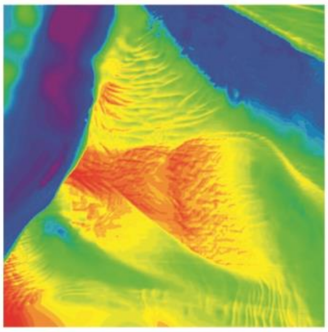
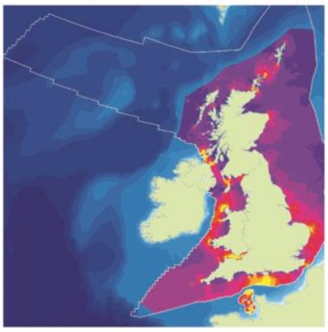
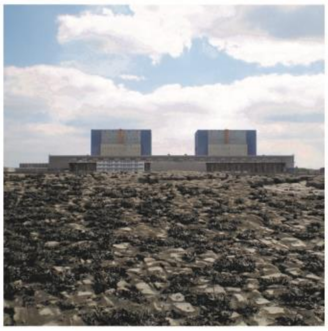
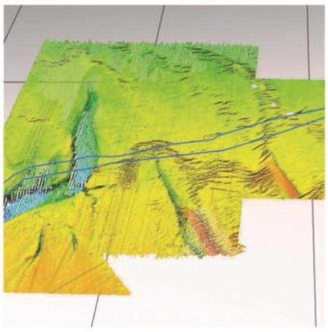
MarineSpace Ltd

Erebus Floating Offshore Wind Farm

Volume 3, Annex 6.1: Marine and Coastal Processes Technical Annex

November 2021

Innovative Thinking - Sustainable Solutions

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1 Introduction

ABPmer has been commissioned to undertake the Environmental Impact Assessment (EIA) for the potential impacts of the Erebus floating offshore wind farm (hereafter referred to as the 'Proposed Development') in relation to marine and coastal processes, which is a collective term for the following:

- Water levels;
- Currents;
- Waves (and winds);
- Sediments and geology (including seabed sediment distribution and sediment transport);
- Seabed geomorphology; and
- Coastal geomorphology.

The array area for the Proposed Development would be located approximately 35km offshore, southwest of Pembrokeshire, Wales (Figure 1). Electricity generated would be transported to the shore by an offshore export cable installed within the Proposed Development offshore Export Cable Corridor (ECC), making landfall in West Angle Bay, inside the entrance to Milford Haven.

This technical report provides a detailed assessment of the changes to suspended sediment concentrations (SSC), bed levels and sediment type as a consequence of sediment disturbance during the construction and decommissioning phases of the Proposed Development. The findings of this report have been summarised in Volume 1 Chapter 6: Marine and Coastal Processes and are used to inform assessments for other EIA receptor groups which may potentially be sensitive to changes in SSC and sediment deposition. The effects of scour during operation and maintenance are assessed directly within the main Environmental Statement (ES), Volume 1 Chapter 6. Potential effects on the other marine and coastal processes elements listed above, i.e. water levels, currents, waves (and winds), seabed geomorphology and coastal morphology are also presented in detail in ES Volume 1, Chapter 6.

Local increases in SSC may potentially result from the disturbance of sediment by construction, repair or maintenance related activities, namely due to:

- Drilling of pin pile anchors;
- Sandwave levelling by dredging and/or Mass Flow Excavation (MFE);
- Cable burial by ploughing, trenching and jetting (including initial installation and any subsequent cable repairs and/or remediation in the Operational phase);
- Release of drilling fluid during HDD punch out; and
- Open-cut trenching at the landfall.

The following other activities may cause some localised disturbance of sediment but at a rate, scale and duration less than or similar to the activities above and so are not explicitly assessed:

- Installation of drag embedment anchors and associated anchor/mooring systems;
- Installation of suction pile anchors; and
- Deployment of cable protection.

The effects of dredging for the creation of temporary floatation pits near to the landfall are similar to those described in this report for sandwave levelling and are assessed directly within Volume 1 Chapter 6.

Any material mobilised by the activities listed above 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.

The potential changes assessed in this technical annex are summarised in Table 1, alongside the activities giving rise to the change and the project phases in which the change may potentially occur. 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.

Table 1. Potential impacts, pathways and receptors relevant to marine and coastal processes assessed in this technical annex

Potential effect/ change	Relevant activities/ infrastructure	Project phase	Pathway/Receptor
Potential increases in SSC and associated changes to seabed substrate.	Drilling of anchors into hard rock seabed Sandwave levelling Cable burial activities Release of drilling fluid during HDD punch out Open cut trenching	Construction Operation and Maintenance Decommissioning	**Pathway** [Sediment transport]

In most cases, marine and coastal processes are not in themselves receptors but are, instead, 'pathways' which have the potential to indirectly impact other environmental receptors. Table 1 highlights that changes caused to SSC and associated sediment deposition are considered here as potential pathways of change that will be assessed by other EIA topics in relation to other sensitive receptors.

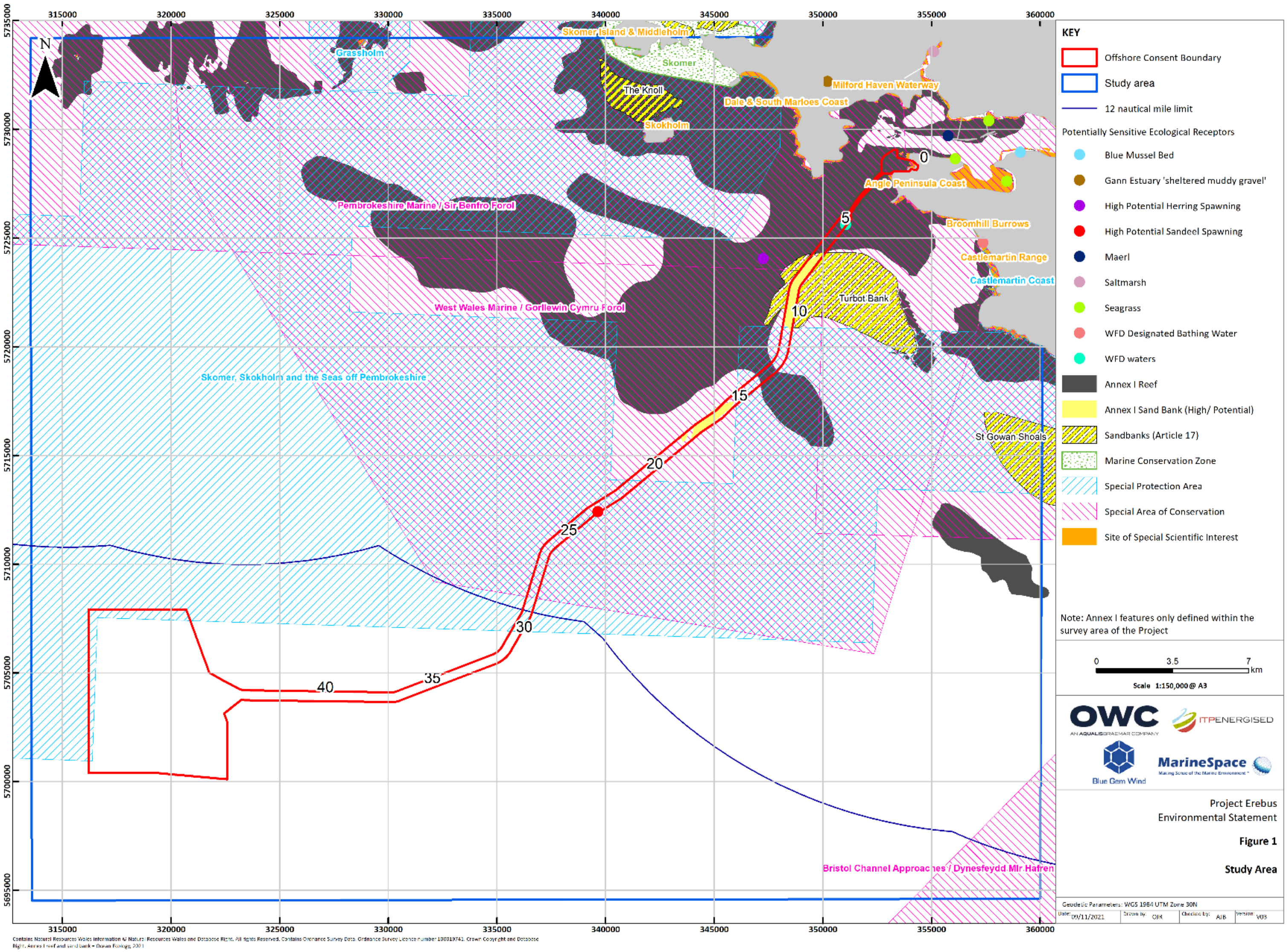

Figure 1. Erebus offshore wind farm marine and coastal processes study area

2 Baseline conditions

A description of the baseline environment across the marine processes Study Area is provided in Volume 1 Chapter 6: Marine and Coastal Processes, drawing upon the findings of the project-specific oceanographic, geophysical and geotechnical surveys, and other pre-existing data. Realistic worst case scenarios used in the assessments presented in this Annex are also set out in Volume 1 Chapter 6: Marine and Coastal Processes.

A summary of the relevant baseline characteristics within and nearby to the array area of the Proposed Development is provided below, based on the data sources described in Volume 1 Chapter 6: Marine and Coastal Processes.

- Tidal current speeds vary continuously in response to flood/ebb, spring/neap, equinox/solstice and other tidal cycles, as well as with depth and in conjunction with any non-tidal surge influence. Based on the site specific metocean survey in the array area and other hindcast data, peak depth averaged current speed on a mean spring tide within the array area is approximately 0.6 to 0.8 m/s, increasing gradually along the ECC to between approximately 1.0 and 1.4 m/s in the approaches to Milford Haven. In the mouth of Milford Haven but outside (west) of West Angle Bay, speeds are lower, approximately 0.6 m/s; within West Angle Bay, currents are only slight due to the limited volume of water exchanged during each tide. Peak depth averaged current speed on a mean neap tide is approximately half the spring value.

- Tidal currents disperse sediment plumes by advection. The path followed by tidal currents, and the maximum distance that tidal currents might displace water in one flood or ebb cycle from a given location, is a limiting factor in the maximum spatial extent of sediment plume effects. The tidal ellipse's shown in Figure 3 illustrate the approximate elliptical path (length, width and orientation) followed by water in the study area during a mean spring tidal cycle. During mean spring tidal conditions, the approximate overall tidal excursion distance is: 10 km in the array area; 14 to 15 km in the middle of the ECC (around KP20); 18 to 19 km nearshore (around KP10); and up to 10 km within Milford Haven Estuary. Tidal excursion distances on a mean neap tide (not shown) are approximately half the corresponding mean spring value. The spring tidal excursion buffer in Figure 3 indicates the maximum extent of water displacement (and therefore any plume effects) arising from any location within the array area or ECC.

- From the 26 water samples collected in the inshore/ nearshore ECC (out to KP8) during November 2020, observed SSC was nearly always less than 10 mg/l, which is low in absolute and relative terms; only one sample (from close to the seabed near the entrance to West Angle Bay) was higher at 23 mg/l. Monthly averaged satellite imagery of suspended particulate matter (SPM) also suggest that average (surface) SPM concentration is generally low throughout the ECC and array area during summer months (<1 mg/l within the array area, to around 3 mg/l at the landward end of the ECC). SPM concentrations increase slightly during winter but are still relatively low in absolute terms, increasing from around 3 mg/l at the array area to approximately 8 mg/l in the approaches to West Angle Bay. In practice, higher values (potentially several tens or hundreds of mg/l) are realistically anticipated in some locations during larger spring tides and storm conditions, with the greatest concentrations encountered closer to the seabed generally, especially where and when wave action penetrates to the seabed.

- SSC varies with height in the water column. Sediment is naturally re-suspended by the action of currents and waves at the seabed, so SSC levels are higher, lower in the water column.

Sediment grains naturally settle downwards under gravity but are also re-suspended upwards by turbulence, which is greater nearer the seabed. This results in an equilibrium state, and a non-linear profile of SSC (i.e. rapidly decreasing with height above the seabed);

- Referring to the results of the geophysical survey (Rovco, 2021), bedrock is exposed at the seabed at various locations within the ECC between approximately KP4.2 and KP8.5, with additional areas of shallow bedrock <5 m below seabed present intermittently along the route. In the array area, bedrock (assumed chalk) is not exposed at the seabed at any point and the minimum depth below seabed it has been interpreted at is 3.7 m. The deepest the bedrock has been observed is 82.4 m below seabed. In general, the bedrock deepens to the west, with various channels incised into its surface;

- Based on the results of the geophysical survey of the ECC and array area, and 119 seabed grab samples, and the interpretation of those data in the Project Ground Model (Blue Gem Wind, 2021), seabed sediments are characterised as:
  - **Northern half of the array area:** sandwave features up to approximately 6 m height comprising mainly sand, and megaripples, above a thin veneer (1 to 2 m) of sand to gravelly or muddy sand (typically 10 to 20% but up to 50% fines), overlying Pleistocene glacial tills comprising a consolidated poorly sorted mixture of clay, sand, gravel, shells, cobbles and boulders;
  - **Southern half of the array area and western half of the ECC (west of KP25)**: a thin veneer (1 to 2 m) of sand to gravelly sand (typically 10 to 20% but up to 50% fines), with megaripples, overlying Pleistocene glacial tills comprising a consolidated poorly sorted mixture of clay, sand, gravel, shells, cobbles and boulders;
  - **Eastern half of the ECC (KP25 to 5):** isolated sandbank feature or local accumulations up to 10 to 20 m high/thick comprising mainly sand and gravelly sand, with sandwaves and megaripples, otherwise a thin cover (1 to 2 m) of sand to gravelly sand with sandwaves and megaripples, overlying Pleistocene glacial tills comprising a consolidated poorly sorted mixture of clay, sand, gravel, shells, cobbles and boulders;
  - **In the approaches to Milford Haven and West Angle Bay (KP5 to 3):** rock platform (excluding Row's Rocks channel). Locally thin or absent veneer (<1 m) of sandy gravel or gravelly sand.
  - **Within Row's Rocks channel and West Angle Bay (KP3 to 0):** Row's Rocks channel is incised into the bedrock platform and locally infilled with between 5 to10 m of muddy sandy gravel and sands (Blue Gem Wind, 2021). Areas of sandy gravel and sandy mud and exposed bedrock in the approaches to West Angle Bay. Sandy beach (with some muds) of variable thickness overlying a rocky platform within West Angle Bay.

- A summary of the sediment types within the array area, ECC and at the cable landfall is presented in Figure 2.

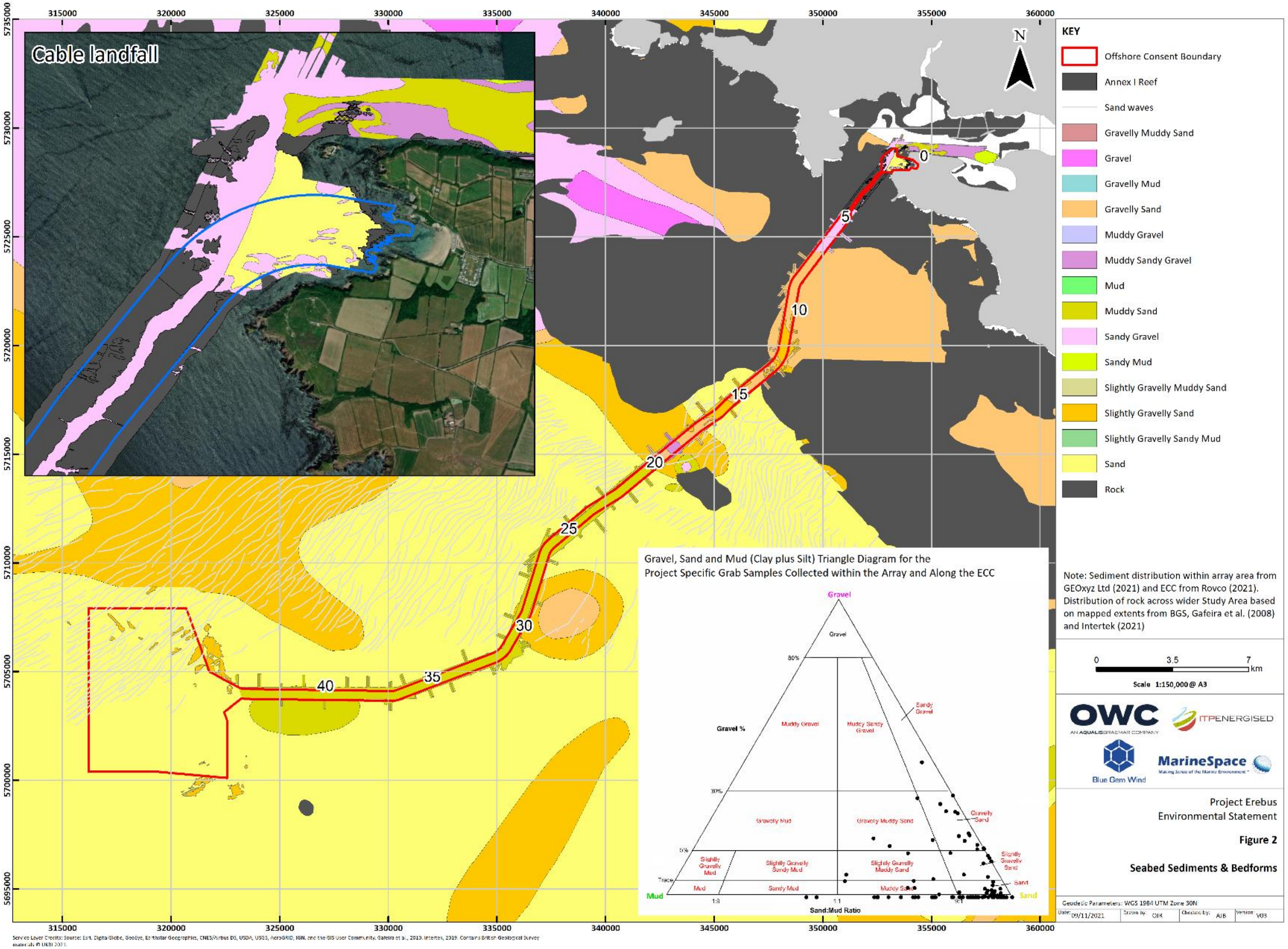

Figure 2. Seabed sediments in the array area and ECC, and at the cable landfall

3 Methodology

3.1 Introduction

Sediment disturbed and released into the water column during the construction, operational (cable repair/remediation events) and decommissioning phases 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.

Coarse grained sediments (i.e. sand/ gravel) will behave differently to fine grained sediments (i.e. silt/ clay) 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 (e.g. 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.

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 re-deposition of sediment 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.

3.2 Spreadsheet based numerical models

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 used 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,b; 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 net tidal current drift rate and direction in the area, which vary both temporally and spatially in speed and direction;

- A representative current speed for the array area is 0.5 m/s, which is representative of higher tidal flow conditions occurring on most flood and ebb cycles for a range of spring and neap conditions (See Section 2 for full range across the area). 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 horizontal eddy dispersion coefficient, Ke, estimated as Ke = κu*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 (κ = 0.4) and u* is the friction velocity (u* = √(τ/ρ). Where ρ is the density of seawater (ρ = 1027 kg/m^3) and τ is the bed shear stress, calculated using the quadratic stress law (τ = ρ C_d U2, Soulsby, 1997) using a representative current speed for the Proposed Development site (U = 0.5 m/s) and a drag coefficient value for a rippled sandy seabed (C_d = 0.006);

- The interpreted geophysical data and sediment grab samples from the array area indicate that in general there are four characteristic surficial sediment types present, namely:
  - Sand (<10% mud);
  - Slightly gravelly sand (0.5 to 2% gravel);
  - Muddy sand (10 to 25% mud); and
  - Sandy mud (50 to 60% mud).
- To estimate the time-scale in suspension, sediment is assumed to settle downwards at a calculated (theoretical) settling velocity for each grain size fraction (from Soulsby, 1997, 0.0001 m/s for fines, 0.05 m/s for (medium) sands and 0.5 m/s for gravels and generally coarser sediments, including clastic drill arisings).

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 range of total water depths representative of the site 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; and

- 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 x 1 m).

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). When drilling anchor piles, the point of sediment release is likely to be static and so the width of deposition is characterised based on the footprint of release and a small amount of lateral dispersion between surface and seabed prior to deposition;

- 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; and

- This model provides a 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).

The numerical model for SSC resulting from dispersion of fine sediment is constructed on the basis of the initial dispersion into the receiving waters, and then further dispersion of the plume as a whole, as per the following example for overspill for a trailing suction hopper dredger (TSHD):

- 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 0.5 m/s);

- Sediment is discharged at a representative rate (e.g. 30 kg/s for dredging over-spill) into a minimum volume of water 100 m^3 = 10 m x 10 m x 1 m deep;

- This volume of water will be refreshed every 20 seconds (10 m / 0.5 m/s);

- The total sediment input is 20 s x 30 kg/s = 600 kg;

- The resulting initial concentration in the receiving water is 600 kg / 100 m^3 = 6 kg/m^3 = 6,000 mg/l;

- The initial concentration plume would 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; and

- Assuming a faster current speed, faster vessel motion or larger footprint of release would 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*.

4 Assessment

An assessment of activity types identified during the Proposed Development that have the potential to cause significant sediment disturbance have been provided within this section; any other activities not deemed to present a worst case scenario (such as open cut trenching within the intertidal area) are not considered to cause significant or worst case sediment disturbance and are discussed only within Volume 1, Chapter 6.

4.1 Drilling of pile anchors

4.1.1 Summary

If used, pile anchors 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 volume to assist in the piling process.

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 3.2.

4.1.2 Evidence base

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.

Limited evidence, at the Lynn and Inner Dowsing offshore wind farms (CREL, 2008) from the field is provided by the during- and post-construction monitoring of monopile installation using drill-drive methods into chalk. It is recognised that the underlying geology, foundation/anchor dimensions and drilling apparatus will differ in the array area of the Proposed Development; it is also not yet known how the drilled (mainly glacial till) sub-soils will disaggregate. However, there is similarity in the potential presence of chalk bedrock within the arisings (Blue Gem Wind, 2021; to be confirmed during subsequent geotechnical campaigns).

The installation of steel monopiles at the Lynn and Inner Dowsing offshore wind farms (4.7 m diameter and up to 20 m penetration depth) were 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 100 m 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.

The dimensions of the (mainly chalk) drill arisings deposit created was measured by geophysical survey and characterised as a conical mound, approximately 3 m thick at the peak, extending laterally (from the peak to ambient bed level) up to 10 m in what is assumed the downstream direction and 5 m in the other. The volume of the deposit (measured as approximately 290 m^3) was similar to the total volume of the drilled hole (347 m^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.

4.1.3 Assessment of change

The greatest potential change to SSC and thickness of sediment deposition is associated with the largest rate and total volume of drilling. The realistic worst-case scenario for a single pile occurs as a result of fully drilling (100% of the volume of) the maximum pile diameter (2.5 m) and depth (55 m) at a representative, drilling rate of 5 m/hour. For the array as a whole, the realistic worst-case scenario is associated with up to 35 individual anchor piles (5 piles for each of 7 WTGs, 2.5 m drill diameter; 55 m depth; at a variable spacing within the array area). In practice, it is unlikely that all, if any, of the anchors will require drilling.

The distribution of grain/clast sizes in the drill arisings for individual anchor 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 realistic worst-case scenario for sediment release by drilling activities is summarised in Table 2.

Table 2. Realistic worst-case scenario for sediment release by drilling pile anchors

Parameter	Realistic worst case scenario	Working and Other Assumptions
Number of pile anchors to be drilled	35	Up to 100% of 35 anchor piles may be drilled (5 piles each for 7 WTGs). Pile anchors for a single semi-submersible floating platform may be separated by ~1000 m or more; anchors from adjacent semi-submersible floating platforms will be no closer than 100 m to each other.
Maximum drill diameter used	2.5 m	100 % of the monopile internal area will be drilled
Total volume of drill arisings from one pile anchor	270 m^3	2.5 m drill diameter, 55 m depth
Total volume of drill arisings for entire array (35 anchor piles)	11,340 m^3	270 m^3 x 35 pile anchors + 20% contingency
Sediment mineral density	2,650 kg/m^3	Assumed value for quartz sand (Soulsby, 1997).
Total mass of drill arisings from one pile anchor	715,500 kg	270 m^3 x 2,650 kg/m^3 Assuming the drilled material is fully consolidated with minimal voids
Total mass of drill arisings from all pile anchors	30,051,000 kg	11,340 m^3 x 2,650 kg/m^3

Parameter	Realistic worst case scenario	Working and Other Assumptions
		Assuming the drilled material is fully consolidated with minimal voids
Drilling rate	5 m/hour	11 hours to install 1 monopile (55 m divided by 5 m/hour)
Maximum sediment release rate whilst drilling	18.1 kg/s	2.5 m diameter, 5 m/hour = 221 m^3/hr = 0.06 m^3/s x 2,650 kg/m^3 Assuming the drilled material is fully consolidated with minimal voids
Consolidated packing density	0.6	Assumed value for a typical, medium sorted sand (Soulsby, 1997).
Total (consolidated) volume of drill arisings from one pile anchor	450 m^3	270 m^3 divided by 0.6
Total (consolidated) volume of drill arisings from all pile anchors	18,900 m^3	11,340 m^3 divided by 0.6
Area over which sediment is released at or above the water surface	5 m^2	Assumed value – sediment is released at or above the water surface in an area approximately equal to the area of the drilled hole (2.5 m diameter). Using a larger value will increase initial dispersion, decrease SSC and reduce the thickness of subsequent deposits and *vice versa*.
Area over which sediment is released at or above the water surface	5 m^2	Assumed value – sediment is released at or above the water surface in an area approximately equal to the area of the drilled hole (2.5 m diameter). Using a larger value will increase initial dispersion, decrease SSC and reduce the thickness of subsequent deposits and *vice versa*.

Levels of SSC resulting from drilling pile anchors assuming 100% of the drill arisings are fines are shown in Table 3 for the following range of dispersion scenarios:

- Initial dispersion near the point of release (total mass evenly dispersed in a volume of water 10 m wide, 10 m length, 1 m depth);
- Vertical diffusion to 5 m from surface, 20 m lateral spread in footprint dimensions;
- Vertical diffusion to 15 m (approximately quarter water depth from surface), 50 m lateral spread in footprint dimensions;
- Vertical diffusion to 35 m (approximately half water depth from surface), 100 m lateral spread in footprint dimensions; and
  Vertical diffusion to 70 m (approximately full water column, so affecting the seabed), 100 m lateral spread in footprint dimensions.

The approximate timeframe and distance downstream from the point of release for each dispersion scenario is indicated, based on the representative rates of settling, lateral dispersion and current speeds previously described in Section 3.2.

Table 3. Suspended sediment concentration as a result of drilling 100% of the volume of one anchor pile (100% drill arisings as fines)

Parameter			Anchor Pile
Rate of sediment release (kg/s)			18.1
Total mass released into receiving water (kg)			361.3
Representative current speed (m/s)			0.5
Plume Width (m)	Plume Depth (m)	Plume Section Length (m)	Resulting SSC (mg/l)
20	5	10	3,613
30	15		361
60	30		80
150	70		20

Levels of SSC and the estimated area and average thickness of sediment thickness resulting from drilling pile anchors assuming 100% of the drill arisings are sands or gravels are shown in Table 4 for a single pile anchor.

Table 4. Suspended sediment concentration and sediment deposition as a result of drilling 100% of the volume of one anchor pile (100% drill arisings as sands or gravels)

Sediment Type	Water Depth (m)	Settling Rate (m/s)	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)
100% Sand	65	0.05	1,300	650	23,487	55,066	0.01
	72		1,440	720	26,016	67,260	0.01
	79		1,580	790	28,546	80,672	0.01
	85		1,700	850	30,714	93,138	0.00
100% Gravel	65	0.5	130	65	2,349	1,916	0.23
	72		144	72	2,602	2,320	0.19
	79		158	79	2,855	2,763	0.16
	85		170	85	3,071	3,174	0.14
Sediment Type	**Water Depth (m)**	**Diameter of Midwater SSC Influence (m)**	**Area of Midwater SSC Influence (m^2)**	**Midwater Average SSC (mg/l)**	**Diameter of Near-Bed SSC Influence (m)**	**Area of Near-Bed SSC Influence (m^2)**	**Near-Bed Average SSC (mg/l)**
100% Sand	65	39	1,184	305	54	2,280	158
	72	43	1,435	252	59	2,772	130
	79	47	1,710	211	65	3,313	109
	85	50	1,964	184	70	3,814	95
100% Gravel	65	14	154	235	19	276	131
	72	15	182	198	20	330	110
	79	16	213	170	22	389	93
	85	18	241	150	24	443	82

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 5 for drilling a single pile anchor. 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 minimum c thickness of 0.05 m).

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 would 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 (i.e. the angle of repose for such loose sediments = 32°). The height of cones with two and three times the extent of the steepest cone are provided for comparison. The largest possible areas impacted by uniformly distributed thicknesses of 0.5 m, 0.25 m and 0.05 m (more likely associated with sand sized material) are also provided (making no assumptions regarding the shape of the area).

Table 5. Alternative potential extents and thicknesses of sediment deposition as a result of drilling 100% of the volume of one pile anchor (100% drill arisings as sands or gravels)

Anchor Type / Operation	Deposition Scenario	Nominal Diameter of Influence (m) as a Result of Drilling for One Pile Anchor	Thickness of Deposit (m)*
Drilling of one pile anchor (270 m^3 drill arisings per anchor; equivalent volume when deposited at seabed = 450 m^3 (based on a packing density of 0.6)).	Cone	18 (steepest) 35 53	5.5 1.4 0.6
	Uniform thickness	34 44 107	0.5 0.25 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 (e.g. >5 to 10 m) will be allowed to accumulate in practice. All value pairs are part of a continuous scale of possible outcomes.

The following observations based on the spreadsheet based numerical model results set out in Table 3 to Table 5, are consistent with similarly modelled patterns of change in assessments for other wind farms, and the wider monitoring evidence base.

Assuming that a mixture of sediment grain sizes are present, (including a range of clast sizes from drilled chalk, from liquidised fines to larger clasts) the overall spatial pattern of change due to drilling of a single pile anchor is summarised as follows:

- Due to all sediments, SSC will be increased by thousands of mg/l at and immediately around the point of sediment release, which is at or near the water surface. The spatial extent and duration of this greatest effect will likely be limited to within 50 to 850 m of the drilling, depending on the proportion of sand and gravel (or larger clasts) sized material in the drill arisings. Highest levels of SSC close to the source will be mainly confined to the upper water column. Gravels and sands will settle from that area towards the seabed (within approximately 100 to 1000 m, respectively), causing a more dispersed midwater and nearbed change, with proportionally lower SSC. Greater changes to SSC will persist throughout active drilling but will cease locally within 2 to 30 minutes of stopping (the timescale for sands and gravels to settle to the seabed and for any fines still in suspension to be removed elsewhere by advection and dispersion;

- Due to any fines present, SSC of low tens of mg/l will likely also occur in a narrow plume (tens to a few hundreds of metres wide, up to one tidal excursion in length (up to ~10 km on spring tides in the array area and ~5 km on neap tides; Figure 3) aligned to the tidal stream downstream from the source. If the plume disperses enough vertically from the upper water column to affect SSC at the seabed (combined with proportionally similar lateral dispersion), then it is likely that the plume concentration will be much less than 10 mg/l;

- 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 anchor location, a very slight increase in SSC of a few mg/l at most may occur more widely due to ongoing dispersion and dilution of any fine material; and

- Sufficiently fine sediment may persist in suspension for hours to days or longer, but will become diluted to very low concentrations (<5 mg/l, indistinguishable from natural background levels and variability) within timescales of less than one day.

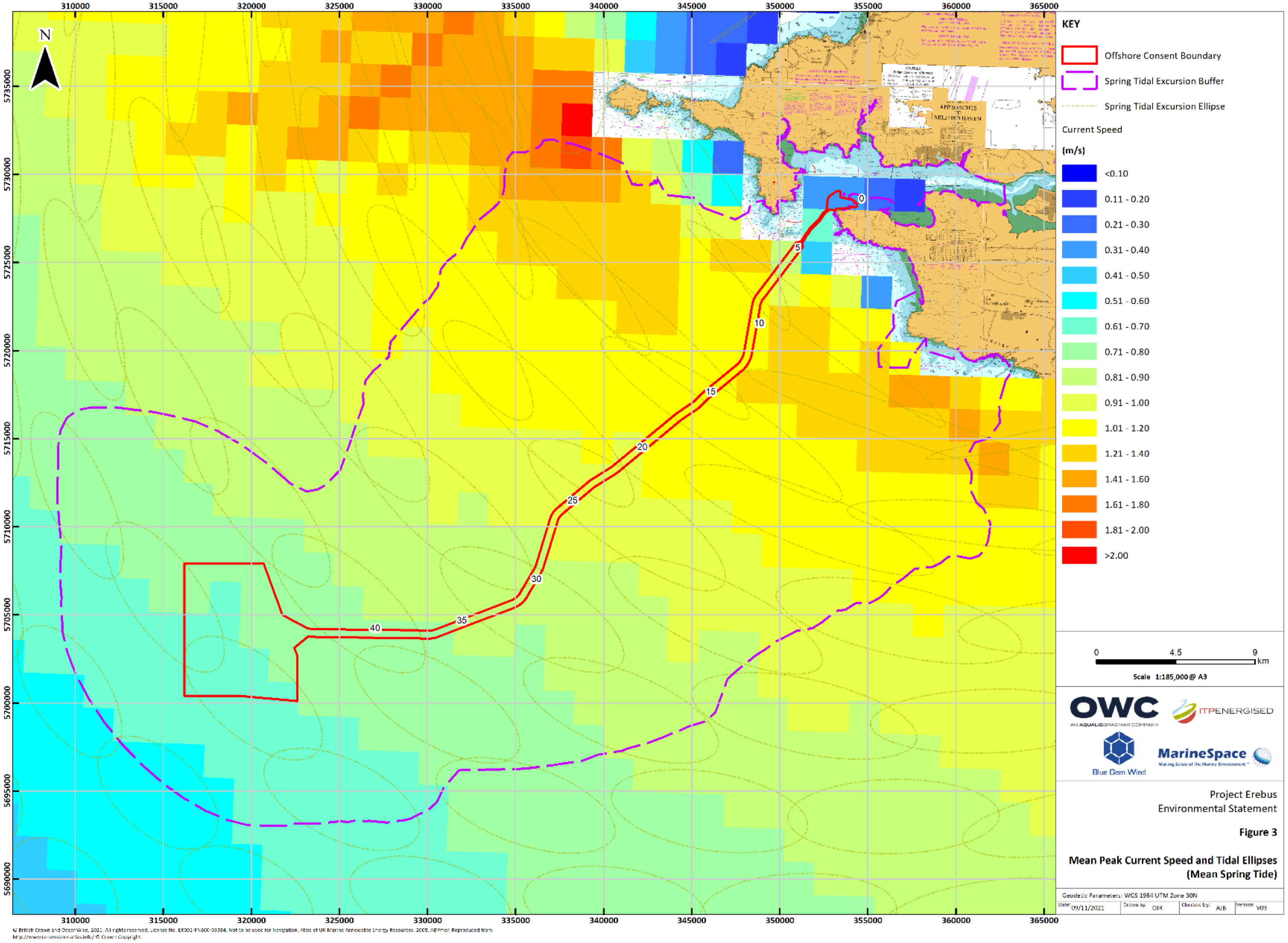

Figure 3. Spring tidal excursion ellipses around the array area and ECC indicating maximum extent of plume dispersion

Sediment deposition as a result of drilling for a single pile anchor are characterised as follows:

- Deposits of mainly coarse grained and clastic sediment deposits will be concentrated within an area in the order of approximately 50 to 200 m downstream/upstream and a few tens of metres wide from individual anchor locations, with an average thickness in the order of less than 0.25 m;
- Deposits of mainly sandy sediment deposits will be concentrated within an area in the order of approximately 650 m to 850 m downstream/upstream and tens to one hundred metres wide from individual anchor locations, with an average thickness in the order of a less than few centimetres;
- Fine grained material will be dispersed widely within the surrounding region and will not settle with measurable thickness; and
- 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 and are likely to vary due to the nature 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 5.

The local patterns of change to SSC and sediment deposition as a result of drilling individual pile anchors are described above. In the array area, up to 35 pile anchors may be installed using drilling. The total sediment volume potentially released by drilling all 35 pile anchors has also been assessed with respect to the total potential extent and thickness of sediment deposition, as summarised below.

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 anchors, the local nature of the drill spoil, the local water depth and the ambient environmental conditions during the drilling activity. However, the maximum total volume of unconsolidated material (assuming a packing density of the deposited material of 0.6) that could be released from drilling all 35 anchors is 18,900 m^3, therefore:

- If the total volume of drill arisings from all pile anchors (18,900 m^3) was distributed equally across the array area (43.57 km^2), the average increase in bed elevation would be 0.0004 m (i.e. <1 mm); and
- A maximum area equal to approximately 0.9% of the array area could potentially be covered by an average thickness of 0.05 m of material.

If drilling occurs simultaneously with other construction activities (e.g. installation of inter-array cables) and these activities 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 effect on SSC in areas of overlap will be additive if the downstream activity occurs within the area of effect from upstream (i.e. sediment is disturbed within the sediment plume from the upstream location). The effect on SSC will not be additive (i.e. 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.

Effects on sediment deposition will be additive if and where the footprints of the deposits overlap. Given that the spacing between anchors on the same semi-submersible floating platform is in the order of approximately 1000 m, it is unlikely that coarse sands or gravels put into suspension will be dispersed far enough (i.e. between adjacent anchor locations) to cause any overlapping effects before being redeposited to the seabed. It is considered unlikely that two pile anchors at the minimum likely separation of 100 m would be simultaneously drilled. Only relatively fine sediment is likely to be advected far enough to potentially cause overlapping effects on SCC.

4.2 Dredging for sandwave levelling

4.2.1 Summary

At a number of locations within the ECC and array area, relatively large mobile bedforms are present and these are associated with a considerable thickness of mainly sandy sediment (locally up to 7 m along the ECC and up to 11.5 m in the array area). To ensure effective burial below the level of the stable bed, it may be necessary to first remove sections of sandwaves, before trenching into the underlying bed; preference will be to undertake any levelling using MFE, however a worst case scenario of dredging (using a TSHD) has been included in this assessment. The locations in the ECC at which sandwave levelling may be required are set out in Table 6. No specific locations for sandwave levelling in the array area have been identified (although sandwaves are predominantly present in the northern half).

Dredging has the potential to cause elevated SSC, mainly 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 the spreadsheet based numerical models.

Dredging is the most likely method to be used for locally displacing larger volumes of sediment to achieve the required width and depth of seabed lowering. The dredging process efficiently removes sediment volume from one area and may return it to the seabed in another (preferably nearby in the case of the Proposed Development).

MFE tools might also be used as part of the sandwave levelling process, but are potentially less efficient at displacing large sediment volumes over distances more than a few tens of metres. A MFE will also displace sediment through a combination of resuspension and fluidisation of the seabed, causing sediment to be simply dispersed away from the local area or to flow away downslope under gravity. Levels of SSC caused by an MFE when used for cable burial and trenching are described in Section 4.3. The total volume of sediment displaced, and therefore the maximum area and thickness of sediment deposit outside of the levelled area is the same as described for dredging.

4.2.2 Evidence base

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 Special Areas of Conservation (SAC) Project (www.ukmarinesac.org.uk) 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."

Dredging for construction aggregates is a common marine activity, including in the nearby 'South West' region, at least 80 km from the Proposed Development within the Bristol Channel. Sediment dredged as part of construction activities will aim to 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.

4.2.3 Assessment of change

The greatest SSC and thickness of sediment deposition as a result of sandwave levelling by dredging is assessed for the largest individual sandwave identified on the ECC. Large sandwaves present in the northern half of the array area may also be subject to some local levelling, however, the dimensions of the individual corridors are not presently known (pending final array layout and cable burial design).

The distribution of grain sizes in the dredging over-spill and spoil release plumes is potentially variable, so results are provided separately for scenarios where 100% of the material is assumed to be either fines, or (medium) sand or (coarse) gravel sized. In practice, depending on the actual ground conditions and dredging vessel used, the distribution of grain size in the over-spill and spoil will be some variable mixture of these with a corresponding intermediate duration in suspension, extent and magnitude of change.

Sandwave levelling totalling 403,000 m^3 is proposed at seven locations along the ECC (location and maximum dimensions are summarised in Table 6). Localised sandwave levelling totalling a further 181,600 m^3 -a conservative estimate based on current layout options, will also be undertaken at multiple, presently unconfirmed locations within the array area. This levelling will be associated with the installation of mooring lines (6,000 m^3), anchors (15,000 m^3) and offshore inter array cables (160,600 m^3).

The realistic worst case scenario for local sediment release by dredging for the largest sandwave in the ECC is characterised in Table 7; a total number of dredging cycles required for all sandwaves in the ECC and array area is also provided. The majority of sandwaves to be levelled along the ECC are located within either an SAC or Special Protection Area (SPA) designated area, one is located just outside the SPA. All other sandwave groups have a smaller volume than the largest one assessed. The instantaneous effects of active dredging and spoil disposal are the same in all cases. A smaller sandwave dredge volume will simply require a smaller number of dredging cycles, and so a smaller overall duration to complete. The assumed width of the trench is the same in all cases. When calculating the dredge volume, the average depth of dredge (taking account of sloped sides to a central maximum) is approximately half the bedform crest height. A 30% contingency has been added to the total estimated volume for all sandwaves in the ECC.

Table 6. Dimensions of areas identified for sandwave levelling along the ECC

Approximate location (KP on the ECC)	Corridor width (m)	Bedform crest elevation above mean undisturbed seabed level (m)	Corridor cross sectional area - triangular shaped (m^2)	Corridor Length (m)	Volume (m^3)
8.0 - 8.5	50	4	100	200	20,000

Approximate location (KP on the ECC)	Corridor width (m)	Bedform crest elevation above mean undisturbed seabed level (m)	Corridor cross sectional area - triangular shaped (m^2)	Corridor Length (m)	Volume (m^3)
12.5 - 13.0	50	2	50	300	15,000
13.5 - 14.0	50	2	50	400	20,000
15.0 - 15.5	50	4	100	400	40,000
15.5 - 16.5	50	5	125	600	75,000
29.0 - 30.0 **	**50**	**6**	**150**	**600**	**90,000**
45.3 - 46.3	50	4	100	500	50,000
	TOTAL			3,000	310,000
	TOTAL + contingency 30%			-	403,000

* Dimensions for individual features do not include the 30% contingency added to the final total volume.
** Realistic worst case - largest individual sandwave to be levelled.

Table 7. Realistic worst case scenario for local sediment release by dredging the largest sandwave group at KP29.0 to 30.0

Parameter	Realistic worst case Scenario	Working and Other Assumptions
Number of sandwaves dredged	Largest 1 of 7	Up to 7 individual sandwaves have been identified for levelling in the ECC (Table 6). This table describes the largest sandwave located around KP29.5.
Dredged area	30,000 m^2	Corridor 600 m length, 50 m width
Depth of dredged area	6 m	Maximum depth of dredging in the centre of the corridor and around the crest. V shaped profile.
Total volume of sediment to dredge for one large sandwave	117,000 m^3	Separately calculated based on the details summarised above, +30% contingency.
Sediment mineral density	2,650 kg/m^3	Assumed value for quartz sand (Soulsby, 1997).
Consolidated packing density	0.6	Assumed value for a typical, medium sorted sand (Soulsby, 1997).
Total mass of sediment to dredge for one large sandwave	186,030,000 kg	117,000 m^3 x 2,650 kg/m^3 x 0.6 Only a fraction of this material will be released as dredge over-spill. The remainder will be deposited to the seabed nearby, within the array area
Dredger hopper capacity	11,000 m^3	The dredging will be undertaken by a trailing suction hopper dredger (TSHD) with an assumed representative hopper capacity of 11,000 m^3
Equivalent number of dredging cycles to dredge one large sandwave in the ECC	10.6 cycles	117,000 m^3 divided by 11,000 m^3

Parameter	Realistic worst case Scenario	Working and Other Assumptions
(Equivalent number of dredging cycles to dredge all 7 sandwaves in the ECC)	36.6 cycles	403,000 m^3 divided by 11,000 m^3
(Equivalent number of dredging cycles to dredge all sandwaves in the array area)	16.5 cycles	181,600 m^3 divided by 11,000 m^3
Dredger sediment over-spill release rate	30 kg/s	Assumed value
Time to fill dredger	4 hours	Assumed value
Total mass of over-spilled sediment from dredging one large sandwave	4,579,200 kg	30 kg/s x 10.6 cycles x 4 hours x 60 min/hour x 60 s/min
Total (consolidated) volume of over-spilled sediment from dredging one large sandwave	2,880 m^3	4,579,200 kg divided by 2,650 kg/m^3 divided by 0.6
Area over which sediment is released at the water surface at any given time	100 m^2	Assumed value – sediment over-spill is released at the water surface in an area approximately 10 m x 10 m = 100 m^2. Using a larger value will increase initial dispersion, decrease SSC and reduce the thickness of subsequent deposits and *vice versa*.

The realistic worst-case scenario for sediment spoil disposal by the dredger, should this occur, is characterised as:

- Dredge spoil will be returned to the seabed by the dredger at a nearby location;
- 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 11,000 m^3 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; and
- 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.

Levels of SSC resulting from active dredging overspill (assuming 100% of the overspill comprises fines) are shown in Table 8 for the range of dispersion scenarios listed below. 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 3.2:

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

- Vertical diffusion to 5 m, 20 m lateral spread in footprint dimensions (approximately 30 seconds to one minute after release, 15 to 30 m downstream);
- Vertical diffusion to 15 m (from surface to approximately half water depth), 40 m lateral spread in footprint dimensions (approximately five to ten minutes after release, 150 to 300 m downstream); and
- Vertical diffusion to 30, 45 or 60 m (so affecting the seabed in varying water depths), proportional lateral spread in footprint dimensions (approximately 30 to 90 minutes after release, 900 to 2,700 m downstream).

Table 8. Suspended sediment concentration as a result of over-spill during active dredging (100% of over-spill as fines)

Plume Width (m)	Plume Depth (m)	Plume Section Length (m)	Resulting SSC (mg/1)
10	1	10	6,000
20	5		600
40	15		100
60	30		33
90	45		15
120	60		8

* Rate of sediment release 30 kg/s; total mass released into receiving water 600 kg; representative current speed 0.5 m/s.

Levels of SSC as a result of overspill during active dredging for any purpose, assuming 100% of the overspill are sands or gravels is shown in Table 9.

The estimated area and average thickness of sediment deposition thickness from overspill, from dredging the largest sandwave, assuming 100% of the overspill is sands or gravels is shown in Table 10. The total area of deposition is estimated as the likely downstream dispersion footprint, times the length of the dredged area.

Table 9. Suspended sediment concentration as a result of over-spill during active dredging (100% over-spill as sands or gravels)

Sediment Type	Water Depth (m)	Settling Rate (m/s)	Duration of Settlement (s)	Distance Plume Advected by Peak Current (m)	Maximum Mass in Suspension (kg)
100% Sand	15	0.05	300	150	9,000
	30		600	300	18,000
	45		900	450	27,000
	65		1,300	650	39,000
100% Gravel	15	0.5	30	15	900
	30		60	30	1,800
	45		90	45	2,700
	65		130	65	3,900

Sediment Type	Water Depth (m)	Diameter of Midwater SSC Influence (m)	Area of Midwater SSC Influence (m^2)	Midwater Average SSC (mg/l)*	Diameter of Near-Bed SSC Influence (m)	Area of Near-Bed SSC Influence (m^2)	Near-Bed Average SSC (mg/l)*
100% Sand	15	9	62	9,679	12	120	5,003
	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
100% Gravel	15	3	8	7,693	4	14	4,231
	30	6	26	2,269	8	50	1,194
	45	8	56	1,069	12	108	553
	65	12	113	532	17	220	272

Table 10. Cumulative sediment deposition as a result of over-spill following dredging of the largest sandwave (100% over-spill as sands or gravels)

Sediment Type	Water Depth (m)	Area of Seabed Deposition (m²)	Average Thickness of Seabed Deposition (m)
100% Sand	15	183,285	0.02
	30	372,875	0.01
	45	568,770	0.01
	65	839,770	0.00
100% Gravel	15	18,113	0.16
	30	36,425	0.08
	45	54,937	0.05
	65	79,929	0.04

Levels of SSC in the passive phase of the plume created during a single dredge spoil disposal event for any purpose, assuming 100% of the material is fines is shown in Table 11.

Levels of SSC in the passive phase of the plume created during dredge spoil disposal for any size levelling assuming 100% of the material is sands or gravels is shown in Table 12; the resulting estimated area and average thickness of sediment deposition thickness are also provided.

Table 11. Suspended sediment concentration as a result of dredge spoil disposal (passive phase only), one full hopper (100% as fines)

Plume Diameter (m)	Plume Depth (m)	Resulting SSC (mg/l)*
50	30	29,692
100	30	7,423
1000	30	74
2000	30	19
5000	30	3

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

Table 12. Suspended sediment concentration as a result of dredge spoil disposal (passive phase only), one full hopper (100% as sands or gravels)

Sediment Type	Water depth (m)	Settling rate (m/s)	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)
	15	0.05	300	150	1,749,000	3,285	0.33

Sediment Type	Water depth (m)	Settling rate (m/s)	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)
100% Sand	30	0.5	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
100% Gravel	15		30	15	1,749,000	113	9.74
	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
Sediment Type	**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)***
100% Sand	15	9	62	1,880,992	12	120	972,287
	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
100% Gravel	15	3	8	14,949,885	4	14	8,221,313
	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

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 13 for dredging overspill during a single dredge cycle at any location, and for all dredging cycles at the single largest sandwave in the ECC. A range of alternative possible value combinations are also provided in Table 14 for the active and passive phases of dredge spoil disposal, for a single event at any location, and for all events for all sandwaves in the ECC and array area. For more details about the basis of these tables, see the previous assessment for drilling (Section 4.1).

Table 13. Alternative potential extents and thicknesses of sediment deposition as a result of over-spill during dredging (for a single dredging cycle and for all 10.6 cycles for the largest sandwave in the ECC)

Type / Operation	Deposition Scenario	Nominal Diameter of Influence (m) as a Result of Dredging Overspill during one dredge cycle (and the combined area of influence for all cycles for the largest sandwave*)	Thickness of Deposit (m)**
Dredging overspill for 1 dredge cycle (271.7 m³); and for 10.6 dredge cycles (total 2,890 m³).	Uniform thickness	53 m (5,780 m², <0.01%, <0.01%)	0.50
		68 m (9,633 m², <0.01%, <0.01%)	0.30
		167 m (57,789 m², <0.01%, <0.01%)	0.05

* Combined area and as a percentage of the total area of the West Wales Marine SAC (7,376 km²) and the Skomer, Skokholm and the Seas off Pembrokeshire SPA (1,668 km²), respectively.
** Average uniform thickness. All value pairs are part of a continuous scale of possible outcomes.

Table 14. Alternative potential extents and thicknesses of sediment deposition as a result of dredging spoil disposal (for a single dredging cycle and for all 36.6 cycles for all sandwaves in the ECC)

Disposal Type / Operation	Deposition Scenario	Nominal Diameter of Influence (m) as a Result of One Spoil Disposal Event (and the combined area* of influence for all cycles for all sandwaves in the ECC)	Thickness of Deposit (m)**
Spoil disposal from the dredger, 36.6 cycles for all sandwaves in the ECC (9,900 m^3 in active phase, 90% of 11,000 m^3).	Cone	49 m (70,406 m^2, <0.01%, <0.01%) 99 m (281,622 m^2, <0.01%, 0.03%) 148 m (633,650 m^2, 0.01%, 0.04%)	15.5 3.9 1.7
	Uniform thickness	159 m (725,400 m^2, 0.01%, 0.04%) 205 m (1,209,000 m^2, 0.02%, 0.07%) 502 m (7,254,000 m^2, 0.10%, 0.43%)	0.5 0.3 0.05
Spoil disposal from the dredger, 36.6 events for all sandwaves in the ECC (1,100 m^3 in passive phase, 10% of 11,000 m^3).	Uniform thickness	53 m (80,600 m^2, <0.01%, <0.01%) 68 m (134,333 m^2, <0.01%, 0.01%) 167 m (806,000 m^2, 0.01%, 0.05%)	0.5 0.3 0.05

* Combined area and as a percentage of the total area of the West Wales Marine SAC (7,376 km^2) and the Skomer, Skokholm and the Seas off Pembrokeshire SPA (1,668 km^2), respectively.

** 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 (e.g. >5 to 10 m) will be allowed to accumulate in practice. All value pairs are part of a continuous scale of possible outcomes.

Table 15. Alternative potential extents and thicknesses of sediment deposition as a result of dredging spoil disposal (for a single dredging cycle and for all 16.5 cycles for all sandwaves in the array area)

Disposal Type / Operation	Deposition Scenario	Nominal Diameter of Influence (m) as a Result of One Spoil Disposal Event (and the combined area* of influence for all cycles for all sandwaves in the ECC)*	Thickness of Deposit (m)**
Spoil disposal from the dredger, 36.6 cycles for all sandwaves in the ECC (9,900 m^3 in active phase, 90% of 11,000 m^3).	Cone	49 m (1,922 m^2, 0.07%) 99 m (7,687 m^2, 0.29%) 148 m (17,296 m^2, 0.66%)	15.5 3.9 1.7
	Uniform thickness	159 m (19,800 m^2, 0.75%) 205 m (33,000 m^2, 1.25%) 502 m (198,000 m^2, 7.51%)	0.5 0.3 0.05
Spoil disposal from the dredger, 36.6 events for all sandwaves in the ECC (1,100 m^3 in passive phase, 10% of 11,000 m^3).	Uniform thickness	53 m (2,200 m^2, 0.08%) 68 m (3,667 m^2, 0.14%) 167 m (22,000 m^2, 0.83%)	0.5 0.3 0.05

* Combined area and as a percentage of the total area of the Erebus array area (43.5 km^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 (e.g. >5 to 10 m) will be allowed to accumulate in practice. All value pairs are part of a continuous scale of possible outcomes.

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 of thousands 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 20 minutes to settle from surface to seabed), and gravels likewise within tens of metres (0.5 to 2 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 20 minutes, depending on the grain size and water depth); and
- 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.

In summary, sediment deposition as a result of active dredging overspill and spoil disposal 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 site 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 650 m downstream/upstream and approximately tens to one hundred metres wide from the site of dredging, 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 or areas of sediment, likely in the order of tens to a few hundreds of metres

in diameter (depending on the pattern of settlement) and realistically only tens of centimetres to a few metres in local thickness. An area equivalent to a circle of approximately 500 m in diameter might be covered to an average depth of 0.05 m. Any larger area of change would 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 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 (~10 to 19 km on spring tides and ~5 to 10 km on neap tides, depending upon the location, see Figure 3) 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 site of dredging, SSC less than 10 mg/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; and

- 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.

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 1.

4.3 Cable burial

4.3.1 Summary

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 array area of the Proposed Development and ECC, 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.

4.3.2 Evidence base

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).

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 0.5 m to 3 m in thickness, underlain by clay. SSC was recorded at a distance of 200 m from jetting and trenching activities and the following values were observed:

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

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).

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 500 m down-tide, i.e. where the concentrations will be greatest, of the cable laying activities showed:

- Marginal, short-term increases in background levels (approximately 9 times increase to the background concentrations); and

- Peak concentrations occasionally reaching 140 mg/l (equivalent to peaks in the naturally occurring background concentrations).

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.

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 1.75 m^2 would be disturbed by the jetting process and the speed of the jetting machine would be 300 m/hour (0.083 m/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 3 m^2 would be disturbed by the jetting process and the speed of the jetting machine would be 91 m/hour (0.025 m/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 63 µm) would form a plume in the water column.

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

- Three export cables were installed to a target depth of approximately 3 m 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 (3,000 mg/l) agreed with regulatory authorities beforehand, even in very close proximity to the works (<50 m); and
- 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 300 mg/l within 200 m of the operation, falling to the measured baseline level (100 mg/l) by 700 m downstream. It is assumed, therefore, that coarser sediments were associated with even lower levels.

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).*

4.3.3 Assessment of change

Offshore export and array cables may be installed by burial into the seabed. The ECC runs from the central eastern edge of the array area to a landfall in West Angle Bay, within Milford Haven Estuary.

For the Proposed Development, the realistic worst-case scenario for sediment release caused by cable burial is characterised in Table 16. 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 realistic worst case 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.

Table 16. Realistic worst case scenario for sediment release by cable installation

Parameter	Realistic worst case Scenario	Working and Other Assumptions
Number of export cable trenches	1	1 single or 2 bundled cables
Length of export cable trench	49 km	-
Maximum rate of cable burial	500 m/hr	Fastest rate through softer sediments
Total length of all array cables	23.9 km	The maximum 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 array and export cable burial	Jetting Mass flow excavator	Jetting and MFE methods have the greatest potential to energetically fluidise and eject material from the trench into suspension. By contrast, the other cable installation techniques described in the project design statement (e.g. ploughing) 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.
Maximum dimensions of array and export cable trench	Up to 1 m wide and 3 m deep with a 'U' shaped profile.	Jetting or MFE might be used at any location but in practice would only be used where surficial sediments are suitable. Target burial depth will typically be up to *circa* 3 m. Conservatively assume 100% of material is ejected from the trench. In practice, the tool and methods used will normally retain the majority of sediment within the trench by design, to backfill and provide protective cover.
Volume of sediment disturbed per metre progress	3.0 m^3	1 m wide x 3 m deep
Sediment mineral density	2,650 kg/m^3	Assumed value for quartz sand (Soulsby, 1997).
Consolidated packing density	0.6	Assumed value for a typical, medium sorted sand (Soulsby, 1997).
Sediment disturbance rate	662.5 kg/s	(3.0 m^3 x 2,650 kg/m^3 x 0.6) x (500 m/hr divided by 3600 s/hr)

The jetting process normally 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. The exact proportion ejected may vary. Values of 20 to 30% have been used in previous investigations of this type (ASA, 2005). Mass flow excavation tools may also fluidise the bed to a degree, but may also be used to excavate an open trench, in which case, a greater proportion of the material will be displaced. For the purposes of this investigation, it is conservatively assumed that 100% of the disturbed material is ejected.

An assessment of potential changes to SSC and bed levels has been undertaken using the spreadsheet based numerical models introduced in Section 3.2. A conservative assumption has been made that sub-soil material with a different grain size distribution to surficial sediments may also be re-suspended.

The seabed and sub-seabed sediment composition within the array area and along the ECC is relatively heterogeneous. In most locations, the majority of disturbed material will be mostly (90% or more) sand and gravels. However, typically up to 10%, and in some areas up to (approximately) 30 to 50% fines are also present. Disturbance of the underlying sub-soils (including poorly sorted glacial tills, mudstone, sandstone with limestone in the ECC, transitioning to chalk in the array area) may also include some proportion of fine grained (i.e. <63 µm grain size diameter) sediments, depending on the degree of disaggregation.

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 realistic worst-case scenario 'end-member' scenarios. These are:

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

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.

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 ECC, are more realistically expected to be used in these areas (DNV, 2014) (Figure 4). Also, even when fully disaggregated, any hard subsurface layers present (including glacial tills, mudstone, sandstone with limestone in the ECC, transitioning to chalk in the array area) are unlikely to 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.

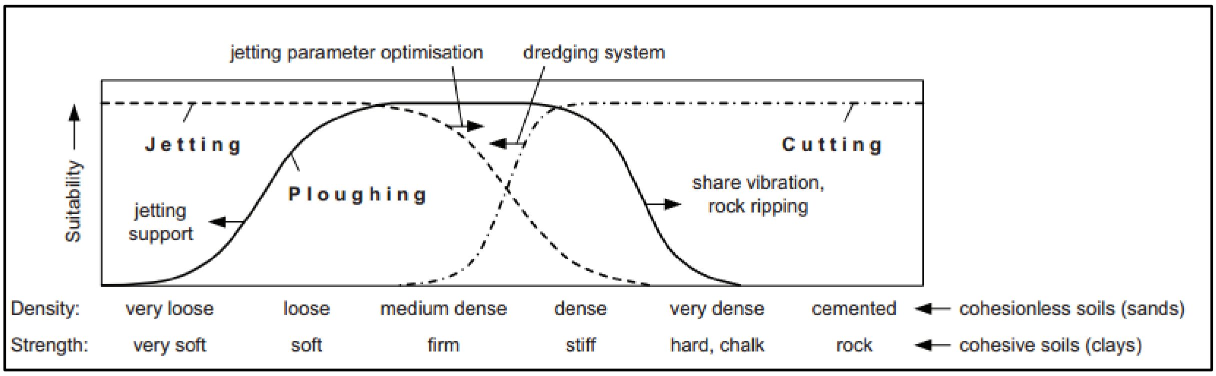

Figure 4. Indicative burial tool suitability in different ground conditions (DNV, 2014)

Results from the assessment scenarios outlined above are presented in Table 17 (for the gravel release scenario) and Table 18 (for the sand release scenario). The predicted levels of SSC (locally and for the short duration before resettlement) are extremely high in absolute and relative terms, so only the overall order of magnitude is shown (millions to hundreds of thousands of mg/l) rather than specific values. However, realistically, due to the relatively low height of ejection and rapid rate of resettlement, the extent and duration of such very high SSC levels are very limited.

Table 17. 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 (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	Mn	6.00
0.5	1	2	1.0	1.0	2.0	Mn	3.00
0.75	1	2	1.5	1.5	2.0	Mn	2.00
1	1	2	2.0	2.0	2.0	Mn	1.50
0.25	5	10	2.5	1.8	7.2	HnTh	1.20
0.5	5	10	5.0	3.6	7.2	HnTh	0.60
0.75	5	10	7.5	5.4	7.2	HnTh	0.40
1	5	10	10.0	7.2	7.2	HnTh	0.30
0.25	10	20	5.0	1.8	7.2	HnTh	0.60
0.5	10	20	10.0	3.6	7.2	HnTh	0.30
0.75	10	20	15.0	5.4	7.2	HnTh	0.20
1	10	20	20.0	7.2	7.2	HnTh	0.15

* Key: HnTh – hundreds of thousands; Mn – low millions.

** Average thickness based on the total volume of sediment released and the distance the plume is advected by the current. Large deposit thicknesses (e.g. >5 to 10 m) in combination with relatively small footprints will more realistically correspond to a broader and less thick deposit with slopes at the angle of repose for the sediment. Each row of results is part of a continuous scale of possible outcomes.

Table 18. 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 (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	1.8	7.2	Mn	0.60
0.5	1	20	10.0	3.6	7.2	Mn	0.30
0.75	1	20	15.0	5.4	7.2	Mn	0.20
1	1	20	20.0	7.2	7.2	Mn	0.15
0.25	5	100	25.0	1.8	7.2	HnTh	0.12
0.5	5	100	50.0	3.6	7.2	HnTh	0.06
0.75	5	100	75.0	5.4	7.2	HnTh	0.04
1	5	100	100.0	7.2	7.2	HnTh	0.03
0.25	10	200	50.0	1.8	7.2	HnTh	0.06
0.5	10	200	100.0	3.6	7.2	HnTh	0.03
0.75	10	200	150.0	5.4	7.2	HnTh	0.02

Representative Current Speed (m/s)	Height of Ejection (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)
1	10	200	200.0	7.2	7.2	HnTh	0.02

* Key: HnTh – hundreds of thousands; Mn – low millions.

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

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 (1, 5 and 10 m). 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 can move relatively quickly (up to 500 m/hr), any influence of the plume experienced downstream will be similarly limited in duration to the order of approximately 7 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. A slower moving tool would cause a longer duration of increased SSC, however, with a proportionally reduced level of SSC due to the lower rate of disturbance.

Following the same principles, changes associated with cable burial into 100% fine grained sediment will be similarly high to that described for sand in Table 18. The limited plume length in a downstream direction (order of 10 m), the duration of change to SSC locally (order of 10 s) 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 persist in suspension for longer than sands (order of days) during which time the plume will be subject to significant dispersion, affecting a progressively larger area, but proportionally reducing the change to SSC to tens of mg/l or less in the same timeframe. As a result of advection and dispersion during the days before settlement, no measurable thickness of fine sediment accumulation is expected.

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 25 m) 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 of the material disturbed is expected to be fines, with a corresponding reduction in the expected levels of SSC; and

- Irrespective of sediment type, the volumes of sediment being displaced and deposited locally are relatively limited (up to 3.0 m^3 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 3.0 m^3 of sediment can be spread to an average thickness of (for example) 0.05 m is 60 m; any larger distance would 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 to a few metres) and that fine material will be distributed much more widely, becoming so dispersed that it is unlikely to settle in measurable thickness locally.

4.4 Drilling fluid release during HDD at the landfall

4.4.1 Summary

Horizontal Directional Drilling (HDD) is the preferred option to transition the offshore export cable to the onshore export cable at a landfall at West Angle Bay. 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 from entry to exit point, with a diameter of up to 1.2 m.

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.

4.4.2 Evidence base

Drilling fluid or drilling mud is a suspension of mainly bentonite clay in 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 any conduit liners or cables during pull back;
- Cooling the reamers (cutting tools);
- Hole stabilization; 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.

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 (30 kg) and 35 litres (80 kg) of dry bentonite clay per m^3 of water (30,000 to 80,000 mg/l).

The use of bentonite has several benefits:

- It is a natural material, so no chemical;
- It is recyclable;
- It is on the PLONOR list, so its discharge is not a danger to the environment; 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 is limited.

4.4.3 Assessment of change

Based on the range of expected HDD lengths and maximum diameter, the maximum volume of drilling mud (and other drill cuttings) contained in one HDD conduit is estimated to be up to 1200 m^3. Several stages of drilling (pilot hole drilling and stages of reaming may result in smaller release events 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, in practice, the fluid present at this stage may have been replaced or otherwise reduced to a concentration lower than required for drilling.

The realistic worst case considered is a release of full concentration drilling mud (80,000 mg/l), up to the total volume of the conduit (1,200 m^3), in a relatively short period of time (minutes to hours), at up to two subtidal HDD punch out locations for the two export cables. The worst case scenario is summarised in Table 19.

Table 19. Realistic worst case scenario for bentonite release during HDD at the landfall

Parameter	Realistic worst case Scenario	Working and Other Assumptions
Number of export cables / HDD conduits	2	Maximum number of HDD conduits exiting in the subtidal area.
Maximum dimensions of one HDD conduit	Length 1000 m Diameter 1.2 m	
Maximum volume of drill fluid in one HDD conduit	1,200 m^3	Maximum conduit volume = 1000 m x π x $(1.2\ m/2)^2$ + contingency.
Maximum concentration bentonite in drill fluid	80,000 mg/l	80 kg per m^3
Maximum total mass bentonite in one HDD conduit	96,000 kg	1,200 m^3 x 80kg per m^3

Because of the time required to drill and finalise each HDD, it is assumed that the releases would not happen simultaneously and with a sufficiently long-time gap between punch out events that no overlapping or cumulative changes to SSC are expected (may be up to a year between the two events). The following assessment considers the change caused for one HDD bore hole.

The initial plume will likely have a very high SSC of bentonite (up to the concentration of the drilling fluid itself) 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 (approximately 96,000 kg) 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 20 shows that concentrations of bentonite will be reduced to naturally occurring background levels when the plume has dispersed to even a relatively small footprint in the order of 500 m across. A larger extent would correspond to a smaller SSC.

Table 20. 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	10	10	800 *
500	15	10	107 *
500	15	500	26 **

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

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 the plume moves out of the estuary and waves are active at the time of the release, wave induced turbulence at the seabed and wave breaking nearshore would result in much higher rates of dispersion in these areas.

The mass of bentonite in suspension is assumed to remain constant over the time frame of 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 would 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.

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).

The main findings of the assessment can be summarised as follows:

- 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 SSC specifically comprising bentonite clay (a natural non-toxic mineral). 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 (e.g. order of <10 mg/l over footprints larger than 500 m over a period of days; or, order of tens to low hundreds of mg/l over footprints less than 500 m over a period of minutes to one hour).

- In any case, the HDD exit point is located several hundred metres offshore of the beach at West Angle Bay in or near to the main channel. The majority of the plume will be advected in the direction of the ambient tidal currents, which are aligned to and will largely follow the path of the main channel of Milford Haven. The direction of transport (into or out of the estuary) will depend on the state of the tide (flood or ebb) at the time of the release. Plumes that are initially advected into the estuary may disperse more widely but may otherwise remain within the estuary. Plumes that are initially advected out of the estuary are likely to be rapidly advected and dispersed alongshore and are unlikely to fully re-enter the estuary on subsequent tides. It is expected that the plume would be dispersed to relatively low concentrations within hours of release and to background concentrations within a few tidal cycles.

- 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 could theoretically contain the majority of that material. Any accumulated material is expected to be reworked and redistributed to not-measurable concentrations and thicknesses over time by wave and tidal action.

- The bentonite in the drilling fluid normally has an overall density and viscosity similar to seawater and so is expected to behave (advect, mix and disperse) in a similar manner. If the drilling fluid behaves as a slightly more dense fluid, it may either accumulate in the HDD exit pit or move over the adjacent seabed downslope under gravity, i.e. in an offshore direction and away from nearshore areas.

5 References

ABPmer, Cefas and HR Wallingford. (2007). Review of Round 1 Sediment process monitoring data - lessons learnt. (Sed01).

ASA (2005). Estimates of seabed scar recovery from jet plough cable burial operations and possible cable exposure on Horseshoe Shoal from sand migration. Report prepared by ASA for Cape Wind Associates, ASA Report 5-128, October.

BERR (2008). Review of Cabling Techniques and Environmental Effects applicable to the Offshore Wind farm Industry.' Department for Business Enterprise and Regulatory Reform in association with Defra.
British Marine Aggregate Producers Association (http://www.bmapa.org).
Blue Gem Wind (2021). Blue Gem Wind Project Erebus Ground Model Phase 1.

CREL (2008). Environmental Report For Monitoring of the Disposal of Drill Arisings: Lynn and Inner Dowsing. Report for Centrica Renewable Energy Limited (CREL). Document number LD-E-CE-013-0117-300100-004-R.

Det Norske Veritas (DNV), (2014). Subsea Power Cables in Shallow Water Renewable Energy Applications. Recommended Practice DNV-RP-J301. 145pp.

DONG Energy (2013a). Burbo Bank Extension Environmental Statement. http://www.burbobankextension.co.uk/en/application-for-consents/environmental-statement. Accessed on 13 March 2017.

DONG Energy (2013b). Walney Extension Environmental Statement. https://infrastructure.planninginspectorate.gov.uk/. Accessed on 13 March 2017.
EMU Limited, (2005). Kentish Flats Monitoring Programme: Turbidity Monitoring. Report No. 05/J/1/01/0733/0500. Report to Kentish Flats Ltd. 13pp.

Gafeira, J., Green, S., Dove, D., Morando, A., Cooper, R., Long, D., & Gatliff, R.W., 2010. Developing the necessary data layers for Marine Conservation Zone selection – Distribution of rock/hard substrate on the UK Continental Shelf.

Intertek (2019). Erebus Stage 1 Floating Windfarm Geological Desk Top Study. P2324_R4791_Rev0

Navitus Bay Development Ltd (2014). Navitus Bay Wind Park Environmental Statement. Volume B – Offshore: Chapter 5 – Physical Processes. Document 6.1.2.5.

Ørsted (2018). Hornsea Three Offshore Wind Farm: Environmental Impact Assessment. https://infrastructure.planninginspectorate.gov.uk/. Accessed on 18 Nov 2020.
Parr, W, Clarke, SJ, Van Dijk, P, Morgan, N. (1998). Turbidity in English and Welsh tidal waters. WRc report No. 10419-0.

Pennekamp, JGS, Epskamp, RJC, Rosenbrand, WF, Mullié, A, Wessel, GL, Arts, T, Deibel, IK. (1996). Turbidity caused by dredging; viewed in perspective. Terra et Aqua, 64, 10-17.
Reach (2007). Asia-America Gateway (AAG) Cable Network, South Lantau, Project Profile 2007. report prepared by Atkins and EGS for Reach Networks Hong Kong Ltd.

Rovco (2021). Blue Gem Wind Project Geophysical & Environmental Final Survey Report. ERE-ENG-RVC-REP-GEO-0010 A05

SeaScape Energy, 2008. Burbo Offshore Wind Farm: Construction Phase Environmental Monitoring Report. CMACS for SeaScape Energy. April 2008.

Soulsby, R.L. (1997). Dynamics of marine sands. A manual for Practical Applications. Thomas Telford, London.

UK Marine SAC Project (www.ukmarinesac.org.uk). Originally Accessed 2016. Presently hosted at http://ukmpa.marinebiodiversity.org/

Vattenfall (2018). Thanet Extension Offshore Wind Farm: Environmental Impact Assessment. https://infrastructure.planninginspectorate.gov.uk/. Accessed on 18 Nov 2020.

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