presence of the cable protection devices will continue to affect patterns of sediment transport following any initial period of accumulation. It follows that any changes to seabed morphology away from the cable protection will also be very small. The presence of cable protection measures does not cause a long-term blockage to sediment transport were used within the cable route corridor.

5.5 Cumulative changes

5.5.1 The primary process mechanisms driving sediment transport within the study area are currents and waves. It has been demonstrated in **Section 6.4: Assessment of change** that the footprint of measurable change to these parameters is too small in both extent (and magnitude) to cumulatively interact with similar changes associated with other developments. It follows that any associated changes to sediment transport will also be similarly limited in extent and as such, no cumulative changes are expected.

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6. Assessment of scour and seabed alteration

6.1 Overview

6.1.1 This section considers the extent to which scour could occur within the proposed DCO Order Limits in response to the installation of various different foundation types and in the absence of scour protection. The assessment quantifies the spatial footprint of scour and associated volume of material that could be eroded in response to tidal and wave driven currents, both for individual foundations and for the full array.

6.1.2 The purpose of this section is to conservatively and quantifiably estimate the area of seabed that might potentially be altered during the operational phase of the wind farm as a result of sediment scour developing adjacent to WTG foundations (in the absence of any scour protection).

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

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

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

6.1.5 Scour assessment for EIA purposes is considered here for three foundation types: monopiles, jacket on pin piles, and jacket on suction bucket. Each foundation type may produce different scour patterns therefore all have been considered.

6.1.6 The concerns under consideration include the seabed area that may become modified from its natural state (potentially impacting sensitive receptors through habitat alteration) and the volume and rate of additional sediment resuspension, as a result of scour. The seabed area directly affected by scour may be modified from the baseline (pre-development) or ambient state in several ways, including:

- a different (coarser) surface sediment grain size distribution may develop due to winnowing of finer material by the more energetic flow within the scour pit;
- a different surface character will be present if scour protection (e.g. rock protection) is used;
- seabed slopes may be locally steeper in the scour pit; and
- flow speed and turbulence may be locally elevated.

6.1.7 The magnitude of any change will vary depending upon the foundation type, the local baseline oceanographic and sedimentary environments and the type of scour protection implemented (if needed). In some cases, the modified sediment character within a scour pit may not be so different from the surrounding seabed; however, changes relating to bed slope and elevated flow speed and turbulence close to the foundation are still likely to apply. No direct assessment is offered within this document as to the potential impact on sensitive ecological receptors.

6.1.8 This section considers the effect of scour immediately around the foundations. More distant turbulent wake effects on the seabed downstream of foundations has been observed at Scroby Sands wind farm, due to the strongly rectilinear nature (minimal rotation) of tidal currents in that location during the flood and ebb tide, and the resulting persistent increase in turbulence in a narrow corridor downstream. This type of turbulent wake effect is not likely to occur at Rampion 2 due to the slight rotation of tidal currents during flood and ebb cycles which will distribute the turbulent effect over a wider area.

6.1.9 The assessment presented here is not intended for use in detailed engineering design. However, methodologies similar to those recommended for the design of offshore wind foundations (DNV, 2016) have been used in some cases where they are applicable. The methods applied to assess scour are set out in **Annex B**.

6.2 Baseline conditions

6.2.1 Where obstacles are not present on the seabed, normal sediment transport processes can cause spatial and temporal variations in seabed level and sediment character in the baseline environment. Scour is a similar but localised change resulting from particular local patterns of sediment transport. Scour may also occur in the baseline environment in response to natural obstacles such as rocky outcrops or boulders. Key features of the baseline environment pertinent to the assessment of scour due to the presence of wind farm infrastructure are summarised below.

- Seabed sediments within and nearby to the proposed DCO Order Limits offshore array areas are typically characterised by the presence of a sands and gravels in varying proportion. A small proportion of fines (muds and silts, typically less than 5%) may also be present in some locations. These sediments are regularly potentially mobilised by the relatively strong tidal currents.
- In the western offshore array area within the proposed DCO Order Limits, the surficial sediment units are either very thin or absent, with the underlying more erosion resistant chalk bedrock exposed at the bed surface. Conversely, where

bedforms are present, mainly in the eastern offshore array area within the proposed DCO Order Limits, the surficial sediment layer may (locally) be several and up to tens of metres thick.

- Locally, the seabed level is expected to vary naturally on hourly timescales in the order of centimetres to tens of centimetres, due to the migration of small scale bedforms due to the action of tidal currents and waves. Larger natural variation in bed level over longer timescales might be associated with regional scale bed level change and the migration of larger sandwave features which are present.

6.3 Evidence base

6.3.1 Whitehouse (1998) provides a synthesis of a range of research papers, industry reports, monitoring studies and other evidence available at that time, describing the patterns and dimensions of scour that result from a variety of obstacle shapes, sizes and environmental conditions. Building upon a theoretical understanding of the processes involved, the accepted methods for the prediction of scour mainly rely on stochastic relationships and approaches (i.e. relationships that are based on and describe the available evidence). As such, scour analysis is an evidence based science where suitable analogues provide the most robust basis for prediction.

6.3.2 Since the publication of Whitehouse (1998), evidence continues to be collected and other predictive relationships have been developed and reported by the research community. In general, more recent observations have confirmed the approaches (and associated ranges of uncertainty) presented in Whitehouse (1998). As the evidence base has grown, additional approaches and relationships have been developed to better predict scour for a wider range of more specific obstacle shapes, sizes and environmental conditions.

6.3.3 Monitoring evidence regarding scour development around unprotected wind farm monopile installations is provided by HR Wallingford et al. (2007) and ABPmer et al. (2010) in a series of monitoring data synthesis reports for the Department for Trade and Industry (DTI) and the Collaborative Offshore Wind Research into the Environment (COWRIE). HR Wallingford et al. (2007) note that the available data support the view that scour is a progressive process that can occur where the seabed sediment is potentially erodible and there is an adequate thickness of that sediment for scouring to occur. Where the seabed comprises consolidated pre-Holocene sedimentary units (such as that encountered within many parts of the offshore array area within the proposed DCO Order Limits), the scour will be slower to develop and limited in depth. For instance, geotechnical surveys at Kentish Flats offshore wind farm (Outer Thames) show that the seabed consists of non-cohesive sands over more resistant London Clay. The post construction monitoring evidence generally indicates that maximum scour rates around the monopiles (of diameter 4.3m) occurred during the first year from installation and then rapidly slowed with near stability occurring by the third anniversary of the works. Scour depths ranged from 1.5 to 1.9m at the monitoring locations and the results indicate that the scour depth is restricted by the cohesive underlying clay formation.

6.4 Assessment of change

Maximum design scenario

6.4.1 The following foundation structures have been considered within the assessment presented in this section:

- WTG monopile foundations:
  - up to 90 x 10m diameter (smaller WTG type); and
  - up to 65 x 13.5m diameter (larger WTG type);
- WTG jacket with pin pile foundations:
  - up to 90 x 30 x 30m base with four 2.5m diameter legs (smaller WTG type); and
  - up to 65 x 45 x 45m base with four 5.0m diameter legs (larger WTG type).
- WTG jacket with suction bucket foundations:
  - up to 90 x 30 x 30m base with four 2.5m diameter legs and four suction buckets, up to 15m diameter and 10m high. (smaller WTG type); and
  - up to 65 x 45 x 45m base with four 5.0m diameter legs and four suction buckets, up to 15m diameter and 10m high (larger WTG type).
- OSS jacket with pin pile foundations:
  - up to three 55 x 65m base with six 5.0m diameter legs.

6.4.2 For each foundation type, both the largest and smallest structures have been considered. This is because the former has the potential to cause the greatest extent of scour at the scale of individual foundations whereas the latter may potentially be associated with the greatest extent of scour at the array scale, owing to the larger number of structures.

Changes caused by scour

Factors affecting equilibrium scour depth

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

- frequency and magnitude of ambient sediment transport;
- ratio of monopile diameter to water depth;
- ratio of monopile diameter to peak flow speed;
- ratio of monopile diameter to sediment grain size; and
- sediment grain size, gradation and geotechnical soil properties.

6.4.4 The influence of these factors where they do apply is to generally reduce the depth, extent and volume of the predicted scour, hence providing a less conservative estimate. For example, a greater frequency and magnitude of sediment transport can reduce the equilibrium scour depth, as the scour hole is also simultaneously being (partially) in-filled by ambient sediment transport.

6.4.5 A limited thickness mobile sediment in parts of the offshore array area will limit the depth of scour pit formation where applicable. However, there are other parts of the offshore array area that could potentially develop the full predicted depth. The above factors have been considered in the context of the proposed DCO Order Limits and were otherwise not found to significantly or consistently reduce the predicted values for the purposes of the EIA.

6.4.6 The greatest influence on local scour depth (other than a limited thickness of mobile seabed sediment) is associated with the installation of scour protection. If correctly designed and installed, scour protection will essentially prevent the development of local primary scour as described in this section. The dimensions and nature of scour protection may vary between designs but, given its purpose, will likely cover an area of seabed approximately like the predicted extent of the scour.

6.4.7 Interaction between ambient currents and the scour protection may lead to the development of secondary scour at its edges. The local dimensions of secondary scour are highly dependent upon the specific shape, design and placement of the protection. These parameters are highly variable and so there is no clear quantitative method or evidence base for accurately predicting the dimensions of secondary scour. However, as for foundations, the approximate scale of the scour depth and extent is likely to be proportional to the much smaller size of the individual elements comprising the protection.

Time for scour to develop around the foundation options

6.4.8 Scour depth can vary significantly under combined current and wave conditions through time (Harris et al., 2010). Monitoring of scour development around monopile foundations in UK offshore wind sites suggest that the timescale to achieve equilibrium conditions can be of the order of 60 days in environments with a potentially mobile seabed (Harris et al., 2011). However, as previously noted, equilibrium scour depths may not be reached for a period of several months or even a few years where erosion resistant sediments/ geology are present. These values account for tidal variations as well as the influence of waves. (Near) symmetrical scour will only develop following exposure to a sufficient flow speed in both flood and ebb tidal directions.

6.4.9 Under waves or combined waves and currents an equilibrium scour depth for the conditions existing at that time may be achieved over a period of minutes, whilst typically under tidal flows alone equilibrium scour conditions may take several months to develop.

Spatial extent of scour

6.4.10 At the Scroby Sands offshore wind farm, narrow, elongated scour features have been observed to extend over tens or hundreds of metres from individual foundations, leading to a more extensive impact than would normally be predicted. The development of elongate scour features at Scroby Sands is considered to have occurred due to the strongly rectilinear nature of the tidal currents (a very well defined tidal current axis with minimal deviation during each half tidal cycle) which allows the narrow turbulent wake behind each foundation to persist over the same areas of seabed for a greater proportion of the time, leading to net erosion in these areas. This process is not dependent on a particular current speed regime. Due to a relatively higher rate of tidal rotation than at Scroby Sands, the development of elongate scour features is not considered likely to occur within the proposed DCO Order Limits.

Predictions of scour dimensions

6.4.11 **Table 6-1** and **Table 6-2** summarise the key results of the first-order scour assessment undertaken using the methodological approach set out in **Annex B**. Results conservatively assume maximum equilibrium scour depths are symmetrically present around the perimeter of the structure in a uniform and frequently mobile sedimentary environment with unlimited seabed thickness. Local scour extent is measured from the edge of the monopile or jacket; ‘global scour’ extent is measured from the centroid of the jacket foundation location. Global scour refers to a region of shallower but potentially more extensive scour associated with a multi-member foundation resulting from the change in flow velocity through the gaps between members of the structure and turbulence shed by the entire structure. Global scour does not imply scour at the scale of the wind farm array.

6.4.12 Scour footprints exclude the footprint of the structure. Local scour pit volumes are calculated as the volume of an inverted truncated cone, minus the structure volume; scour pit volumes for jacket foundations are similarly calculated but as the sum of that predicted for each the corner piles.

Table 6-1 Summary of predicted maximum scour dimensions for largest individual WTG and OSS foundations

Parameter		Larger WTG Type Monopile	Larger WTG Type Jacket Pin Piles	Larger WTG Type Jacket Suction Bucket	OSS Jacket Pin Piles
Equilibrium scour depth (m)	Current only	17.6	6.5	1.6	6.5
	Waves only	Insufficient for scour	0.2	2.2	0.2
	Current + waves	17.6	6.5	3.5	6.5
	Global scour	N/A	2.0	2.0	2.0
Scour extent* (m)	Local scour	28.1	10.4	5.6	10.4
	Global scour	N/A	45	45	100
Footprint* (m^2)	Structure alone	143	64	2,376	58
	Local scour (exc. structure)	3,669	1,948	1,073	2,960
	Global scour (exc. structure)	N/A	6,298	3,986	31,358
Volume* (m^3)	Local scour (exc. structure)	24,950	5,070	4,211	7,605
	Global scour (exc. structure)	N/A	12,596	7,972	62,716
	Drill arisings or bed preparation	8,588	3,817	5,625	11,451

* Based upon the scour depth for current + waves in shallowest part of the array; footprint and volume are per foundation.

Table 6-2 Total seabed footprint of the different WTG foundation types (and three OSS foundations) with and without scour

Parameter	Monopile		Jacket pin pile		Jacket with suction bucket	
WTG Type	**Smaller**	**Larger**	**Smaller**	**Larger**	**Smaller**	**Larger**
Maximum number of foundations	90 WTG + 3 OSS**	65 WTG + 3 OSS**	90 WTG + 3 OSS**	65 WTG + 3 OSS**	90 WTG + 3 OSS**	65 WTG + 3 OSS**
Seabed footprint of all foundations (m^2)	7,242	9,477	3,637	4,308	143,312	154,602
Proportion of offshore array area*	0.01%	0.01%	0.00%	0.00%	0.07%	0.08%
Seabed footprint of all local scour (m^2)	190,079	247,384	60,061	135,497	73,527	78,626
Proportion of offshore array area*	0.10%	0.13%	0.03%	0.07%	0.04%	0.04%
Seabed footprint of all foundations + local scour (m^2)	197,321	256,861	63,698	139,806	216,839	233,228
Proportion of offshore array area*	0.10%	0.13%	0.03%	0.07%	0.11%	0.12%
Seabed footprint of all global scour (m^2)	N/A	N/A	345,080	503,452	205,405	353,158
Proportion of offshore array area*	N/A	N/A	0.18%	0.26%	0.11%	0.18%

* Corresponding proportion of the Rampion 2 Offshore Array Areas (195.5km^2).
** WTG type and size in table column header + OSS jacket on pin piles.

Summary of results

6.4.13 Key findings are summarised below:

- Scour will only occur if and where scour protection is not applied;
- Some or all scour may occur in timescales of hours to days (i.e., before the placement of scour protection) depending on the strength of tidal currents in that place and time. If applied, scour protection will likely cover at least the expected footprint of any scour;
- Sediment plumes potentially caused during more rapid early stages of the scouring process will be localised to the scour hole footprint and up to a few tens of metres downstream (within the length of the disturbed flow field). Once eroded from the local scour pit area, sediment will be transported at the same ambient rate as all other seabed sediment;
- Scour development within the Rampion 2 offshore array area is expected to be dominated by the action of tidal currents but occasional wave contribution is possible for jackets on pin piles or jacket on suction buckets in shallower parts of the offshore array area within the proposed DCO Order Limits;
- Erosion resistant (pre-Holocene) material is present at or close to the seabed in most parts of the western and northeast parts of the offshore array areas within the proposed DCO Order Limits. In practice, this is likely to lead to a natural limitation of scour depth and a related reduction in the footprint and volume of seabed affected by scour in these areas, both for individual foundations and for that proportion of the offshore array area as a whole. The following assessment conservatively assumes no such limit to the dimensions of scour;
- The greatest area of local scour (per WTG foundation) is associated with the larger WTG type monopile, with a potential area of 3,669m^2 susceptible to scour development;
- The greatest volume of local scour (per WTG foundation) is associated with the larger WTG type monopile, with a potential scoured volume of 24,950m^3 per foundation;
- For the offshore array area, the greatest total footprint of local scour is associated with an array of 65 larger WTG type monopile foundations and three OSS jacket with pin pile foundations. The potential spatial extent of this scour (excluding the footprint of the foundations) is 247,384m^2, corresponding to approximately 0.13% of the proposed DCO Order Limits offshore array areas; and
- For the Rampion 2 array as a whole, the greatest total footprint of global scour is associated with an array of 90 x smaller WTG type jacket with pin pile foundations and 3 x OSS jacket with pin pile foundations. The potential spatial extent of this scour is 503,452m^2, corresponding to approximately 0.26% of the total proposed DCO Order Limits offshore array areas.

6.5 Cumulative changes

6.5.1 Scour around all structures will be confined within the proposed DCO Order Limits. Accordingly, there is no potential for cumulative changes arising from interactions with other projects or activities.

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Annex A
Wave model results

The following images present the results of the wave modelling described in **Section 3** of this technical annex.

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Figure A-1 Baseline significant wave height, waves from the southwest, all return periods

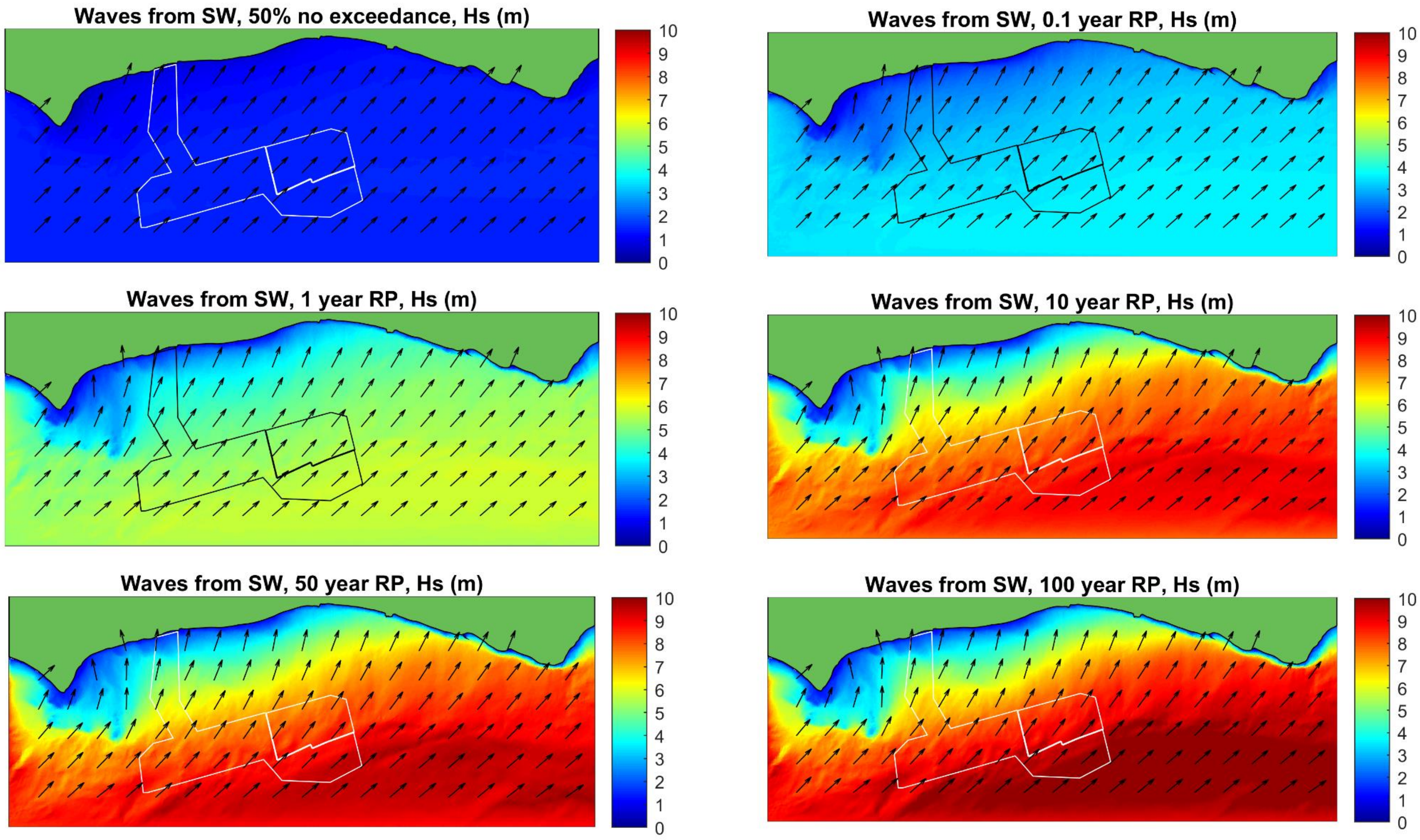


Figure A-2 Baseline significant wave height, waves from the south-southwest, all return periods

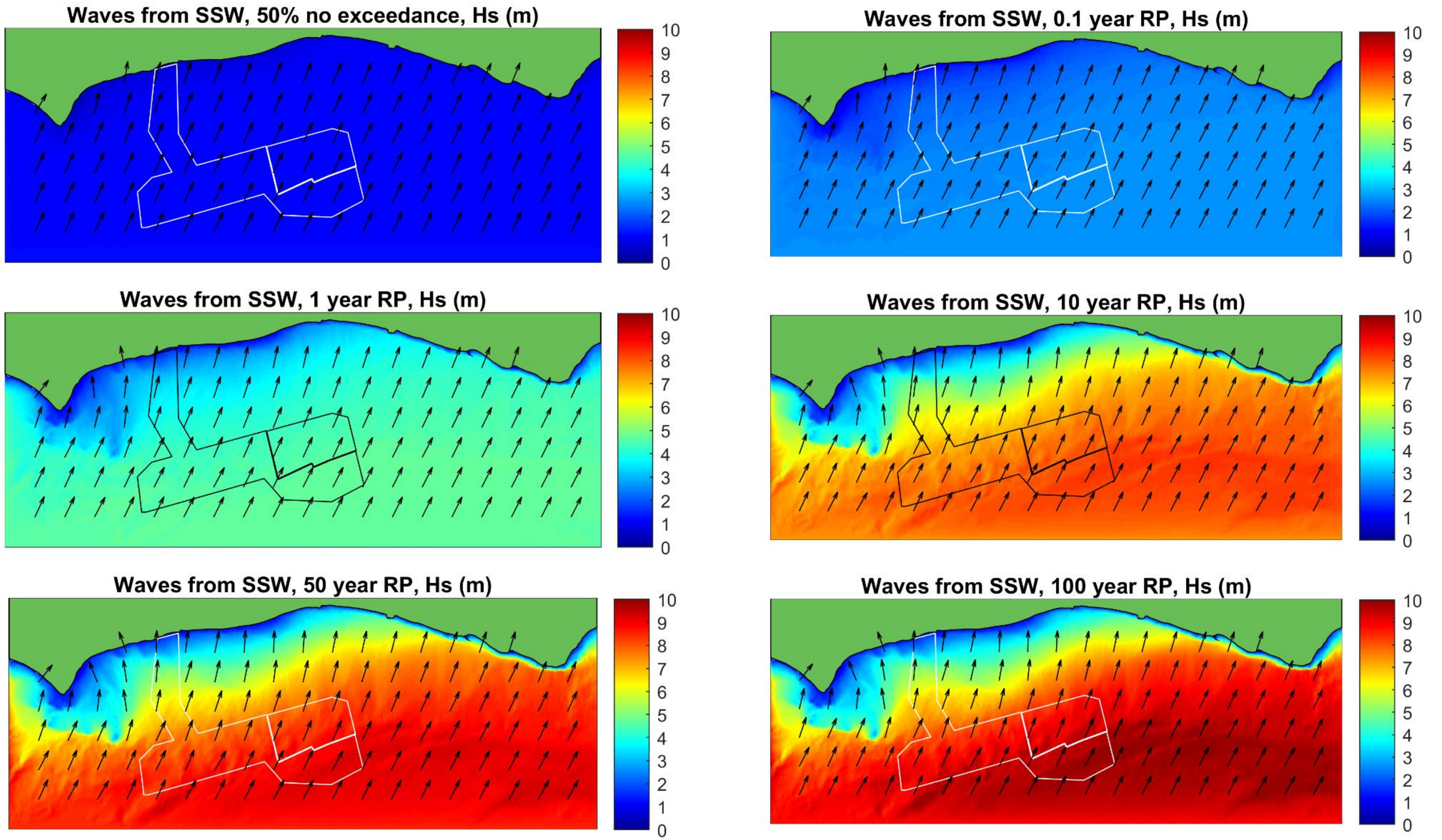
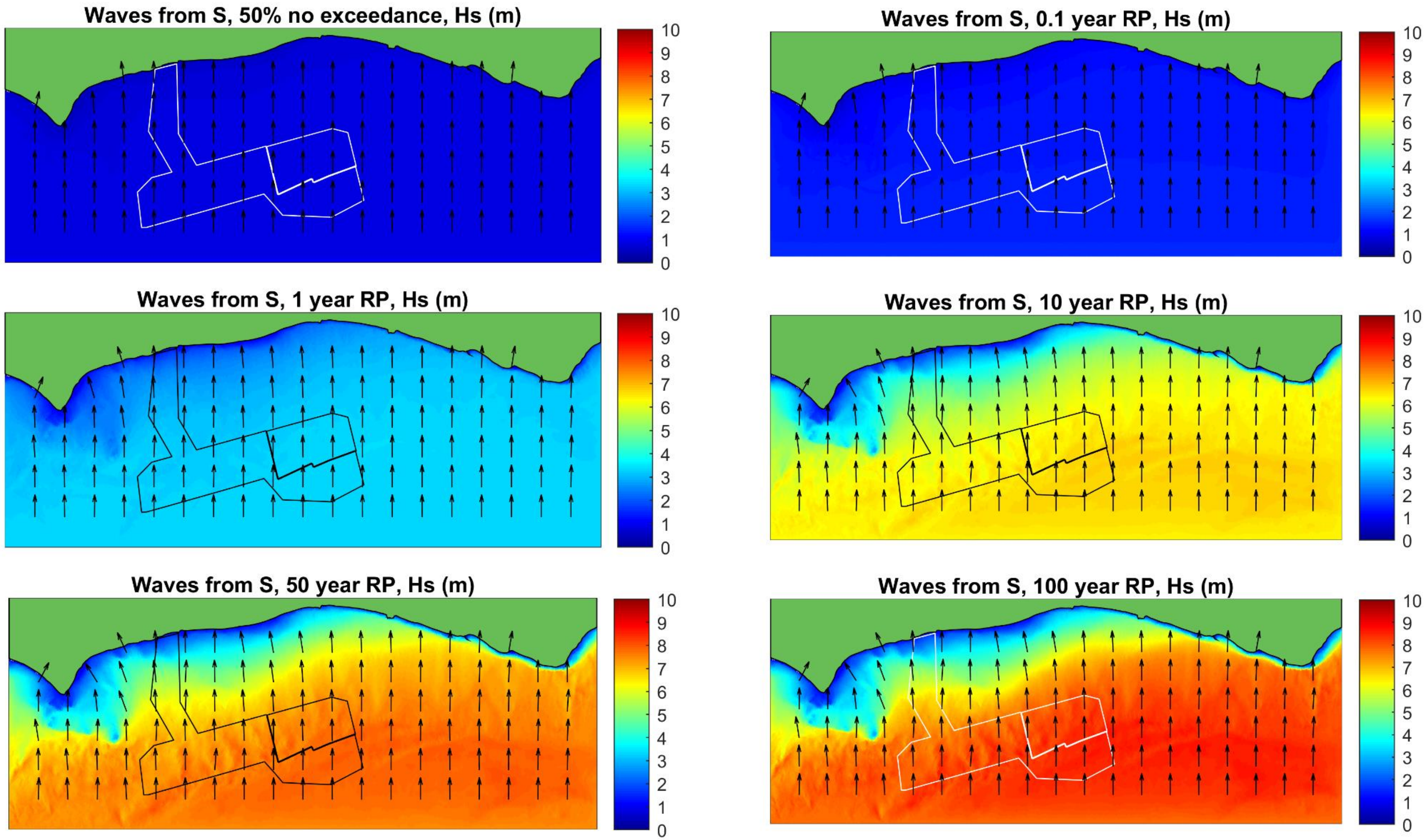


Figure A-3 Baseline significant wave height, waves from the south, all return periods



Waves from S, 50% no exceedance, Hs (m)

Waves from S, 0.1 year RP, Hs (m)

Waves from S, 1 year RP, Hs (m)

Waves from S, 10 year RP, Hs (m)

Waves from S, 50 year RP, Hs (m)

Waves from S, 100 year RP, Hs (m)

Figure A-4 Baseline significant wave height, waves from the south-southeast, all return periods

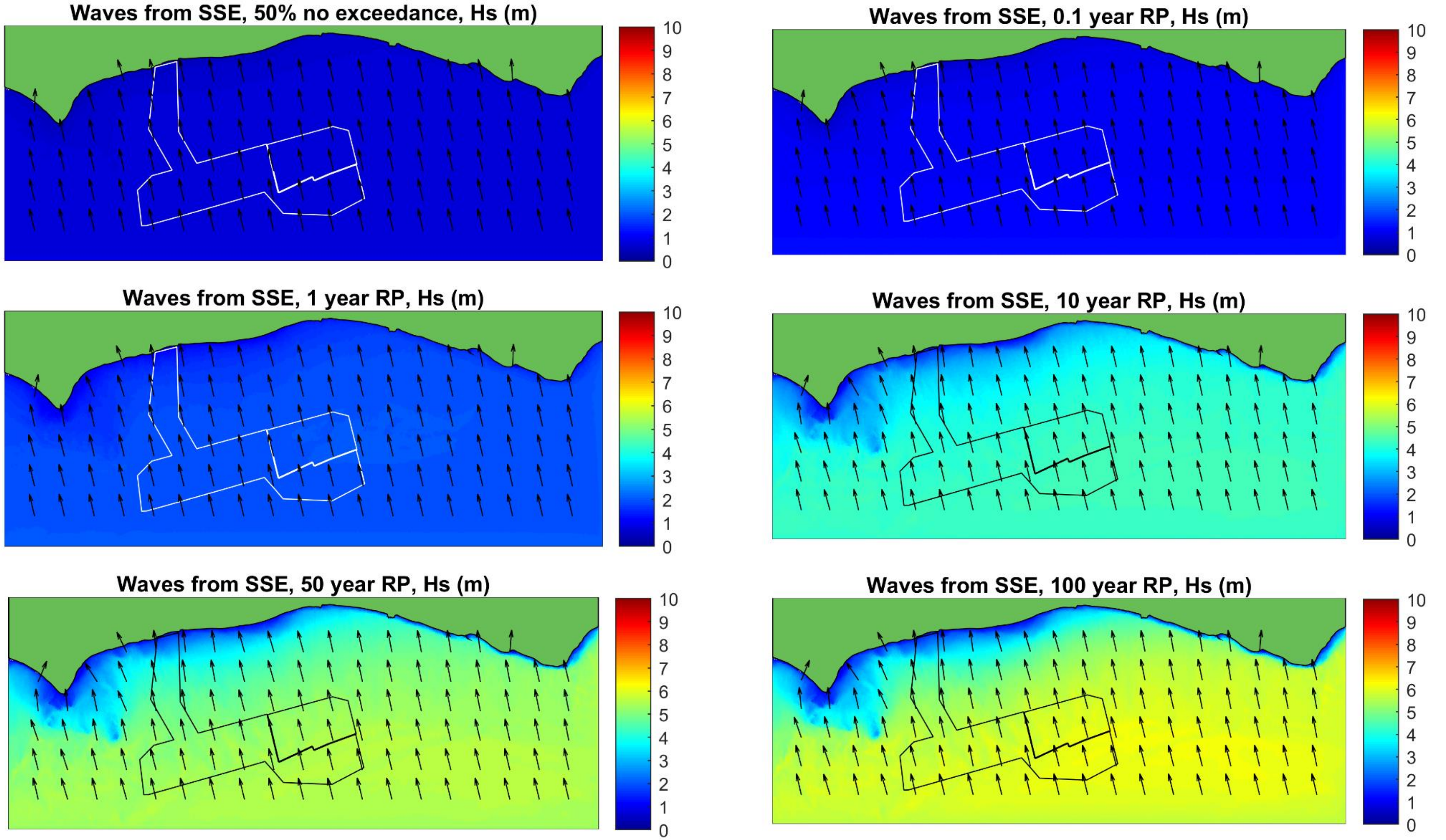


Figure A-5 Baseline significant wave height, waves from the southeast, all return periods

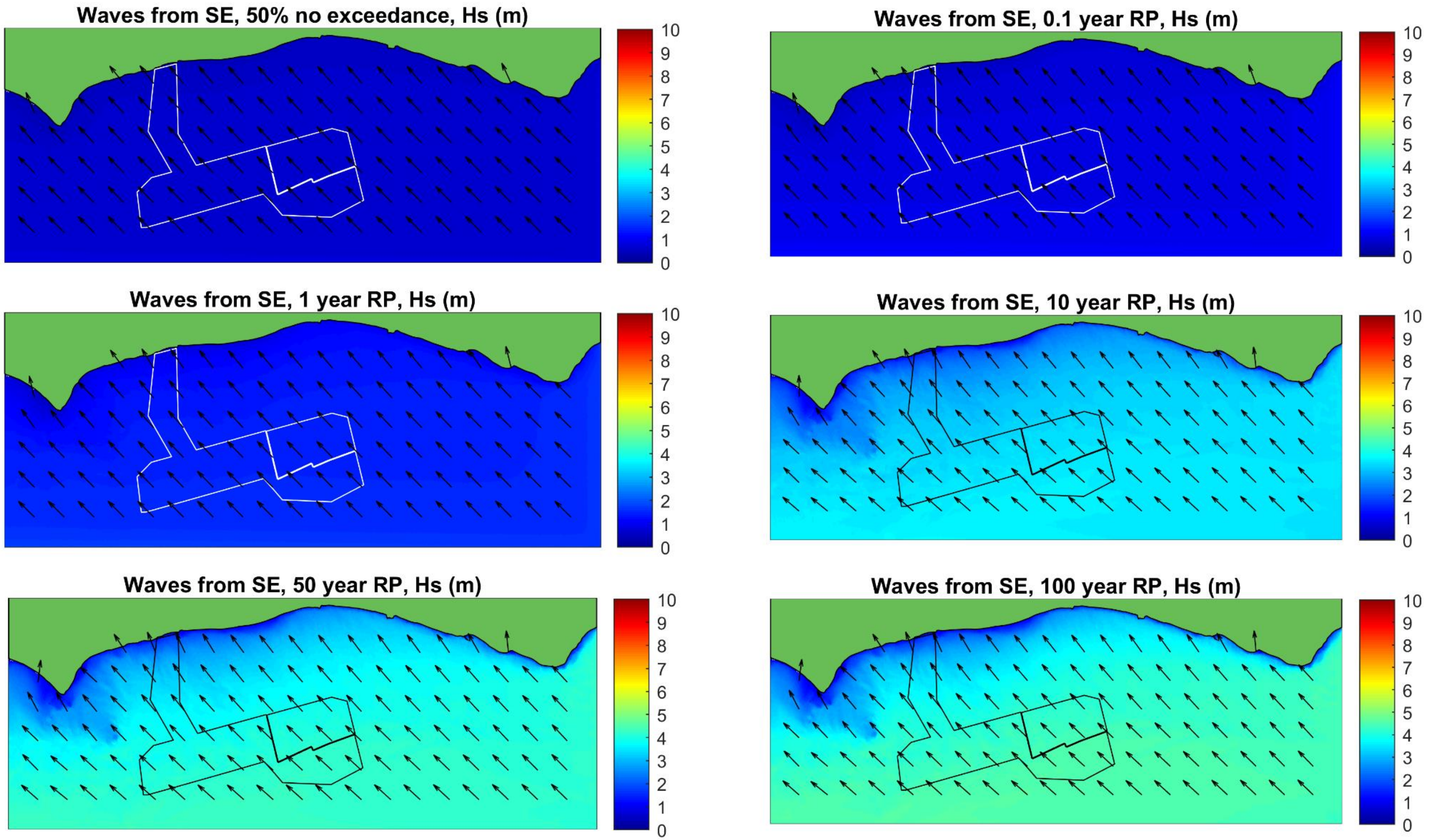


Figure A-6 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the southwest, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 1; Rampion 1 as built

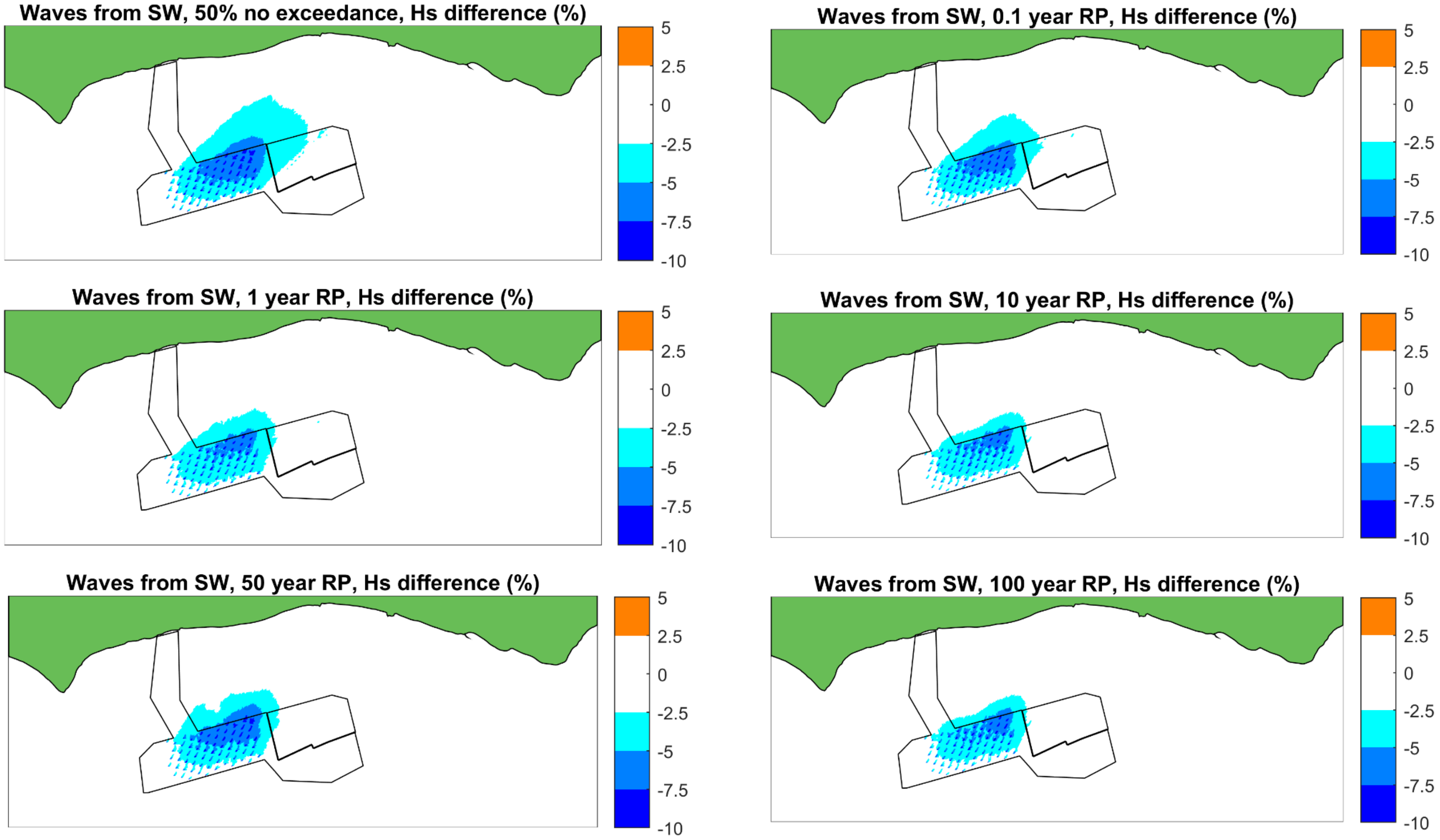


Figure A-7 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south-southwest, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 1; Rampion 1 as built

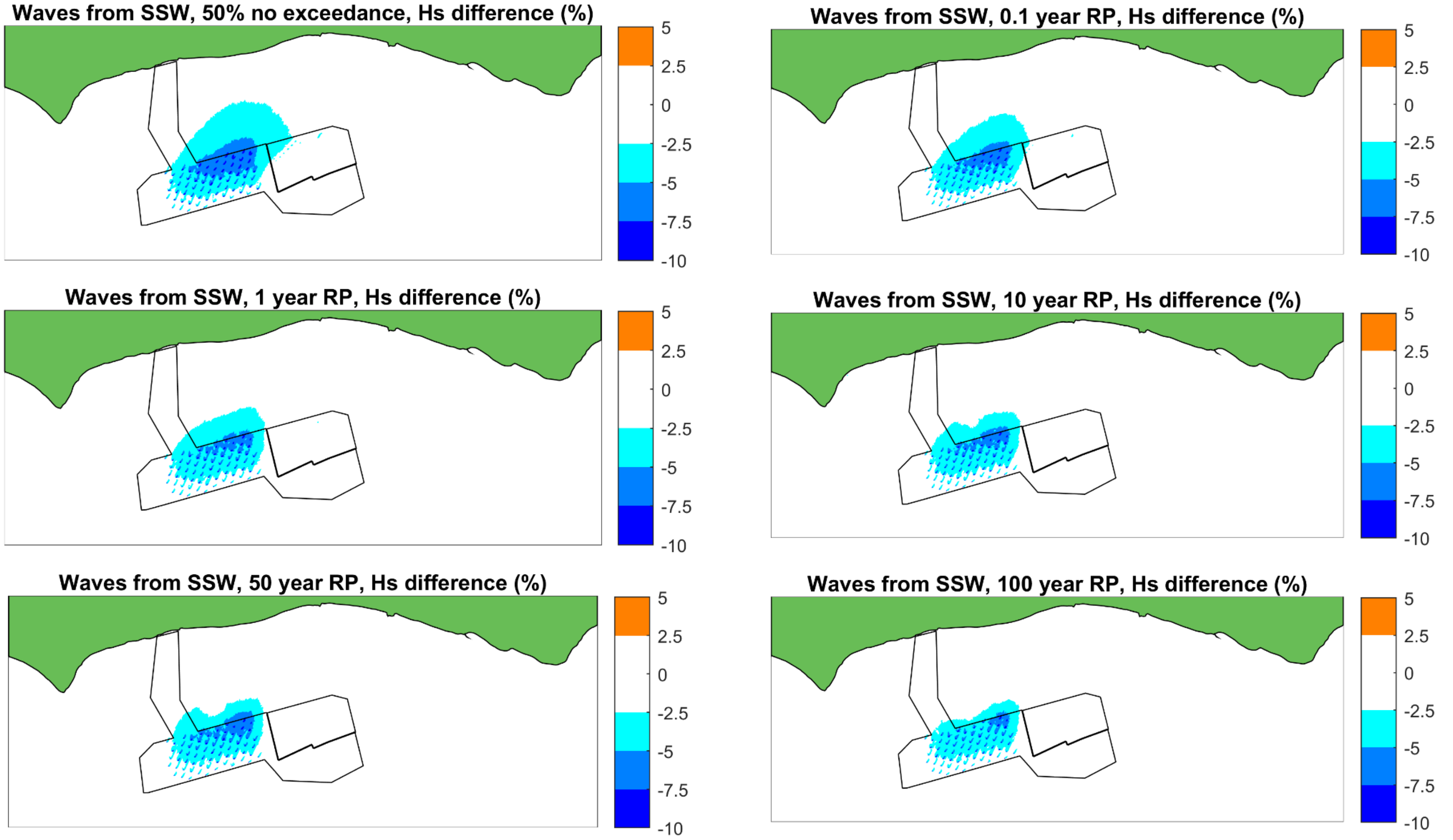
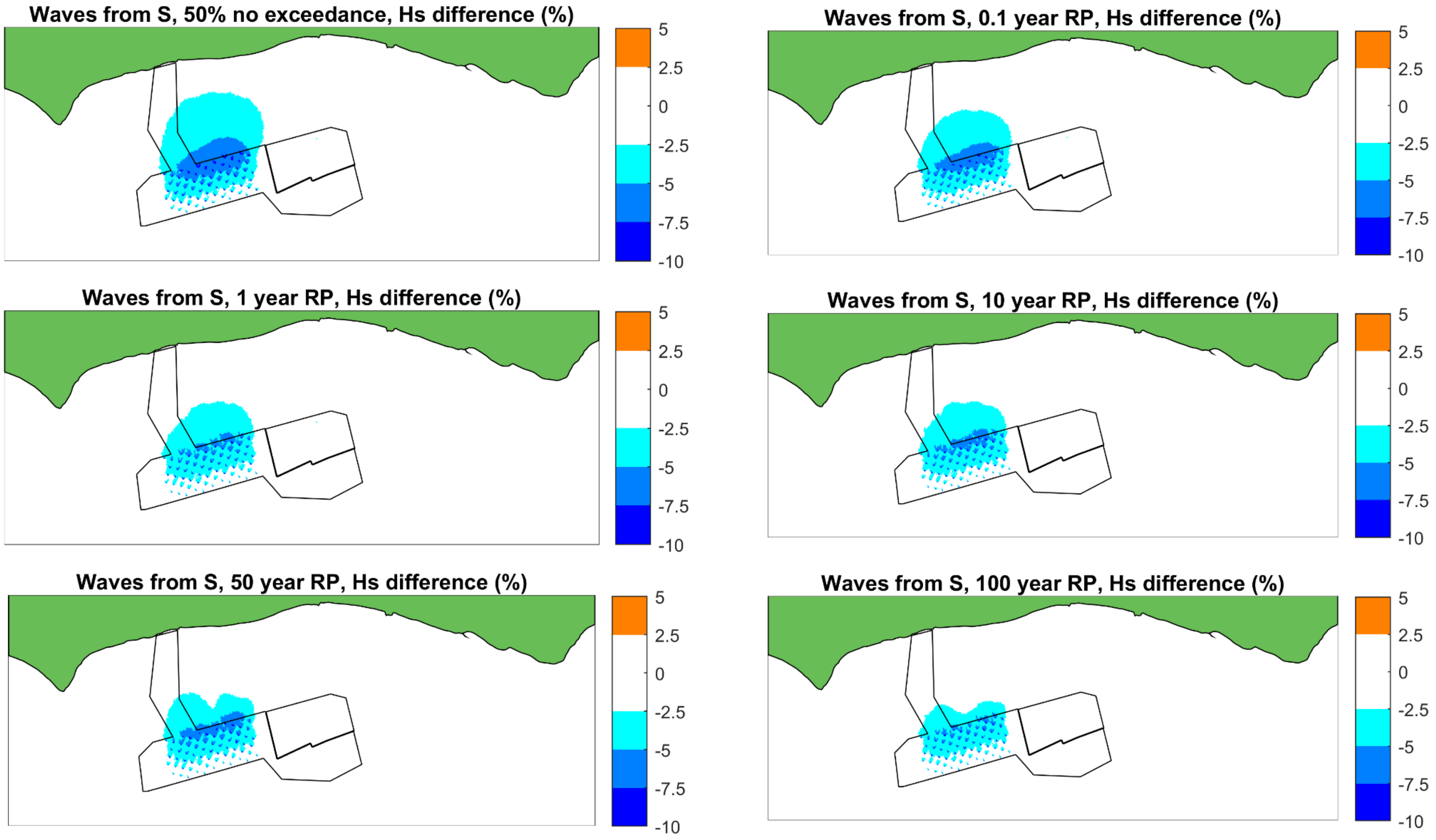


Figure A-8 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 1; Rampion 1 as built



Waves from S, 50% no exceedance, Hs difference (%)

Waves from S, 0.1 year RP, Hs difference (%)

Waves from S, 1 year RP, Hs difference (%)

Waves from S, 10 year RP, Hs difference (%)

Waves from S, 50 year RP, Hs difference (%)

Waves from S, 100 year RP, Hs difference (%)

Figure A-9 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south-southeast, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 1; Rampion 1 as built

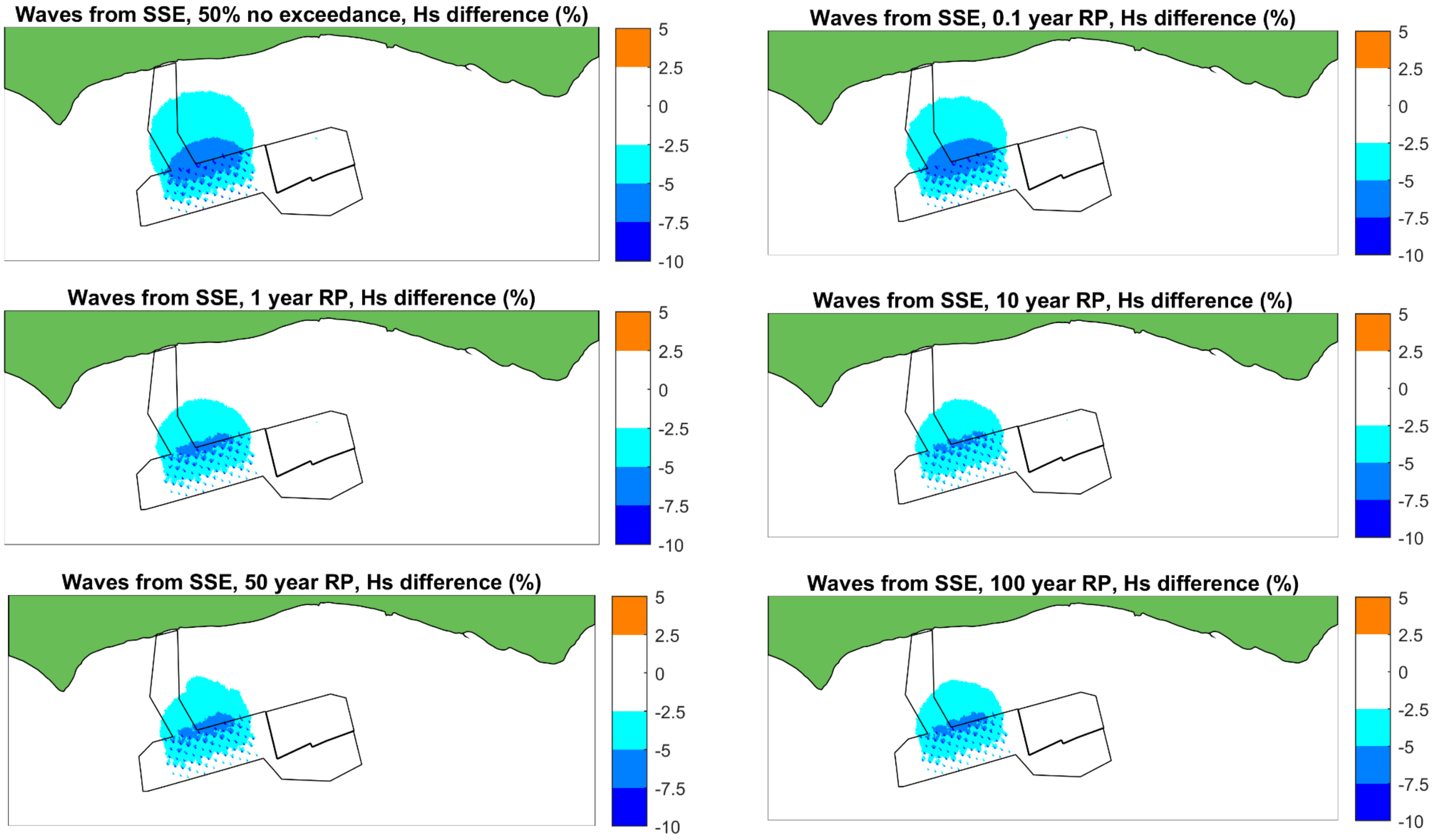


Figure A-10 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the southeast, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 1; Rampion 1 as built

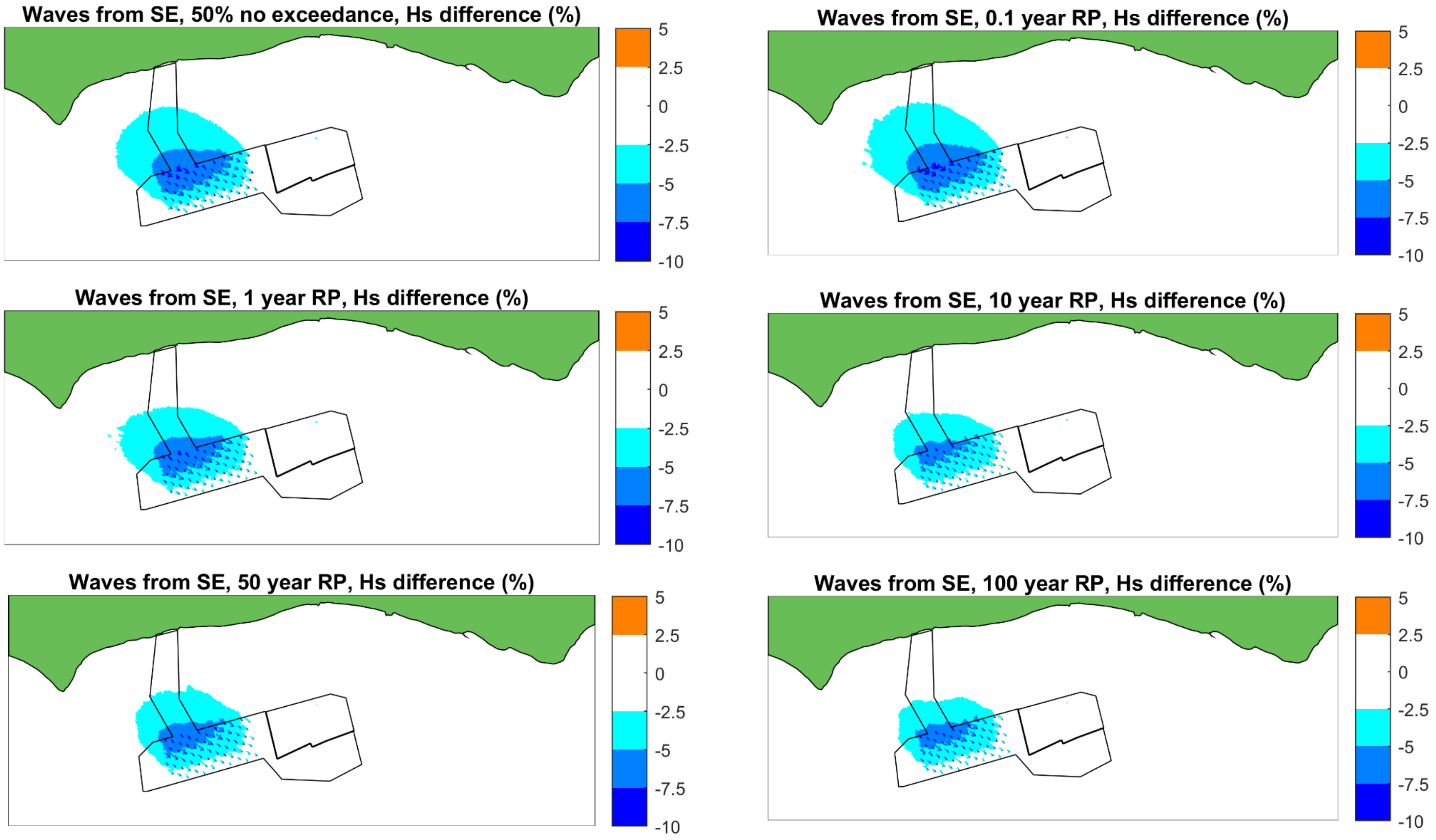


Figure A-11 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the southwest, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 2; Rampion 1 as built

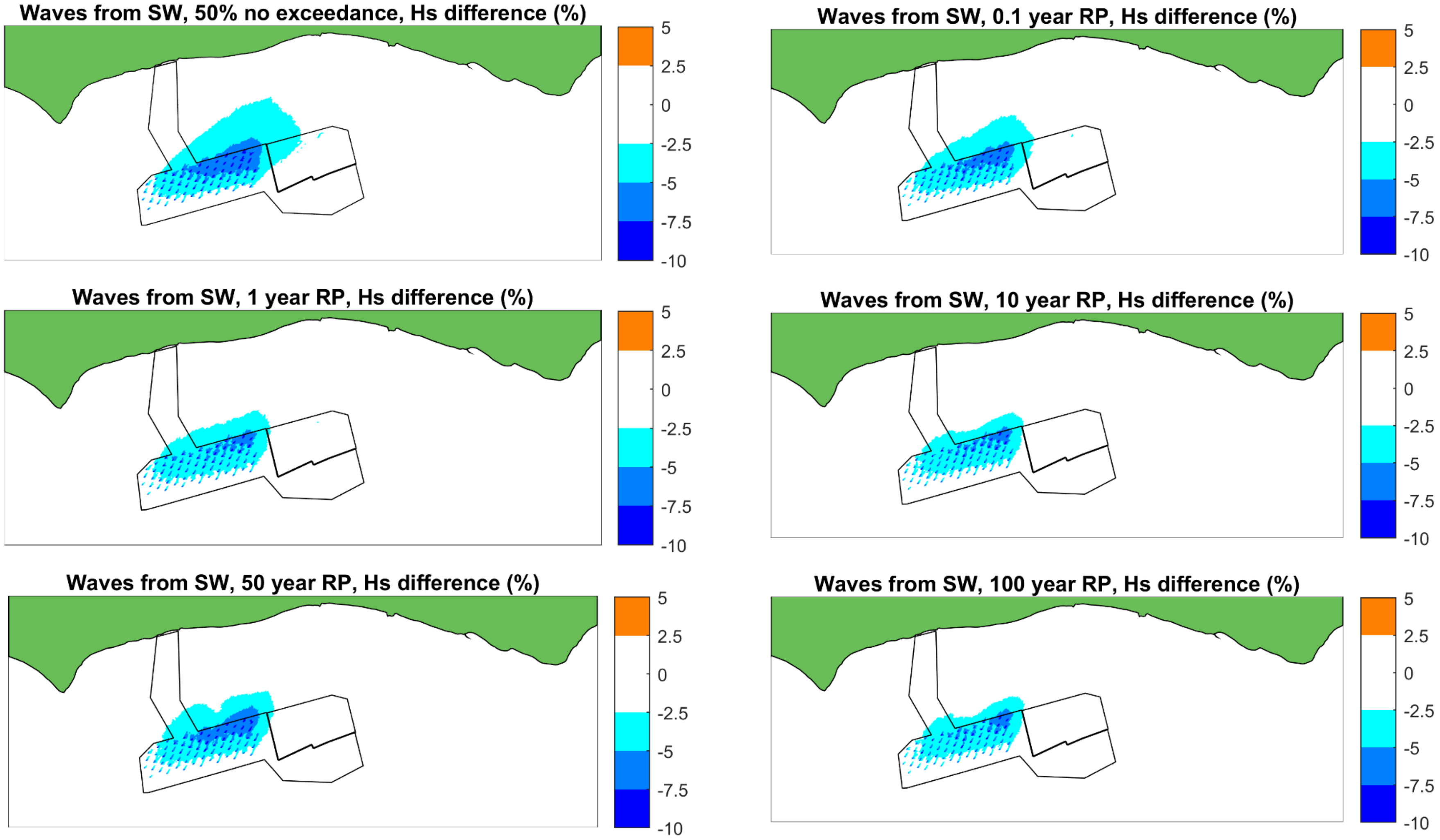


Figure A-12 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south-southwest, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 2; Rampion 1 as built

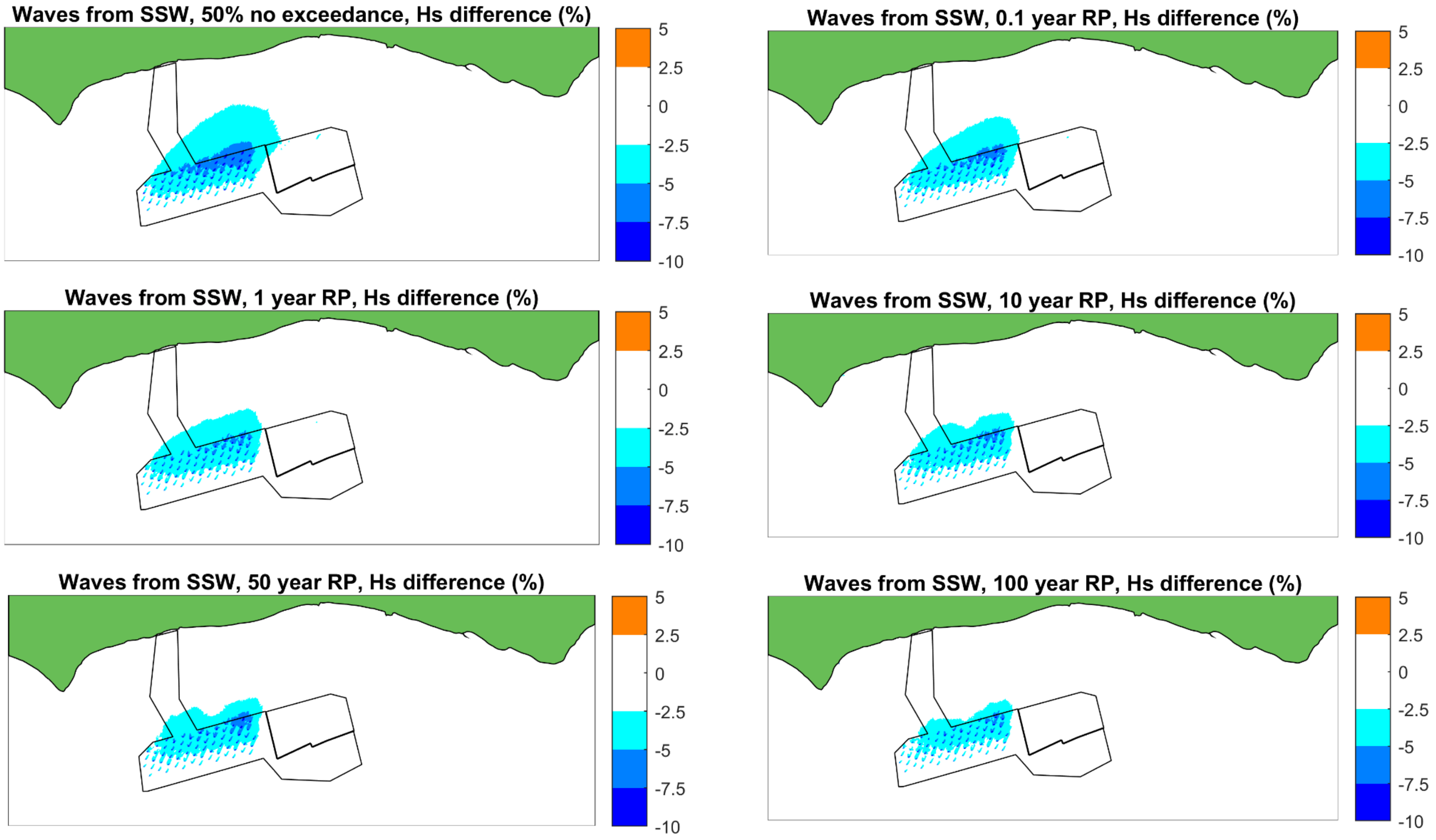


Figure A-13 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 2; Rampion 1 as built

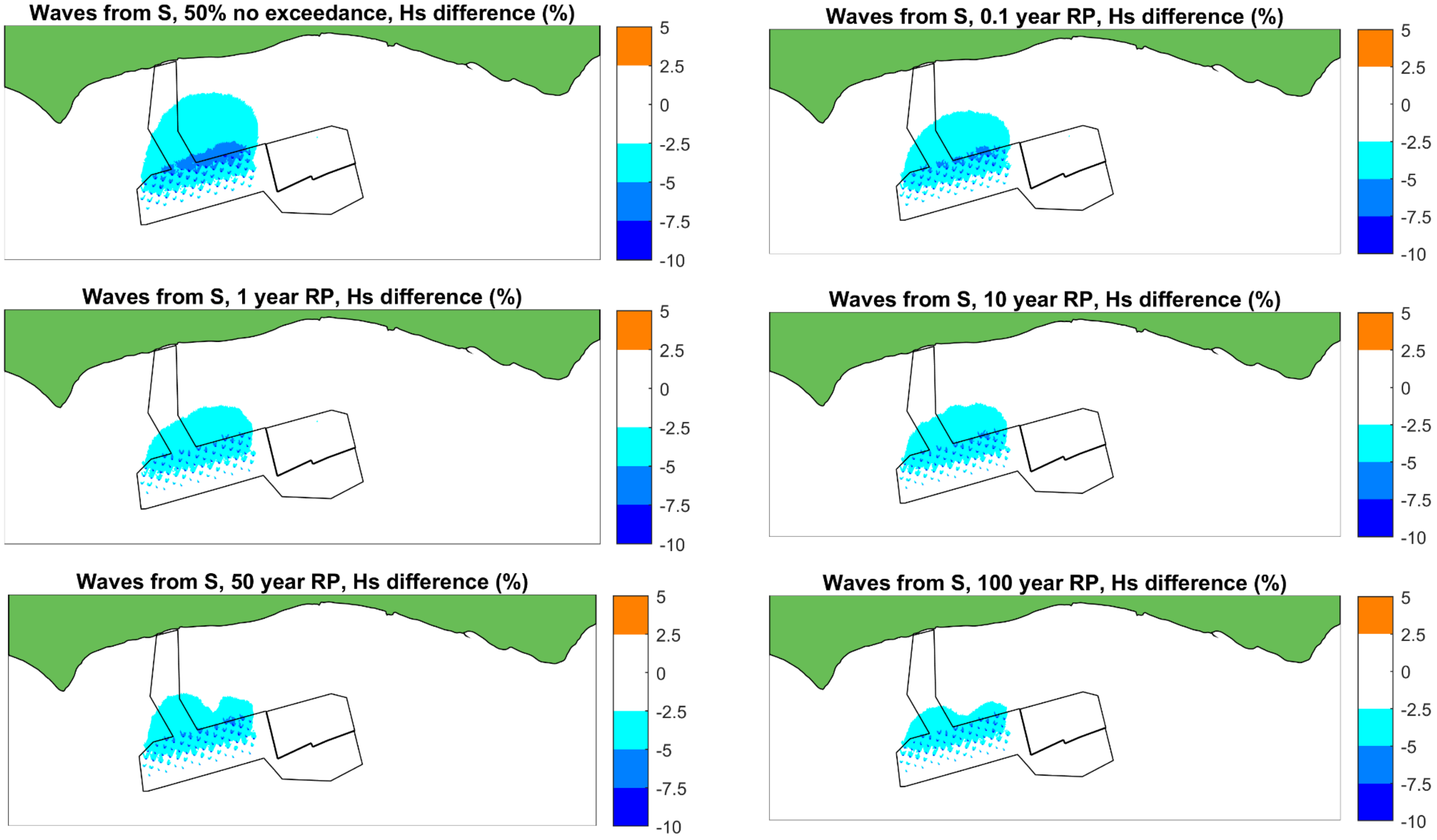


Figure A-14 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south-southeast, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 2; Rampion 1 as built

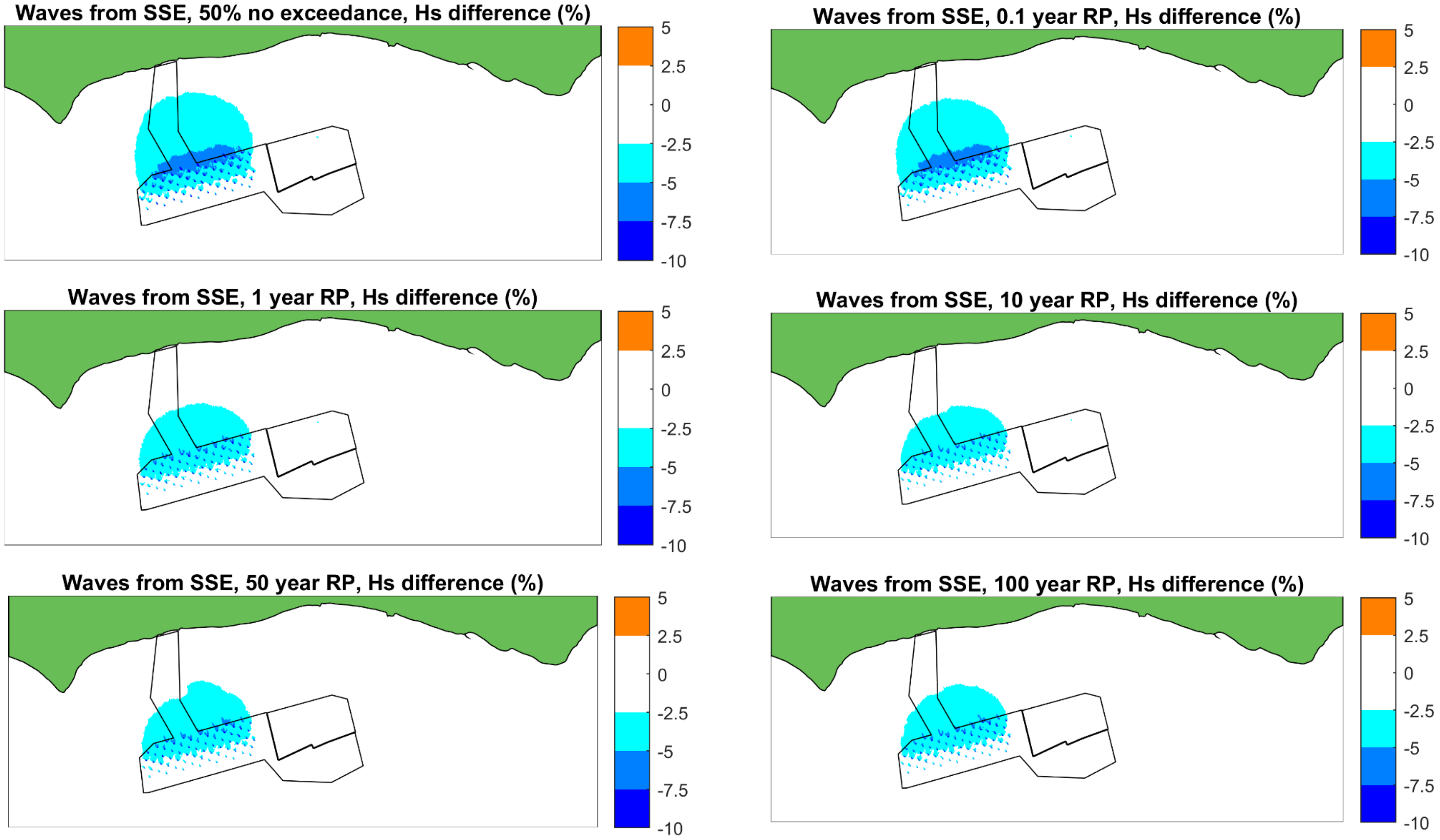


Figure A-15 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the southeast, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 2; Rampion 1 as built

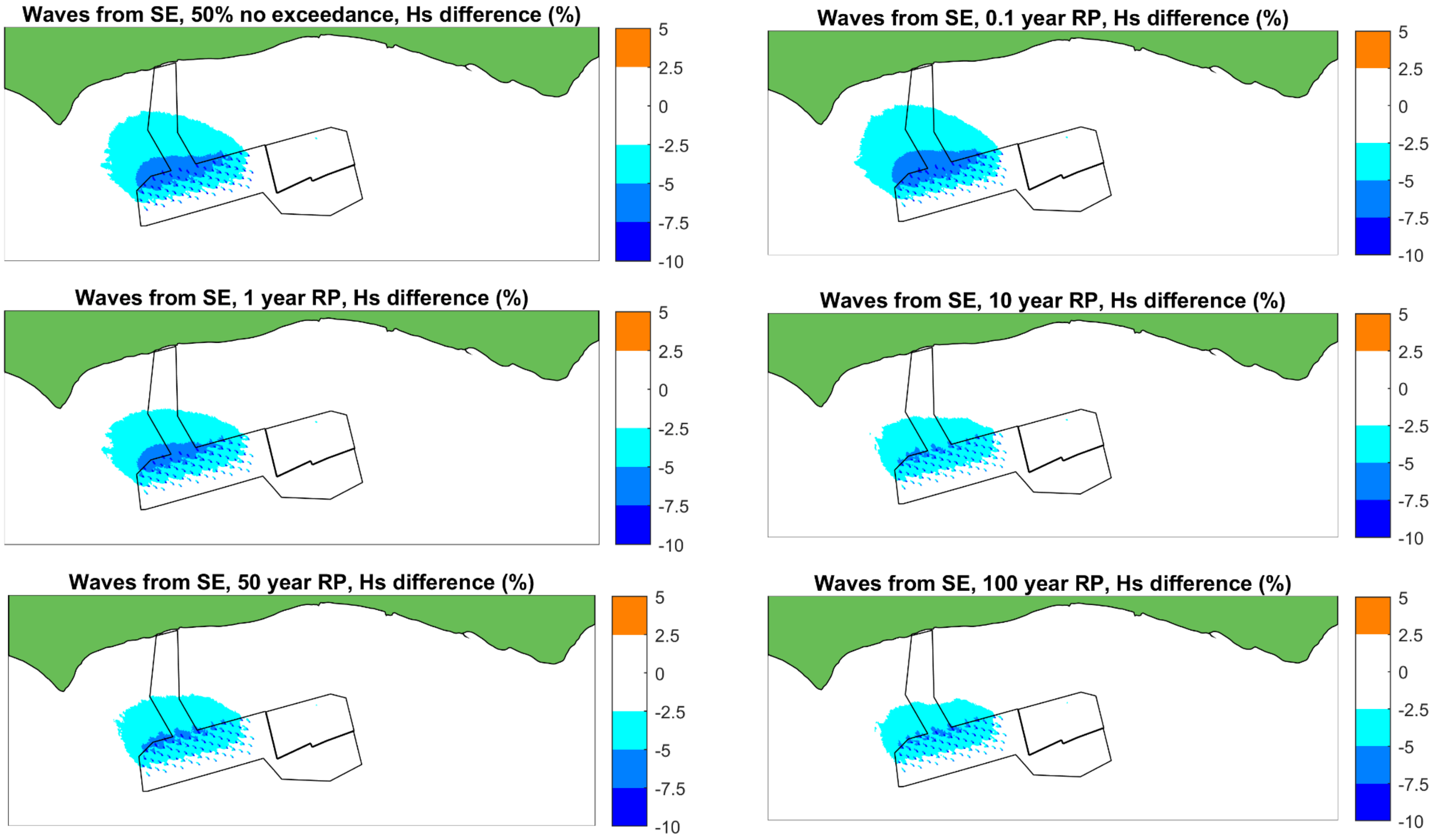


Figure A-16 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the southwest, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 3; Rampion 1 as built

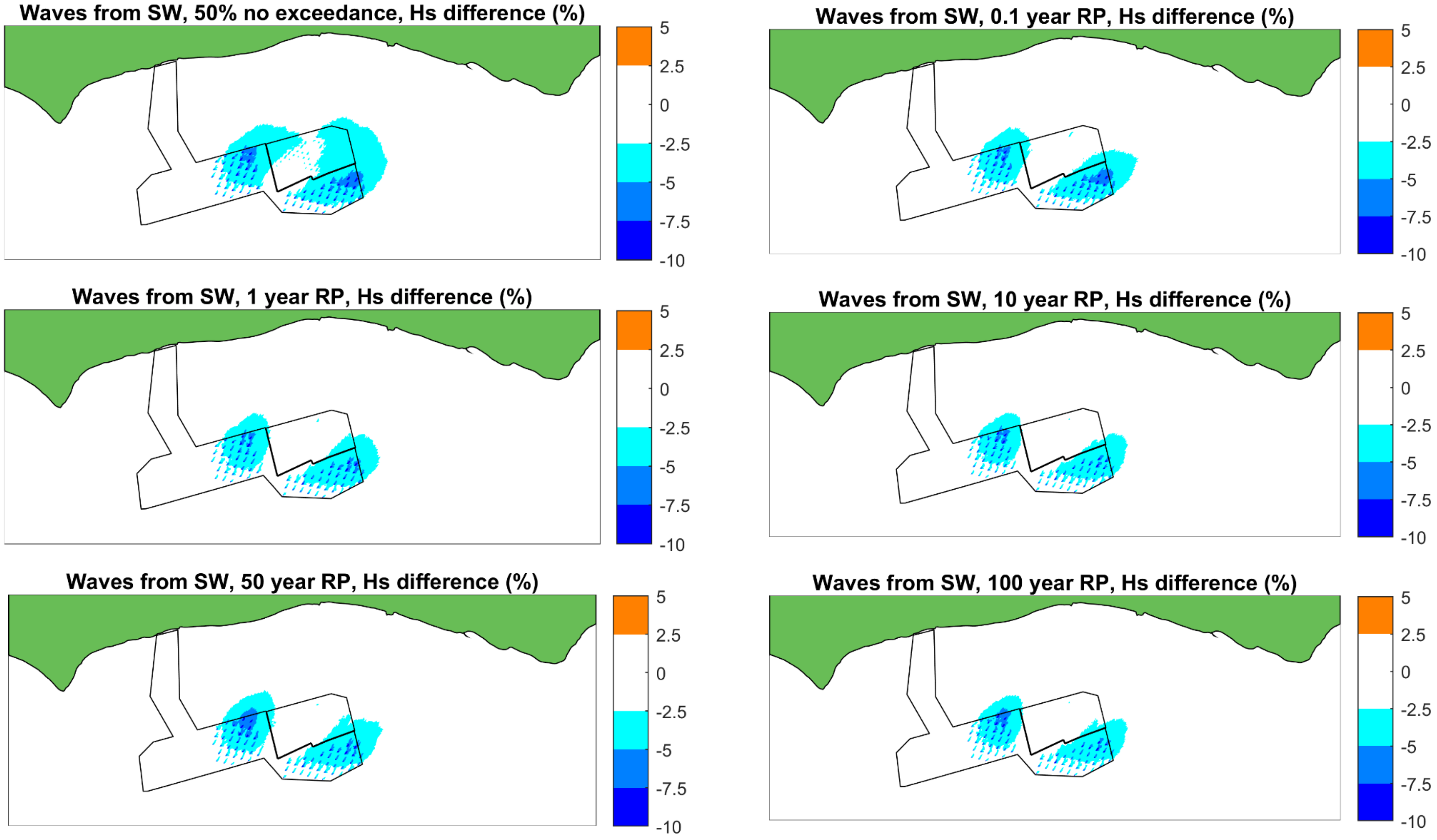
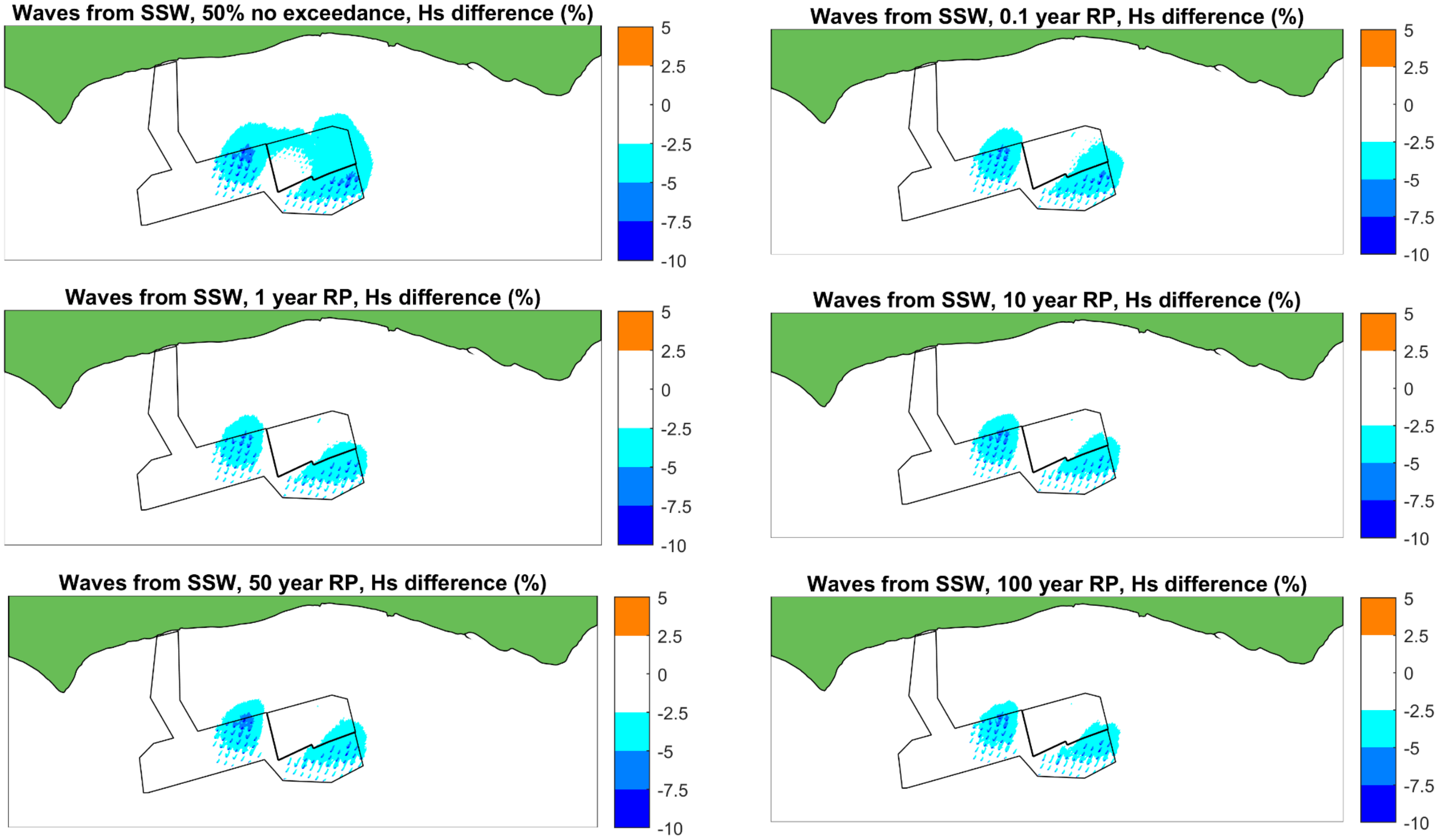


Figure A-17 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south-southwest, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 3; Rampion 1 as built



Waves from SSW, 50% no exceedance, Hs difference (%)

Waves from SSW, 0.1 year RP, Hs difference (%)

Waves from SSW, 1 year RP, Hs difference (%)

Waves from SSW, 10 year RP, Hs difference (%)

Waves from SSW, 50 year RP, Hs difference (%)

Waves from SSW, 100 year RP, Hs difference (%)

Figure A-18 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 3; Rampion 1 as built

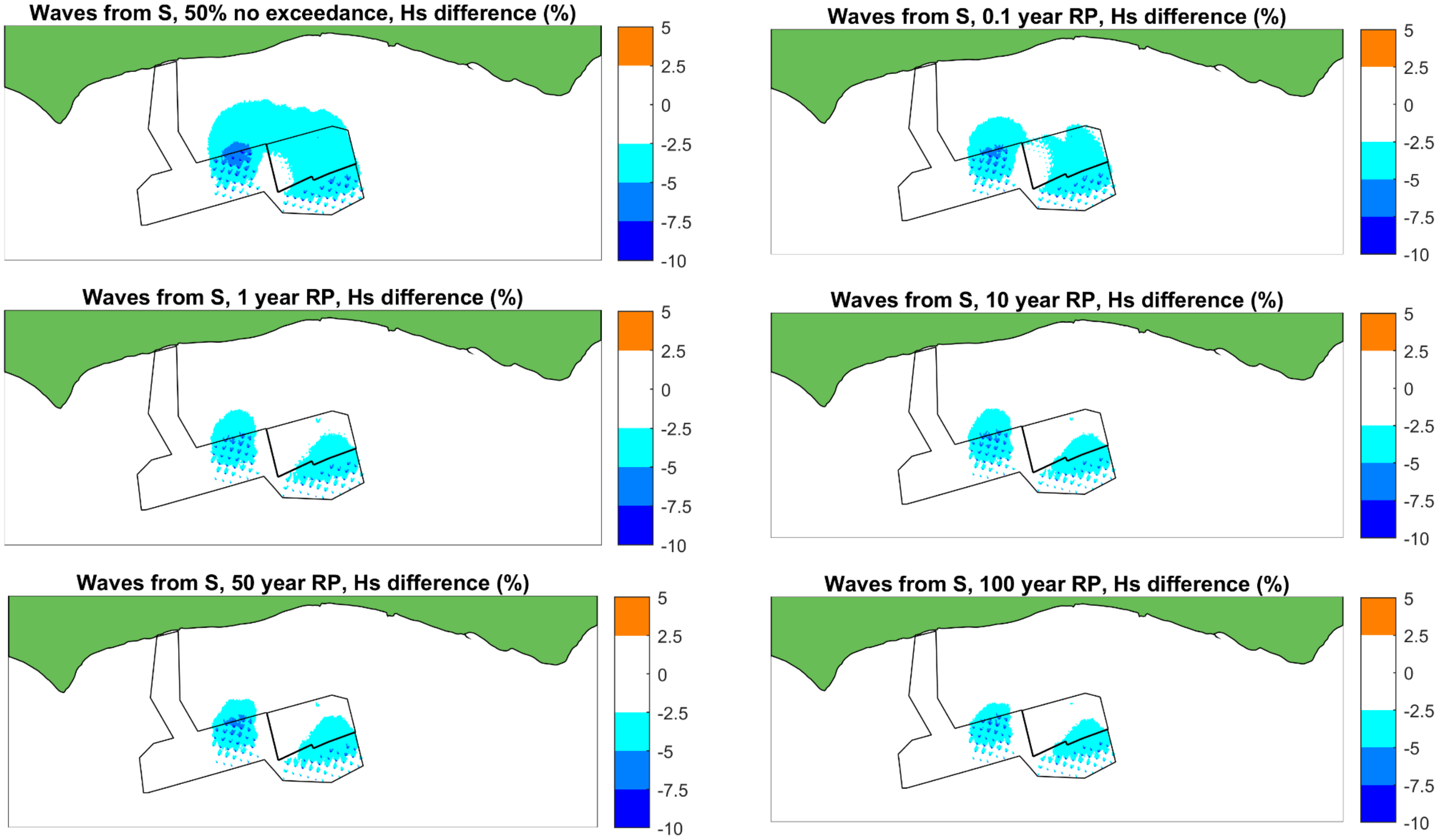


Figure A-19 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the south-southeast, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 3; Rampion 1 as built

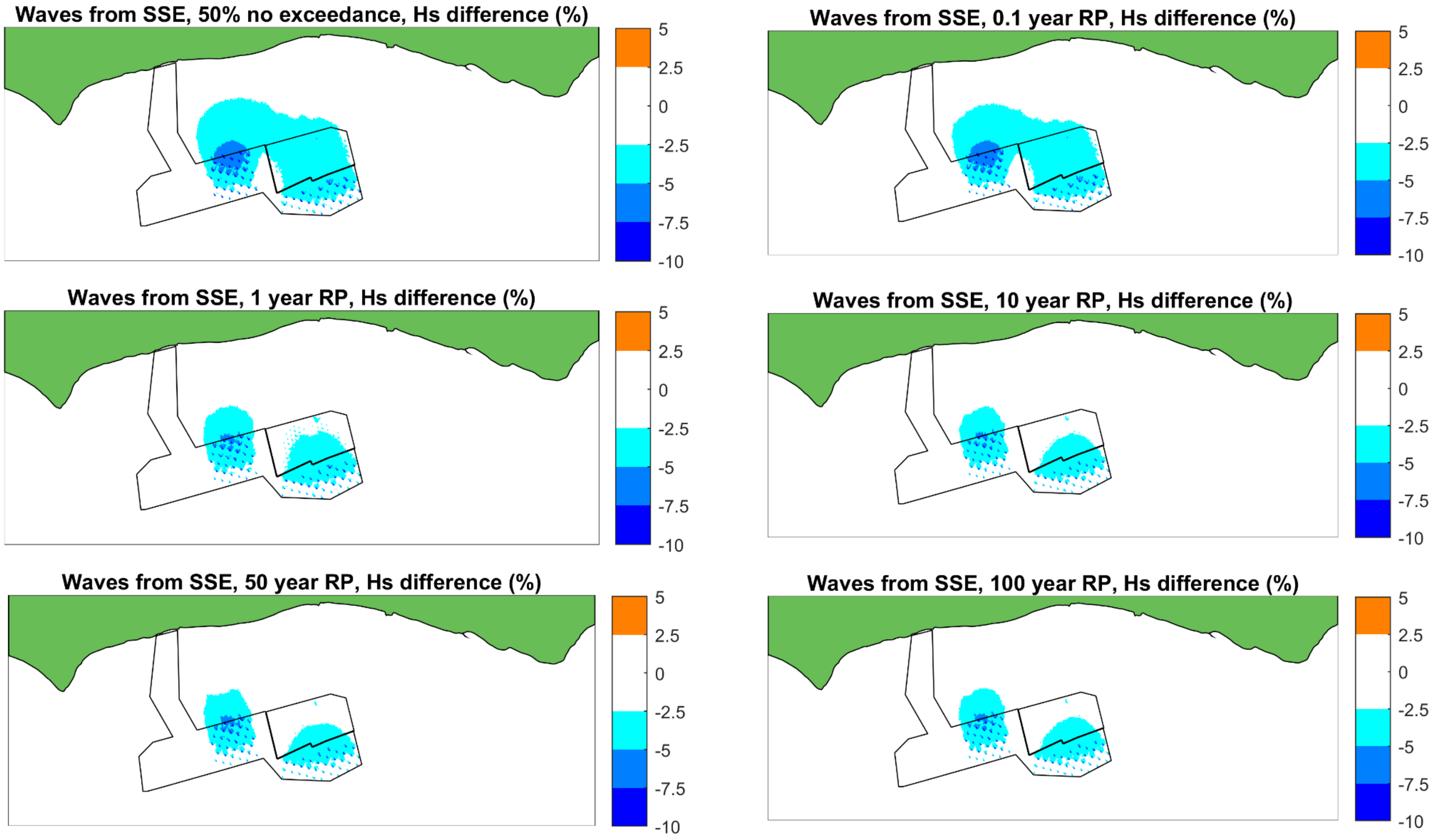
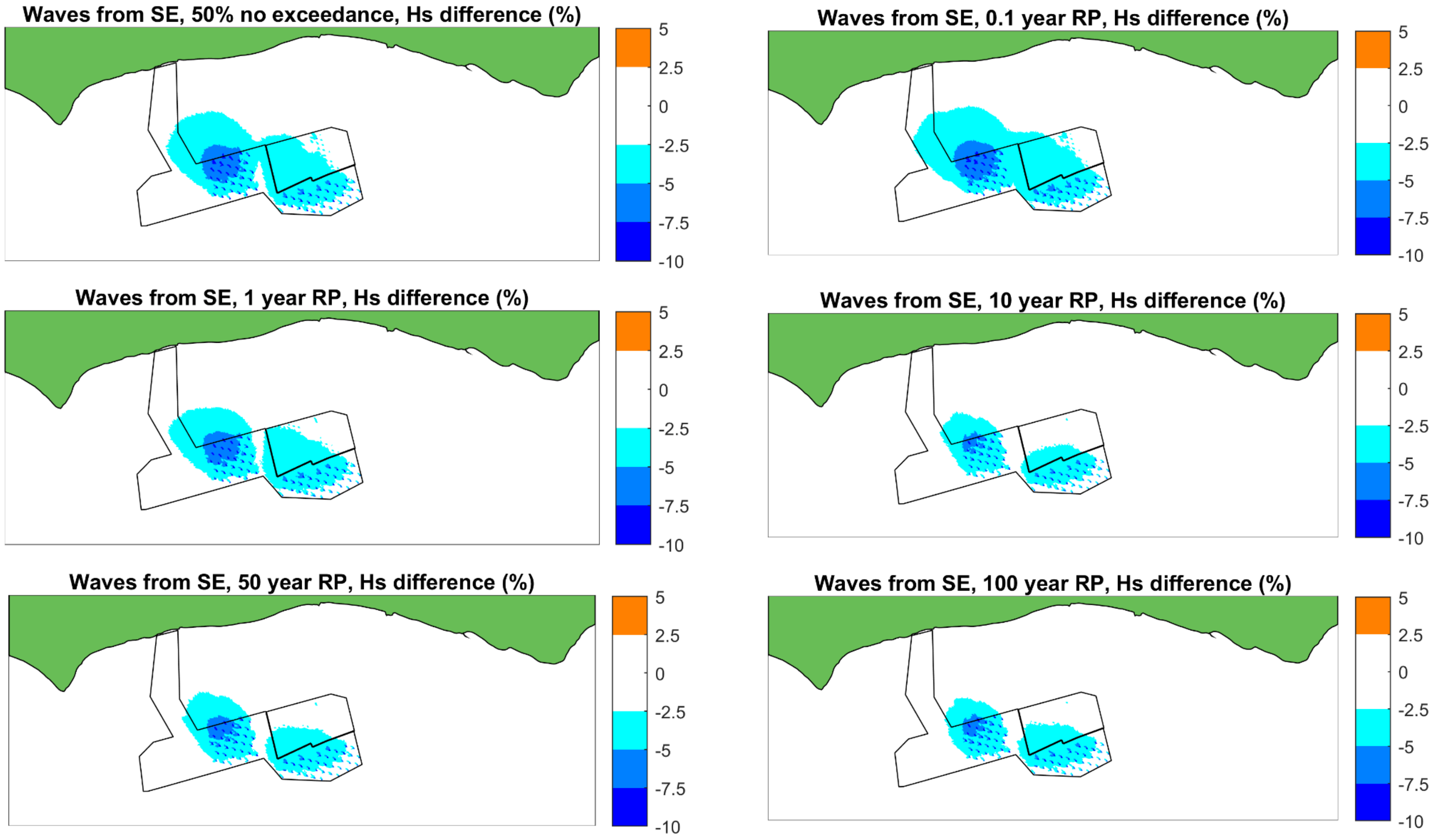


Figure A-20 Percentage difference in significant wave height (scheme minus baseline as a proportion of baseline values), operational phase, waves from the southeast, all return periods. Negative values are a reduction in wave height as a result of the installed infrastructure: Rampion 2 MDS, Layout 3; Rampion 1 as built



Annex B
Scour assessment background and methodology

Overview

In order to quantify the area of seabed that might be affected by scour (either the footprint of scour or scour protection), estimates of the theoretical maximum depth and extent of scour are provided below. Estimates are made of the primary scour, i.e., the scour pit directly associated with the presence of the main obstacle. The equilibrium primary scour depth for each foundation type has been conservatively calculated assuming the absence of any scour protection, using empirical relationships described in Whitehouse (1998). This analysis considers scour resulting from the characteristic wave and current regime, both alone and in combination.

The project description (**Chapter 4: The Proposed Development, Volume 2** of the ES (Document Reference: 6.2.4)) provides maximum design scenario extents of scour protection for each foundation type. Scour protection might be applied around the base of some or all foundations depending upon the seabed conditions and other engineering requirements. By design, scour protection will largely prevent the development of primary scour, but may itself cause smaller scale secondary scour due to turbulence at the edges of the scour protection area.

Assumptions

The following scour assessment reports the estimated equilibrium scour depth, which assumes that there are no limits to the depth or extent of scour development by time or the nature of the sedimentary or metocean environments. As such, the results of this study are considered to be conservative and provide an (over) estimation of the maximum potential scour depth, footprint and volume. Several factors may naturally reduce or restrict the equilibrium scour depth locally, with a corresponding reduction in the area and volume of change.

This study makes the basic assumption that the seabed comprises an unlimited thickness of uniform non-cohesive and easily eroded sediment. The Rampion 2 specific surveys indicate that whilst unconsolidated surficial sediment is present in many areas, this unit is typically thin (generally less than approximately one metre thick) or absent across much of the proposed DCO Order Limits Offshore Array Areas. In practice, once exposed by initial scouring, the more erosion resistant subsoils are expected to either reduce or prevent further scour, limiting the depth, extent and volume of scour accordingly.

The foundation types, dimensions and numbers used in the assessment are consistent with the project design information provided in **Chapter 4: The Proposed Development, Volume 2** of the ES (Document Reference: 6.2.4)

Reported observations of scour under steady current conditions (in rivers for example) generally show that the upstream slope of the depression is typically equal to the angle of internal friction for the exposed sediment (typically 32 degrees in loose medium sand;

Hoffmans and Verheil, 1997) but the downstream slope is typically less steep. In reversing (tidal) current conditions, both slopes will develop under alternating upstream and downstream forcing and so will tend towards the less steep or an intermediate condition. For the purposes of the present study a representative angle of internal friction (32 degrees) will be used as the characteristic slope angle for scour development.

Equilibrium scour depth

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

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

$$\mathrm{S_{extent}} = \frac{S_e}{tan32°} \approx S_e \times 1.6$$

(Eq. 1)

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

$$\mathrm{S_{footprint}} = \pi\ \mathrm{S_{extent}} + \frac{\mathrm{D}^2}{2}\ \ \pi \frac{\mathrm{D}^2}{2}$$

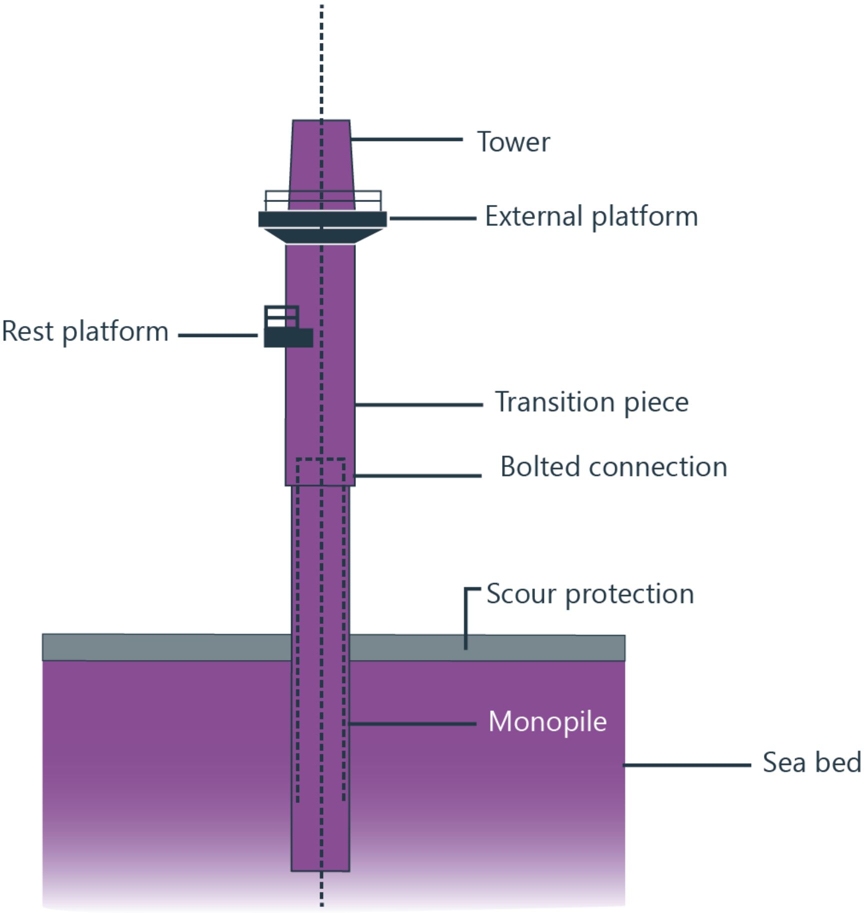
(Eq. 2)

The scour pit volume is calculated as the volume of an inverted truncated cone described by Equations 1 and 2 above, accounting for the presence of the foundation but excluding its volume.

Scour assessment method: Monopiles

The outline design of the proposed monopile structure is shown in **Figure B-1**. Compared to other more complex foundation types, scour around upright slender monopile structures in steady currents is relatively well-understood in the literature and is supported by a relatively large empirical evidence base from the laboratory and from the field. The maximum equilibrium scour depth, adjacent to the structure, below the mean seabed level (S_e), is typically proportional to the diameter of the monopile and is therefore expressed in units of monopile diameter (D).

Figure B-1 Outline design of a typical steel monopile foundation (with scour protection)



Under steady currents

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

$$\frac{S_c}{D}=1.3\pm\sigma_{S_c/D}$$

(Eq. 3)

Where S_c is the equilibrium scour depth due to currents and $\sigma_{Sc/D}$ is the standard deviation of observed ratio S_c/D. Based on the experimental data, $\sigma_{Sc/D}$ is approximately 0.7, hence, 95 percent of observed scour falls within two standard deviations (in the range $0 < S_c/D < 2.7$). Based on the central value $S_c = 1.3$ D (as also recommended in DNV, 2016), the maximum equilibrium depth of scour for the largest diameter monopile (10m) is estimated to be 13m. The equivalent value for the smallest diameter monopile (8.5m) is 11.1m.

Under waves and combined wave-current forcing

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

$$KC = \frac{U_{0m} T}{D}$$

(Eq. 4)

Where U_{0m} is the peak orbital velocity at the seabed (using methods presented in Soulsby, 1997) and T is the corresponding wave period. Sumer and Fredsøe (2001) found that for KC less than 6, wave action is insufficient to cause significant scour in both wave alone and combined wave-current scenarios.

Values of KC are less than six for monopiles in the proposed DCO Order Limits, for a range of extreme wave conditions (**Figure B-1**) and for the full expected range of tidally affected water depths (approximately 16 to 70m). Therefore, it is predicted that waves do not have the potential to contribute to scour development around monopiles in the proposed DCO Order Limits.

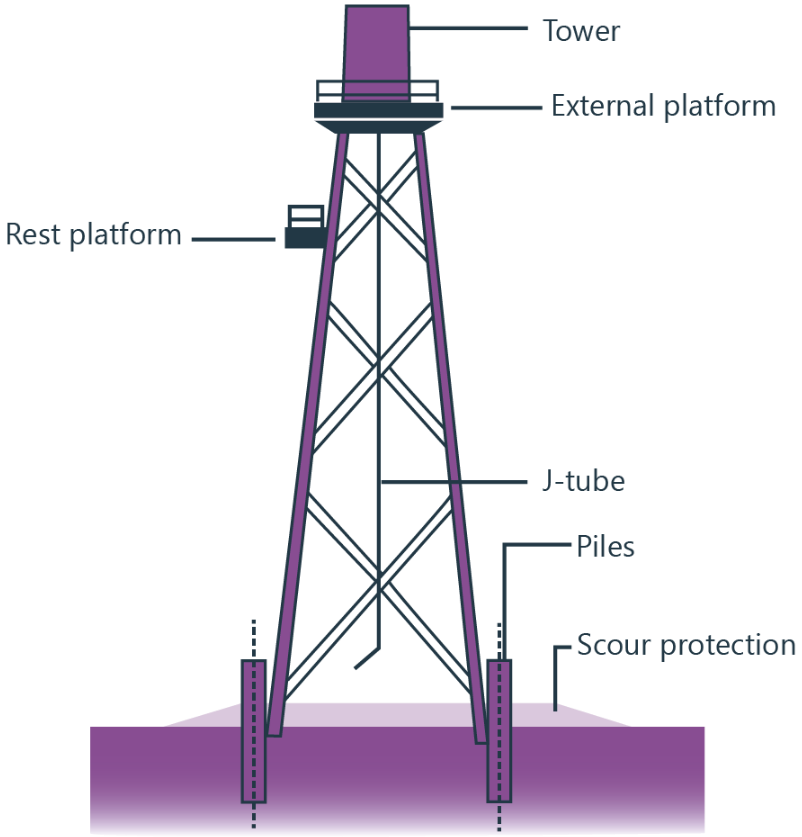
Table B-1 Extreme wave conditions considered

Return Period (years)	Significant Wave Height (m)	Peak wave period (s)
1-year RP	5.2	9.5
10-year RP	7.4	11.3
100-year RP	8.7	12.2

Scour assessment method: Jacket foundations

The outline design of the proposed jacket foundation for WTGs is shown in **Figure B-2**. Above the seabed, jacket foundations comprise a lattice of vertical primary members and diagonal cross-member bracing, up to three metres and two metres in diameter, respectively. Near-bed horizontal cross-member bracing may be present but is assumed to be sufficiently high above the bed to not induce significant local scour. The jacket foundation will have a nominally square plan view cross-section with base edge dimensions up to 30m.

Figure B-2 Outline design of a representative jacket foundation (with scour protection)



The jacket foundation is anchored to the seabed at each corner by a pile driven into the seabed, up to three metre in diameter. A jacket foundation structure may result in the occurrence of both local and group or global scour. The local scour is the local response to individual structure members. Global scour refers to a region of shallower but potentially more extensive scour associated with a multi-member foundation resulting from the change in flow velocity through the gaps between members of the structure and turbulence shed by the entire structure. Global scour does not imply scour at the scale beyond the individual foundation (of the wind farm array).

Under steady currents

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

The main scour development will be in proportion to the size of the largest exposed member near to the seabed. In this case, the largest exposed member will be the leg pile. Using Equation Three, the scour depth for the larger WTG type jacket foundation (leg pile diameter three metres) is therefore estimated as 3.9m. The equivalent value for the smaller WTG type jacket foundation (leg pile diameter of 2.5m) is 3.25m.

In the case of currents, inter-member interaction has been shown to be a factor when the gap to pile diameter ratio (G/D) is less than three. In this case limited experiments by

Gormsen and Larson (1984) have shown that the scour depth might increase by between five and 15%. However, in the case of the present study the gap ratio for members at the base of the jacket foundation structure is much greater than three, and so no significant in-combination change is expected.

Empirical relationships also presented in Sumer and Fredsøe (2002) indicate that the depth of group scour (measured from the initial sediment surface to the new sediment surface surrounding local scour holes) for an array of piles similar to a jacket foundation (2 x 2) can be approximated as 0.4 D (approximately 1.2m based on three metre diameter jacket leg pile). On the basis of visual descriptions of group scour pits, their extent from the edge of the structure is estimated as half the width of the structure and following a broadly similar plan shape to that of the (square) jacket foundation.

Together, the predicted maximum scour depth at the corner piles (3.9m) and the group scour (1.2m) is conservatively consistent with evidence from the field reported in Whitehouse (1998), summarising another report that scour depths of between 0.6m and 3.6m were observed below jacket structures in the Gulf of Mexico (although these could potentially be constrained from the maximum possible equilibrium scour depth by environmental factors and could also be subject to uncertainties in the seabed reference datum against which to measure the scour).

On the basis of the proposed jacket design, the diagonal bracing members are not predicted to induce seabed scouring due to the distance of separation from the seabed.

Under waves and combined wave-current forcing

Values of the KC parameter (Eq. 4) were calculated for a 4m diameter jacket leg pile from the extreme wave conditions estimated for the proposed DCO Order Limits Offshore Array Areas (**Figure B-1**). Values of KC are less than six over the full expected range of tidally affected water depths (approximately 16 to 70m) and so it is predicted that waves do not have the potential to contribute to scour development around the base of the jacket foundations.

The diagonal bracing members will have a smaller diameter and so a larger KC value. However, they are again not predicted to induce seabed scouring due to the distance of separation from the seabed. For moderate KC numbers a sufficient distance to avoid scour is approximately one diameter for a horizontal member, increasing to approximately three diameters under increasing KC numbers.

As such, little or no significant additional scour is predicted to result from waves, either alone or in combination with currents.

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Rampion 2
WIND FARM