XLINKS’ MOROCCO-UK POWER PROJECT

Environmental Statement

Volume 3, Appendix 8.1: Sediment source concentrations and assessment of disturbance

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Glossary

Term	Meaning
Offshore Cable Corridor	The proposed corridor within which the offshore cables are proposed to be located, which is situated within the UK Exclusive Economic Zone.
Proposed Development	The element of the Xlinks Morocco-UK Power Project within the UK. The Proposed Development covers all works required to construct and operate the offshore cables (from the UK Exclusive Economic Zone to Landfall), Landfall, onshore Direct Current and Alternating Current cables, converter stations, and highways improvements.
d50	Particle size corresponding to the cumulative frequency of 50%.

Acronyms

Acronym	Meaning
ES	Environmental Statement
CBRA	Cable Burial Risk Assessment
Cefas	Centre for Environment, Fisheries and Aquaculture Science
DVV	Double Van Veen
EA	Environment Agency
HDD	Horizontal Directional Drilling
MFE	Mass Flow Excavation
MMO	Marine Management Organisation
NE	Natural England
OCC	Offshore Cable Corridor
PEIR	Preliminary Environmental Impact Report
SSC	Suspended Sediment Concentration

Units

Units	Meaning
hr	hour
m/hr	Metres per hour (speed)
m/s	Metres per second (speed)
m^2	Square metres
m	Metres
mg/l	Milligram per litre
m^3	Metres cubed i.e. m x m x m
m^3/hr	Metres cubed per hour
km	Kilometre
τ_{max}	Maximum shear stress
τ_{mean}	Mean shear stress

1 SEDIMENT SOURCE CONCENTRATIONS AND ASSESSMENT OF DISTURBANCE

1.1 Introduction

1.1.1 This report presents sediment concentration information and an assessment of potential sediment transport along the UK Offshore Cable Corridor (OCC) to support, in particular, Volume 3, Chapter 8: Physical processes of the Environmental Statement (ES) chapter.

1.1.2 Sediment sampling undertaken for the Proposed Development is presented alongside freely available modelled datasets from Cefas to contextualise the baseline conditions. Possible increases in suspended sediment concentration (SSC), due to anticipated construction activities, are defined using the Environment Agency's 'SeDiChem' tool (EA & APEM, 2019) and through a review of ES Chapters for similar schemes.

1.1.3 This information is used to assess potential sediment transport and deposition at locations along the OCC, considering the effects of waves and currents as well as sediment resuspension and scour. The results from this assessment are presented along with assumptions, limitations, and conclusions.

1.2 Baseline data

Sediment Sampling

1.2.1 Fifty-one sediment grab stations were sampled along the OCC. The majority of stations were sampled with a Double Van Veen (DVV) grab (2 x 0.1 m^2), and further stations with coarser sediments sampled with a 0.01 m^2 mini-Hamon grab. Samples were acquired to provide data on physico-chemistry and macrofauna at the sampling locations.

1.2.2 Typically, the sediments along the OCC are classified as 'Very Fine' to 'Medium' sands, with median particle size (d50) values between 0.07 mm and 0.47 mm (**Plate 1.1**). Coarser sediment of 'Very Fine Pebbles' and 'Medium Pebbles' were found at two grab stations only.

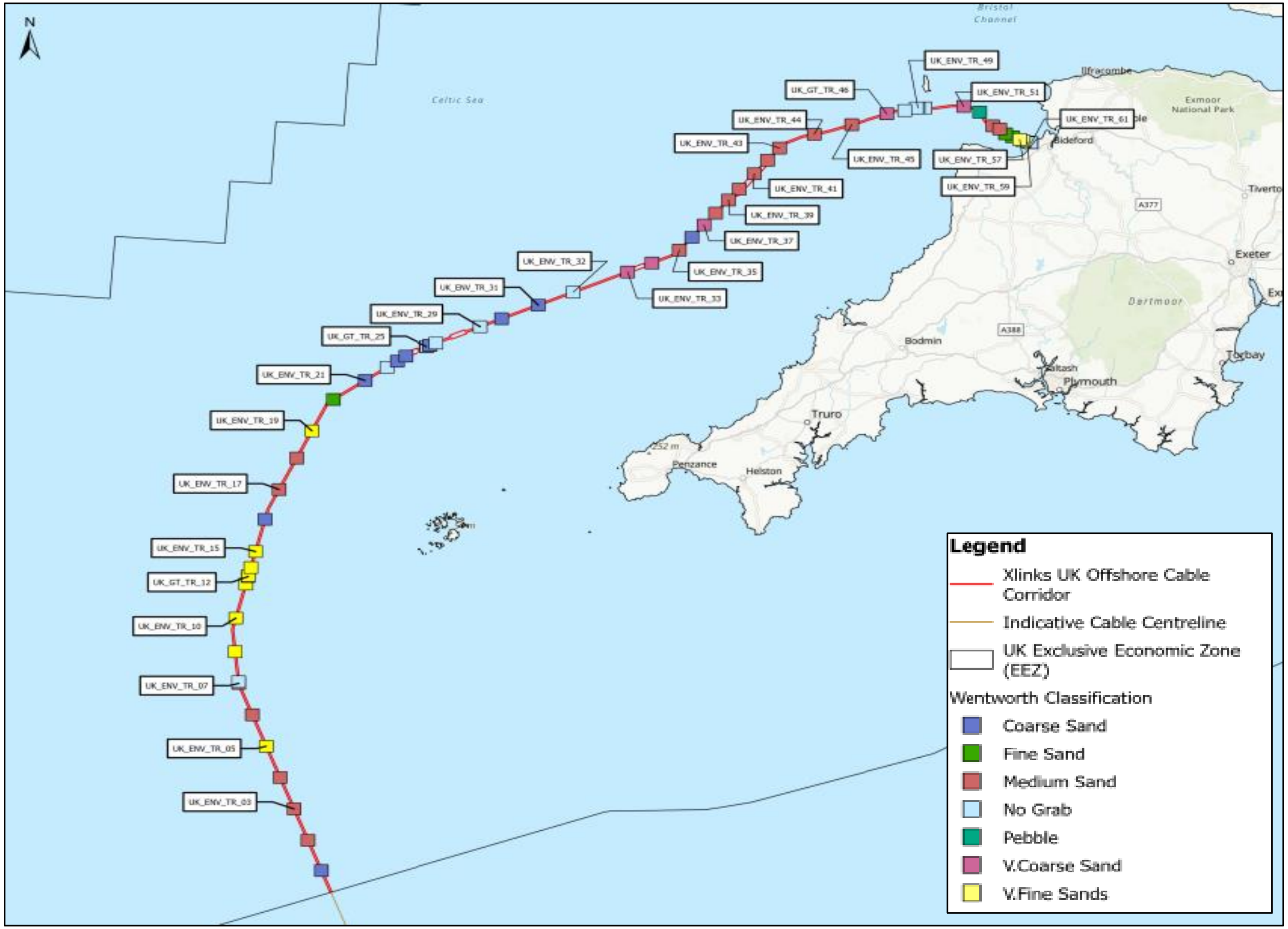

Plate 1.1: Sediment Sampling Locations and Wentworth Classification

Cone Penetration Testing

1.2.3 Data from Cone Penetration Testing (CPT) investigations were acquired at all 44 planned locations, with a total of 25 re-attempts conducted due to insufficient penetration, failure to meet class specification requirements or in one instance, as a result of a communication issue with the CPT unit during the acquisition (UK_GT_CPT_53). All but one station achieved CPT accuracy class determination of either 1 or 2 based on the reference deck offset readings and the classification limits specified by International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE, 1999).

1.2.4 **Table 1.1** shows a comparison of the CPT results at the start (seabed surface) and end (depth below seabed) of the investigation. Values of Cone Tip Resistance (Qc), Local Sleeve Friction (Fs) and Friction Ratio (Rs) were compared at the start and end of the penetration test. As shown in this table, the results are very similar at the start (surface) and end (at depth) of the CPTs (other than at location 1 where trenching will not take place since HDD is proposed).

1.2.5 Therefore, the sediment classification and associated d50 values, inferred from the surface grab samples (summarised in **Plate 1.1**), are considered suitable to represent marine sediments across the full depth of penetration. This analysis provides confidence that the sediment dispersion calculations that have been undertaken using surface grab characteristics are representative of dispersion that may be associated with disturbance of deeper sediments. Calculations based on surface sediments will sufficiently represent sediment disturbance associated with trenching activities which will extend to an approximate maximum trench depth of 1.6 m.

1.2.6 A further review of the CPT logs and interpretative report confirms that the upper 1 to 2 m of the seabed predominantly comprises fine, medium and coarse sands (other than areas where chalk bedrock is present). This provides confidence in the analysis and homogeneity of the upper seabed substrate.

Table 1.1: Comparison of CPT results at the start of test (surface) and end of test (full penetration depth below seabed)

Location	Name	Penetration Depth (m)	Start of Test			End of Test			Classification Start = End
			Qc (MPa)	Fs (Mpa)	Rf (%)	Qc (MPa)	Fs (Mpa)	Rf (%)	
10	UK_04	5.71	1	0.066	6.60%	0.99	0.059	5.96%	Yes
10	UK_05	4.46	0.92	0.058	6.30%	0.94	0.06	6.38%	Yes
9	UK_11	1.15	1.016	0.065	6.40%	0.892	0.054	6.05%	Yes
9	UK_12	2.3	0.941	0.062	6.59%	0.945	0.062	6.56%	Yes
8	UK_17	1.66	0.879	0.0539	6.13%	0.903	0.054	5.98%	Yes
8	UK_18	1.54	0.882	0.051	5.78%	0.88	0.056	6.36%	Yes
7	UK_30	5.2	0.89	0.045	5.06%	0.89	0.045	5.06%	Yes
7	UK_33	4.22	0.662	0.028	4.23%	0.625	0.027	4.32%	Yes
6	UK_37	3.2	0.751	0.035	4.66%	0.69	0.0226	3.28%	Yes
6	UK_41	1.45	0.585	0.023	3.93%	0.599	0.026	4.34%	Yes
5	UK_46	0.63	0.514	0.02	3.89%	0.575	0.024	4.17%	Yes
5	UK_46	1.01	0.565	0.025	4.42%	0.562	0.026	4.63%	Yes

3	UK_51	1.24	0.53	0.0264	4.98%	0.5	0.0155	3.10%	Yes
3	UK_51	1.41	0.519	0.0193	3.72%	0.498	0.0165	3.31%	Yes
2	UK_53	4.72	0.307	0.011	3.58%	0.352	0.016	4.55%	Yes
1	UK_59	5.21	0.223	0.013	5.83%	0.193	0.001	0.52%	No

Background Sediment Concentrations

1.2.7 **Plate 1.2** shows the varying background surface suspended sediment (particulate matter) concentrations along the Offshore Cable Corridor. This data has been extracted from the Cefas dataset 'Monthly average non-algal suspended particulate matter concentrations' (Cefas 2018).

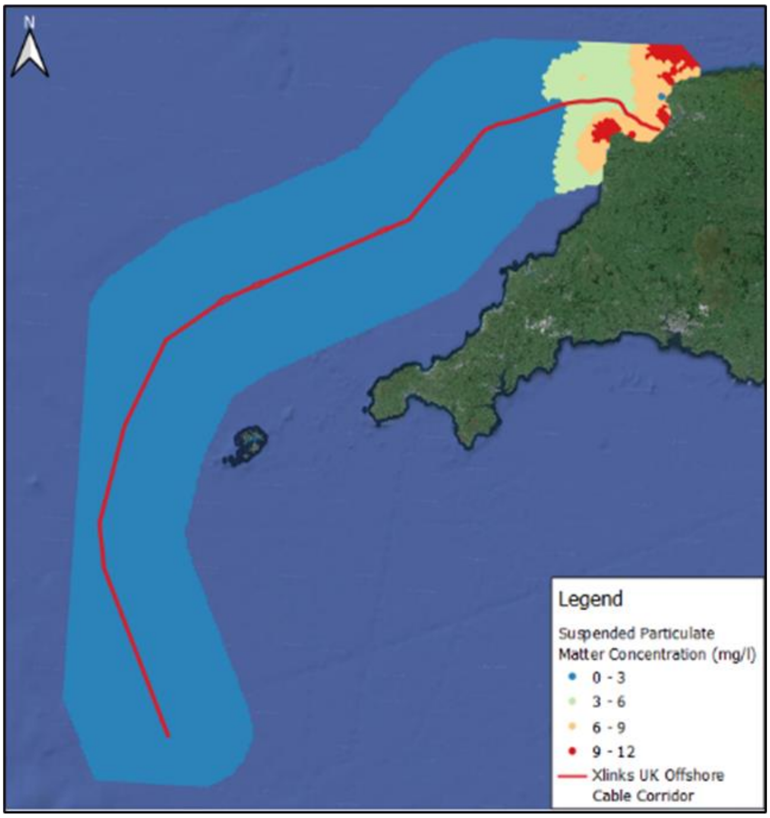

Plate 1.2: Monthly Average Suspended Particulate Matter Surface Concentrations 1998-2015

1.2.8 **Table 1.2** shows the same data in terms of the minimum, maximum, and average suspended sediment concentrations for shallow waters (<5 m depth), coastal waters (5-20m depth), and deep waters (>20 m depth) along the OCC. It should be noted that no construction activities are anticipated within shallow water as the Horizontal Directional Drilling (HDD) exit pits will be located in water depths of between 5 m and 10 m.

Table 1.2: Suspended Sediment Concentrations by Water Depth

Water Depth	Minimum Concentration (mg/l)	Maximum Concentration (mg/l)	Average Concentration (mg/l)

Shallow (<5 m)	1.8	11.5	8.5
Coastal (5m – 20 m)	5.3	11.3	8.4
Deep (>20 m)	0.6	11.6	1.5

1.2.9 This modelled dataset uses monthly average sediment concentrations based on a satellite derived algorithm. This means that the values represent surface concentrations and do not show the likely variation of sediment concentrations at depth within the water column. Additionally, as the data is derived from satellite imagery, some weather conditions such as clouds make data capture more difficult, and thus maximum (short-term peak) concentrations are likely to be missed. Therefore, these results likely underestimate the background sediment concentrations along the OCC, particularly background concentrations at depth, and concentrations in shallow and coastal waters where wave action would be expected to mobilise significant volumes of sediment.

Natural Disturbance

1.2.10 **Plate 1.3** shows the varying sediment type and the number of natural (background) daily disturbances, within a given year, of the surface sediment layer along the Offshore Cable Corridor. This data is from a Cefas model which predicts seabed disturbance caused by waves and currents (Cefas, 2024b) (noting the latest available data are from 2008). It should also be noted that the model excludes additional disturbance due to e.g. mega-ripple occurrence (hence the number of daily occurrences could be greater than shown below).

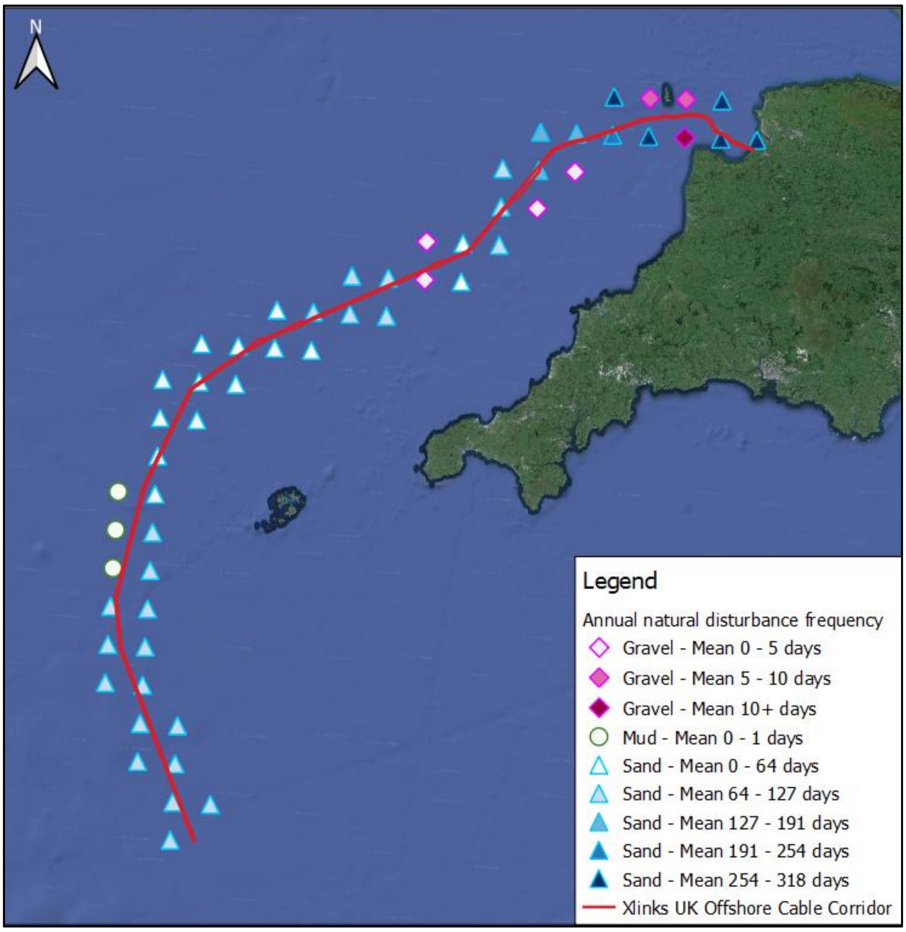

Plate 1.3: Sediment Type and Annual Natural Disturbance Frequency of Surface Sediment Layer (2008 data). Source: Cefas (2016).

1.2.11 **Table 1.3** shows the minimum, maximum and average annual natural seabed disturbance for shallow waters (<5 m depth), coastal waters (5 m – 20 m depth), and deep waters (>20 m depth) along the OCC. As previously stated, no Proposed Development construction activities are anticipated to take place within shallow water.

1.2.12 Due to the coarse nature of the Cefas model, only one data point was located within the shallow waters and the coastal waters along the Offshore Cable Corridor, hence a single value is given for each depth zone. This data indicates that the seabed is naturally very disturbed by e.g. baseline current actions, particularly in shallow and coastal areas, which is consistent with visual and anecdotal observations from this area.

Table 1.3: Suspended Sediment Concentrations by Water Depth

Water Depth	Minimum Days of Disturbance	Maximum Days of Disturbance	Average Days of Disturbance
Shallow (<5 m)	314		
Coastal (5 m – 20 m)	318		
Deep (>20 m)	0	315	74

Waves and Currents

1.2.13 Measured and modelled wave and current data from a range of sources were compiled and analysed along the OCC. This analysis is presented in Volume 3, Appendix 8.2: Wave and Tidal Conditions Technical Note of the ES. Of particular relevance to the sediment transport calculations described in this report are the combination of measured and modelled significant wave heights and modelled depth-averaged tidal currents.

1.2.14 The significant wave height datasets were analysed to determine exceedance thresholds representative of typical summer and winter conditions. Generally, summer conditions are represented by a wave height which is exceeded by 60% of the waves in the dataset and winter conditions are represented by a wave height which is exceeded by 20% of the waves in the dataset.

1.2.15 Current data were extracted from DHI's global MIKE21 model at the same locations as the sediment samples. A spring-neap cycle between September and October 2023 was used to capture peak spring currents as a worst-case scenario.

1.2.16 **Table 1.4** shows the minimum, maximum, and average significant wave heights and current velocities used in the sediment transport calculations.

Table 1.4: Minimum, Maximum, and Average Significant Wave Height and Current Velocities

Variable	Minimum	Maximum	Average
Summer significant wave height (m)	0.80	1.91	1.36
Winter significant wave height (m)	1.75	3.67	2.75
Peak spring depth-averaged current velocity (m/s)	0.64	1.26	0.98

1.3 Source Concentrations

Context

1.3.1 In this section, the anticipated source concentrations for construction activities associated with the Proposed Development are described. A number of sources, including BERR (2008) 'Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry' and the Environment Agency 'SeDiChem' spreadsheet tool (Environment Agency / APEM, 2019) have been used. Source concentrations for construction activities associated with similar schemes have also been reviewed.

BERR (2008)

1.3.2 In 2008, a study was undertaken into the environmental effects of laying cables on the seabed, and the potential mitigation measures required (Department for Business Enterprise & Regulatory Reform (BERR), 2008). As part of this study, the source concentrations associated with construction activities was reviewed.

1.3.3 The report states that it is reasonable to assume that all fine sediments (including sands) would be brought into suspension during cable burial however, the distribution through the water column will depend on a number of factors including particle size and stratification (suspended sediments will tend to be limited to denser, colder water layers). Coarser sediments are also likely to be brought into suspension but will settle quickly back onto the seabed.

1.3.4 The BERR report qualitatively ranks the likely level of seabed disturbance from construction activities, whereby a score of 1 indicates a low level of disturbance and a score of 10 indicates a high level of disturbance. BERR's assessment has been amended to compare likely level of disturbance relative to the ground conditions associated with the Offshore Cable Corridor.

Table 1.5: Level of Sediment Disturbance associated with Cable Burial Operations

		Ground Conditions			
		Sand	Gravels	Unstructured Rock	Structured Rock
Ploughing					
Conventional Narrow Blade		1	1	N/A	-
Advanced with Jetting		2	2	2	-
Deep Burial		1	1	1	-
Rock Ripping		1	1	1	-
Vibrating		1	1	2	-
Other					
Jetting	Fluidisation Erosion	2 3	N/A 3	N/A N/A	N/A N/A
Dredging		4	4	N/A	N/A
Rock Wheel		3	3	3	4
Mechanical Chain Excavators		3	3	3	N/A

1.3.5 Means of quantifying the volume of sediment disturbed by each construction activity varies but can generally be estimated using the following formula (typically used for cutting tools):

$$Depth\ of\ Deployment\ of\ Tool\ (m) \times\ Tool\ Width\ (m) \times\ Progress\ \left(\frac{m}{hr}\right) = Volume\ of\ sediment\ disturbed\ (\frac{m3}{hr})$$

1.3.6 BERR recommends assuming that 10 – 15% of material would immediately backfill into the trench, and the remainder would be deposited on the side of the trench or put into suspension.

Review of similar projects

1.3.7 A review of similar schemes (which used either ploughing or jetting) was also undertaken to understand the level of sediment disturbance which occurred during construction (as measured) or was predicted through the completion of numerical modelling to support ES chapters (i.e. previously accepted values adopted for modelling).

1.3.8 This review is intended to provide broad context, recognising that site and project specific characteristics (e.g. specific sediment properties, water depth and currents, plant and equipment specifics, specific scope of monitoring activities) will vary.

Table 1.6: Increases in Background SSCs for Similar Projects (BERR, 2008)

Scheme	Cable Burial Methodology	Notes
Norfolk (Cromer) Offshore Wind Farm	Ploughing	Assessment completed during construction. Fine sediments were found to disperse through the water column and background SSCs would only be raised a few percent.
Sheringham Shoal Offshore Wind Farm	Ploughing	Assessment completed during construction. Fine sand is likely to remain within the bottom 1 m – 2 m of the water column (likely a conservative assumption) with typical settling velocities of around 10 mm/s.
Nysted Offshore Wind Farm	Jetting	Measurements of turbidity were undertaken continuously during construction. Turbidity levels during cable burial are shown below: • Trenching: Mean = 14 mg/l, Max. = 75 mg/l • Backfilling: Mean = 5 mg/l, Max. 35 mg/l • Jetting: Mean = 2 mg/l, Max. = 18 mg/l Elevations in SSC were recorded up to 200m from the jetting activities
Kentish Flats Offshore Wind Farm	Ploughing	Measurements of turbidity were undertaken continuously during construction. There were marginal, short-term increases in background SSCs (up to 9 %), with peak concentrations reaching 140 mg/l (equivalent to peaks in background SSCs driven by the tidal cycle).

1.4 SeDiChem Tool

1.4.1 The Environment Agency SeDiChem Tool, developed in conjunction with APEM (EA & APEM, 2019), includes a reference library of sediment disturbance SSC uplifts caused by different activities. This data was supplemented by information extracted from recent ES Chapters for similar schemes.

1.4.2 Estimates for SSC uplifts, associated with the construction activities associated with the Proposed Development are presented below.

Route Preparation

1.4.3 Route preparation activities include the clearance of marine debris, removal of 'out of service' cables and seabed levelling. **Table 1.7** outlines two potential methods for seabed levelling, along with estimates for potential SSC uplifts.

1.4.4 The estimated SSC uplifts for mass flow excavation and surface ploughing would be associated with seabed levelling which is expected to present the worst case of all route preparation activities, e.g. generating greater SSC uplifts than clearance of marine debris or removal of cables.

Table 1.7: Estimated SSC Uplift for Route Preparation Construction Activities

Method	Estimated SSC Uplift (mg/l)	Notes
Mass flow excavation (MFE)	10 - 400	Assumed to be similar to jetting (Wood, 2023). Depth average maximum value for sand/ medium sand in marine environment.
Surface plough	~30	Depth average maximum value for fine/ very fine sand in marine environment (EA & APEM, 2019).

HDD Exits

1.4.5 The HDD exit pits would be located between 5 m and 10 m below LAT. The HDD exit pits would be cleared using either backhoe 'dredging' or using MFE. **Table 1.8** outlines the estimates for potential SSC uplifts associated with backhoe dredging and MFE.

1.4.6 Note the construction activities associated with the HDD entry at Landfall have been excluded from this assessment, as the works are above Mean High Water Springs (set landward of and well back from the coastal cliffs).

Table 1.8: Estimated SSC Uplift for Route Preparation Construction Activities

Method	Estimated SSC Uplift (mg/l)	Notes
Backhoe Dredging	10 - 50	Depth average maximum value for silts, sands and gravels (EA & APEM, 2019)
Mass flow excavation (MFE)	10 – 400	Assumed to be similar to jetting (Wood, 2023). Depth average maximum value for sand/ medium sand in marine environment.

Cable Burial and Protection

1.4.7 Cable burial is the preferred method of protection for the cable bundles. It is proposed that the cables would be buried to a target depth of 1.5 m, in a narrow trench of 1 m width (up to 1.5 m). **Table 1.9** outlines the proposed trenching methods along with estimates for potential SSC uplifts. Where full depth burial is not possible, supplementary rock protection may be required. It is understood that the rock protection would be placed using a fall-pipe vessel or similar. It is assumed that the uplift in SSCs associated with the installation of rock protection would be less than for water jetting and/ or mechanical cutting and has therefore been excluded from this assessment (to focus on assessment of the worst-case activities/ conditions).

Table 1.9: Estimated SSC Uplift for Cable Burial Construction Activities

Method	Estimated SSC Uplift (mg/l)	Notes
Water jetting	10 – 400	Depth average maximum value for sand/ medium sand in marine environment (EA & APEM, 2019).
Mechanical cutter	10 – 50	Depth average maximum value for fine sediment/ sand and gravel in a marine environment (EA & APEM, 2019).

1.5 Discussion

1.5.1 As stated within the UK Marine SAC project (Parr et al., 1998), 'dredging activities often generate no more increased suspended sediments than commercial shipping operations, bottom fishing or generated during severe storms'. It is likely that natural events, such as storms, floods and large tides, can increase SSC over much larger areas, and for longer time periods. Furthermore, the effects on SSC as a result of cable burial activities are generally short term (e.g. <1 week) and near field (<1 km from the activity) (Department for Business Enterprise & Regulatory Reform (BERR), 2008).

1.5.2 The qualitative assessment of sediment disturbance from cable laying undertaken by BERR (2008) indicates a relatively low level of disturbance (where a score of 1 is low, and 10 is high). For the construction activities associated with the Proposed Development, ploughing has a score of 1 for disturbance (in all sediment types relevant to the Proposed Development), jetting has a score of 2 (for fluidisation), and mechanical cutting has a score of 3. This indicates that the level of disturbance associated with the Proposed Development is likely to be low.

1.5.3 The two activities likely to cause the largest increases in SSCs are MFE (associated with route preparation and also potentially associated with HDD exit pit clearance) and jetting (associated with cable burial). The Environment Agency SeDiChem Tool indicates a maximum SSC increase in the order of 400 mg/l for MFE and 400 mg/l for jetting (noting these are depth-averaged values). Therefore, there could be a maximum, short-term, nearfield increase in SSC of up to 400 mg/l. Due to relatively deep water and limited wave/ tidal current energy at the seabed, sediment would likely be constrained to the bottom 1-2 m of the water column along most of the length of the OCC (except for coastal waters when wave action influences vertical mixing).

2 SEDIMENT TRANSPORT

2.1 Previous Assessment

2.1.1 To support the previous physical processes Preliminary Environmental Impact Report (PEIR) chapter, a high-level assessment of sediment transport was carried out which compared estimated tidal current velocities at seabed level to calculated critical values (for sediment mobilisation) to determine where along the OCC sediment motion could be initiated. Analysis of sediment fall velocities and tidal ellipses was used to estimate a potential worst case distance and direction of sediment particle transport. Following comments received from the Marine Management Organisation (MMO), Environment Agency (EA), and Natural England (NE) on the PEIR assessment, the influence of waves and sediment resuspension has subsequently been incorporated into this study.

2.2 Analysis Locations

2.2.1 The OCC was split into 10 sections (**Plate 2.2**; **Table 2.1**) based on sediment size and water depth. Sediment transport calculations were carried out for each section under a range of wave and current conditions. Measured wave data were obtained at all available locations along the cable route. It is noted that some sections (e.g. 8-10) use the same measured wave data since no other offshore wave buoys were available. This is considered reasonable as given the depth of water and similar exposure at these locations (>90 m), the wave conditions are not likely to vary significantly.

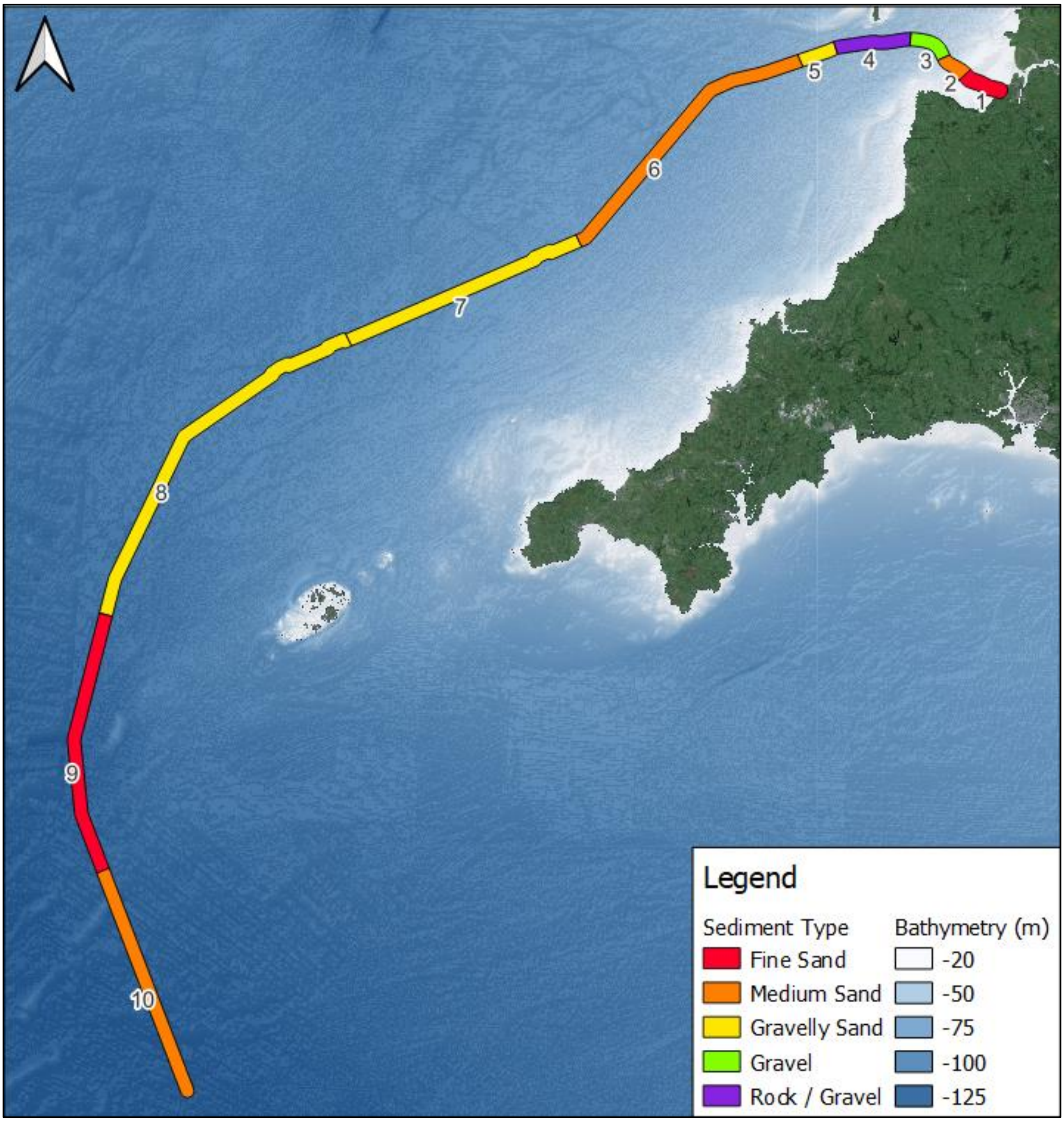

Plate 2.1 OCC sections for Sediment Transport Calculations

Table 2.1: Sediment Transport Calculation Locations with Associated Sediment, Depth, Wave, and Current Characteristics

Location	Sediment Sample Locations Included	Sediment Type	Average Sediment d_{50} (mm)	Average Water Depth (m)	Winter Significant Wave Height (m)	Summer Significant Wave Height (m)	Average Peak Spring Current (m/s)	Maximum Peak Spring Current (m/s)
1	55-61	Fine sand	0.16	12.5	1.75	0.80	1.08	1.26
2	53-54	Medium sand	0.30	30	1.75	0.80	1.02	1.02
3	51-52	Gravel	4.87	45	2.52	1.22	1.18	1.20
4	Between 46 & 51	Rock & gravel	3.00*	52.5	2.52	1.22	1.18	1.20
5	46	Gravelly sand	0.96	57.5	2.52	1.22	1.15	1.15
6	35-45	Medium sand	0.56	65	2.64	1.28	0.81	0.97
7	30-34	Gravelly sand	0.64	80	2.77	1.33	0.70	0.74
8	16-27	Gravelly sand	1.08	100	3.67	1.91	0.63	0.64
9	6-15	Fine sand	0.18	115	3.67	1.91	0.71	0.79
10	1-5	Medium sand	0.33	122.5	3.67	1.91	0.85	0.86

* No sediment grab sample was available in this section so a value of 3mm was assumed based on available seabed substrate classification information

2.3 Methodology

Process

2.3.1 As described in **Section 1**, construction activities along the cable route will cause sediment to be temporarily disturbed. **Plate 2.2** outlines the methodology used to assess potential sediment transport pathways.

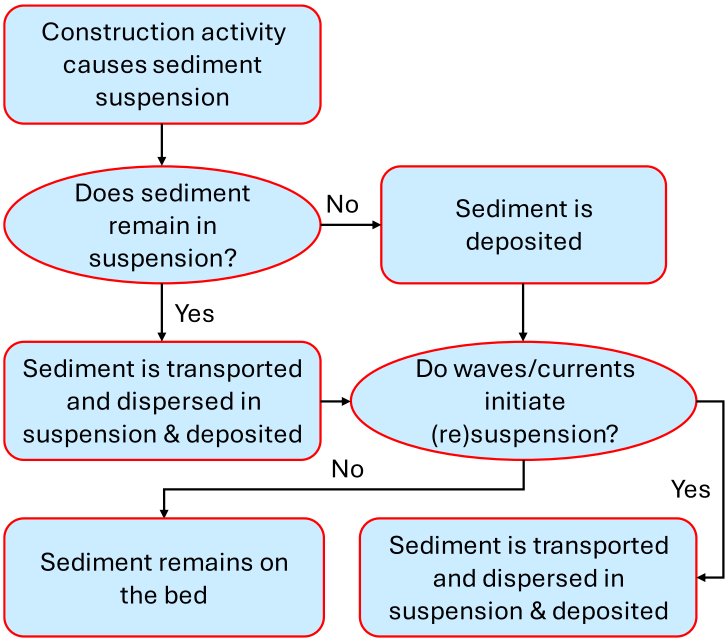

Plate 2.2: Sediment transport method schematic

2.3.2 Initially, the locations where sediment could remain in suspension due to wave action and tidal currents were identified. In these locations, the duration, distance and direction of transport in suspension were calculated. Subsequently, for all locations it was determined whether the natural wave and current conditions exceeded the threshold bed shear stresses to initiate sediment motion and re-suspend the sediments.

Bed Shear Stress

2.3.3 Water moving over the seabed exerts frictional force on the sediment. In a coastal environment, the magnitude of this bed shear stress (τ) is influenced by a combination of wave orbital motions and tidal currents. Depending on the sediment properties and bed shear stress, sediment may be transported along the bed, lifted into suspension, and/ or transported (in suspension).

2.3.4 Bed shear stresses were calculated along the OCC for the sections shown in **Plate 2.1** and compared to threshold values to determine the locations where sediment motion, suspension, and transport could occur.

2.3.5 Due to the influence of waves varying over a wave cycle, both maximum (τ_{max}) and mean (τ_{mean}) bed shear stress values were calculated. The method presented in Soulsby, et al. (2005) was used to calculate the bed shear stresses under combined waves and currents for the scenarios shown in **Table 2.2**.

Table 2.2: Wave and Current Scenarios used in Bed Shear Stress Calculations

Scenario	Wave Conditions	Current Conditions (peak spring depth-averaged)
1	Winter significant wave height	Average over OCC section considered
2	Summer significant wave height	Average over OCC section considered
3	Winter significant wave height	Maximum over OCC section considered
4	Summer significant wave height	Maximum over OCC section considered

2.4 Sediment in Suspension

Settling and Friction Velocities

2.4.1 For sediment to remain in suspension, the grain settling velocity must be less than the friction velocity (which relates to the upward turbulent component of flow velocity). Equations 102 and 32 from 'Dynamics of Marine Sands' (Soulsby, 1997) were used to calculate sediment settling and friction velocities respectively.

2.4.2 A comparison of the settling and friction velocities highlight the locations along the OCC where sediment is likely to remain in suspension under natural hydrodynamic/ geomorphological conditions, i.e. without additional disturbance of the bed from construction activities such as trenching (**Table 2.3**).

Table 2.3: Locations where Sediment Naturally Remains in Suspension (Peak Spring Tide)

Scenario	Location - Does sediment naturally remain in suspension?									
	1	2	3	4	5	6	7	8	9	10
1	Yes	No	No	No	No	No	No	No	Yes	No
2	Yes	No	No	No	No	No	No	No	Yes	No
3	Yes	No	No	No	No	No	No	No	Yes	No
4	Yes	No	No	No	No	No	No	No	Yes	No

2.4.3 These results show the locations where it is possible for sediment to remain in suspension and can therefore be transported and dispersed by tidal currents for the worst-case peak spring tidal conditions.

Transport Distance in Suspension

2.4.4 The calculations described in the section above, consider sediment motion and suspension under peak spring tide current velocities. To assess the potential associated sediment suspension durations and transport distances, the same calculations were repeated in the locations where sediment remains in suspension with varying current velocities over a 13-hour tidal cycle. This assessed the duration of the tidal cycle where it is possible for sediment to remain in suspension and determine how far it may be transported.

2.4.5 All scenarios in **Table 2.3** show the same spatial patterns of sediment suspension (i.e. at which sections along the OCC sediment can remain in suspension). The worst-case in terms of wave heights and current velocities (scenario 3 - winter significant wave height and maximum current velocity over OCC section) was assessed for sediment transport distances.

2.4.6 Potential sediment transport distances and directions were assessed using tidal excursion ellipses generated from current velocity and directional data over a tidal cycle. The current velocities extracted from DHI's global MIKE21 (see **Section 2**) are depth-averaged. They were converted to bed currents using method 2 from 'Tidal Current Vertical Profiles' (National Ocenaography Centre). This more accurately represents the conditions at the depth where sediment is likely to be released during construction (or maintenance) activities.

2.4.7 As noted in BERR (2008), sediment released during construction activities is generally likely to remain in the lower 1-2 m of the water column. Depth-averaged tidal current velocities were converted to 2 m above the bed. This is a conservative assumption as velocities increase with (vertical) distance from the bed.

2.4.8 The overall potential sediment transport distances were determined based on the maximum continuous duration that it is possible for sediment to remain in suspension due to tidal current velocities. **Table 2.4** shows the predicted maximum distance of sediment transport where sediment naturally remains in suspension (locations 1 and 9). This is a maximum theoretical distance calculated from tidal current velocity and direction (and does not consider dispersion of sediment during transport which would reduce the concentration from its source levels).

Table 2.4: Predicted Maximum Distance of Sediment Transport

Location	Distance above bed (m)	Maximum continuous duration in suspension (hrs)	Maximum distance travelled in suspension (km)	Direction travelled
1	1	6	14.0	West Southwest to East Northeast
9	1	4	6.9	Southwest to Northeast
1	2	6	15.2	West Southwest to East Northeast
9	2	4	7.5	Southwest to Northeast

2.4.9 It is noted that in Bideford Bay (location 1; **Plate 2.1**) the shape of the coastline may constrain sediment transport. In all other locations (other than 1 and 9) sediment was not estimated to remain in suspension. **Plate 2.3** shows an example of a potential (worst case) sediment transport distance associated with sediment disturbance during a peak spring tide in section 1 at a height of 2m above the bed.

2.4.10 **Plate 2.4** shows an example of sediment transport distance associated with sediment disturbance during a mean neap tide in section 1 at a height of 2m above the bed.

2.4.11 **Plate 2.5** shows an example of sediment transport distance associated with sediment disturbance during a peak spring tide in section 9 at a height of 2m above the bed.

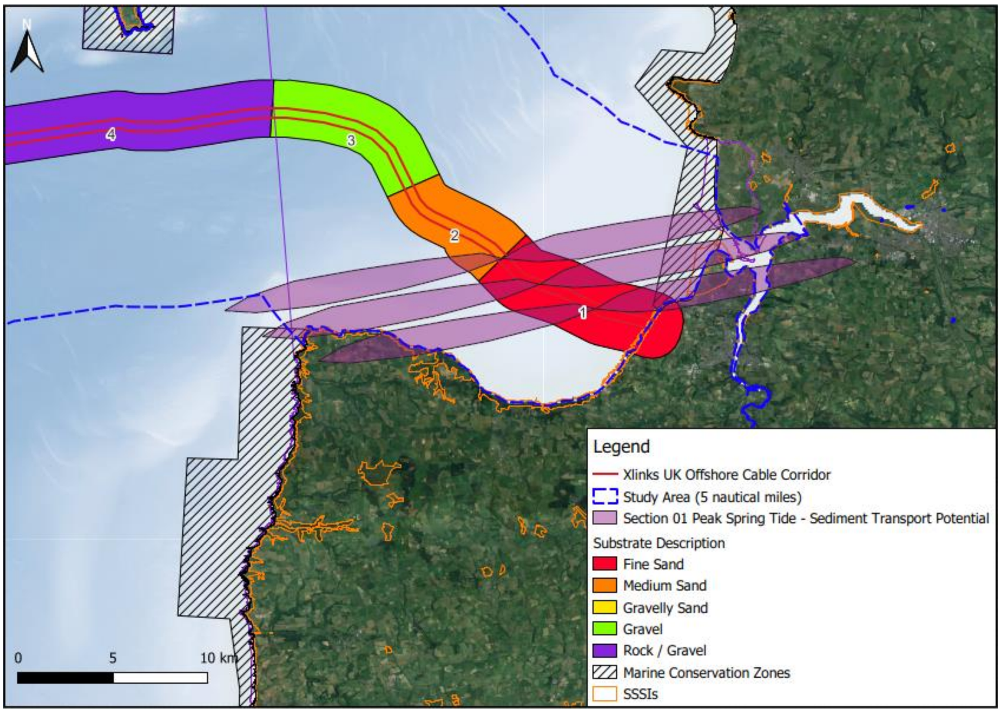

Plate 2.3: Peak Spring Tidal Excursion Ellipse at Section 1

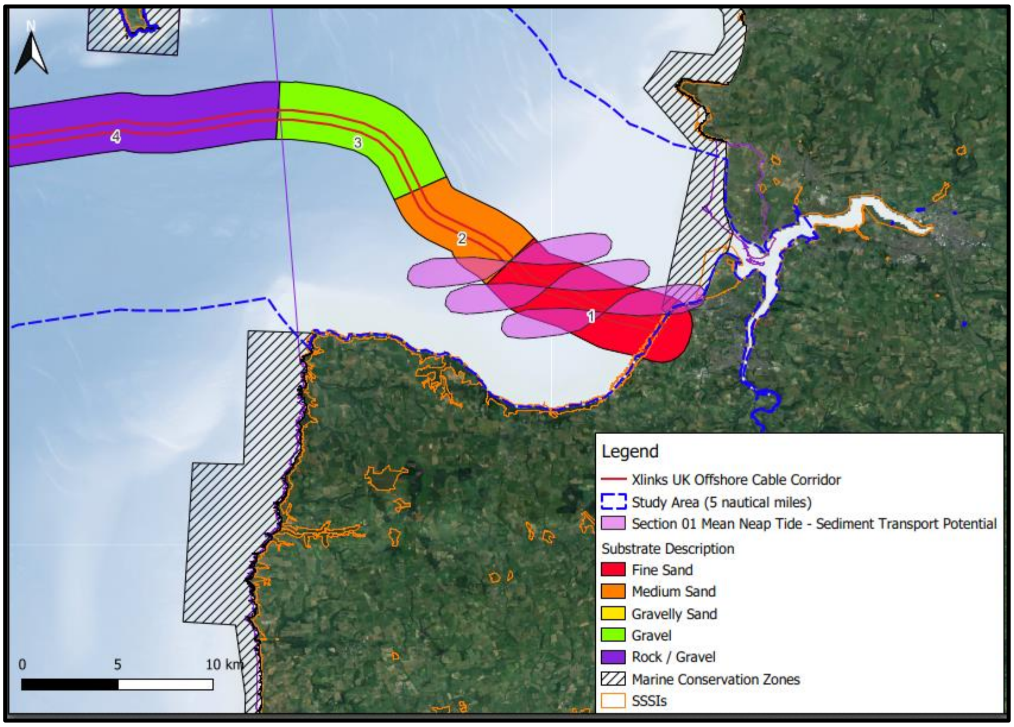

Plate 2.4: Mean Neap Tidal Excursion Ellipse at Section 1

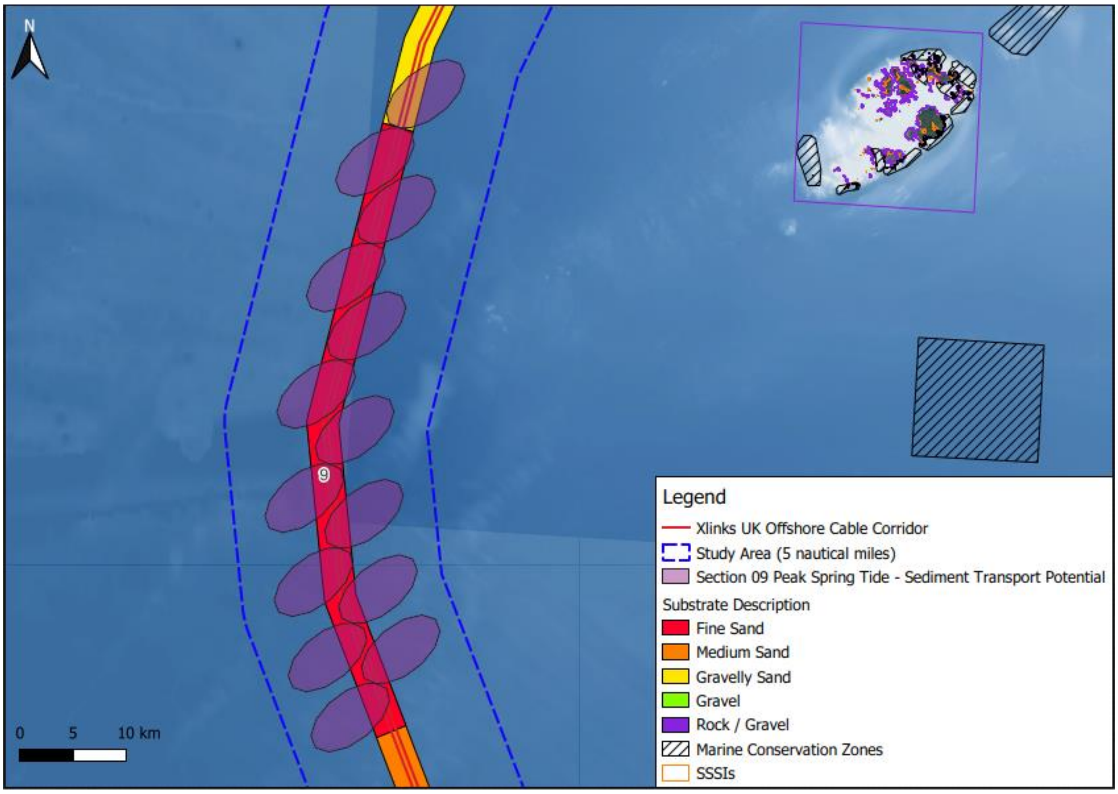

Plate 2.5: Peak Spring Tidal Excursion Ellipse at Section 9

2.4.12 The sediment transport excursion ellipses do not consider the concentration of suspended sediment. In reality, as tidal currents transport sediment away from the disturbance activity (i.e. ploughing of trench), the suspended sediment concentration will reduce (due to advection and/ or dispersion) as distance from the OCC increases. Therefore, at the furthest point (along the predicted ellipse) from the OCC, sediment concentrations will be lowest, tending towards background.

2.4.13 Outside of sections 1 and 9, the combination of anticipated currents and sediment particle size, mean that any disturbed sediments would be expected to deposit immediately i.e. fall out of suspension within tens of metres of the disturbance activity.

2.5 Sediment Resuspension

Initiation of Sediment Motion

2.5.1 Sediment motion is initiated when the bed shear stress exerted by the flow exceeds a critical threshold. The critical threshold is determined by the submerged weight of the sediment, which is calculated from the sediment grain diameter and density. Equations 74, 75, and 77 from 'Dynamics of Marine Sands' (Soulsby, 1997) were used to calculate the threshold bed shear stress for the initiation of sediment motion.

2.5.2 A comparison of the calculated maximum bed shear stresses and critical thresholds shows the locations along the OCC where is it possible for sediment motion to occur under natural conditions, i.e. without additional disturbance from construction activities (**Table 2.5**).

Table 2.5: Locations where Sediment Motion is Naturally Initiated

Scenario	**Location - Is sediment motion initiated naturally?**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes
3	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes

2.5.3 Initiation of sediment motion does not necessarily mean that the sediment will be transported for a significant distance. Rather, sediment transport in suspension occurs when the sediment is lifted into the water column and able to remain in suspension, as detailed in **Section 2.4**.

Initiation of Sediment Suspension

2.5.4 Similarly to the initiation of sediment motion, sediment suspension is also initiated when the bed shear stress exerted by the flow exceeds a critical threshold. The threshold of suspension is greater than the threshold of motion as more energy is required to lift the sediment from the bed.

2.5.5 Equation 3.2 from 'Simple General Formulae for Sand Transport in Rivers, Estuaries and Coastal Waters' (Van Rijn, 1993) was used to calculate the threshold Shields parameter for suspension. This was used in equation 74 from

'Dynamics of Marine Sands' (Soulsby, 1997) to determine the threshold bed shear stress for initiation of sediment suspension.

2.5.6 A comparison of the calculated mean bed shear stresses and critical thresholds shows the locations along the OCC where sediment initiation is likely to occur under natural conditions, i.e. without additional disturbance from construction activities (**Table 2.6**). The mean stress is used in this comparison because the maximum stress will not be sustained over the duration of the wave cycle, and therefore will not act on the sediment for long enough to initiate suspension.

Table 2.6: Locations where Sediment Suspension is Naturally Initiated

Scenario	Location - Is sediment suspension initiated naturally?									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
2	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
3	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
4	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes

2.5.7 As shown in **Section 2.4**, sediment only remains in suspension in sections 1 and 9. As sediment has not been shown to get transported between adjacent sections (due to the direction of transport in suspension relative to the OCC alignment), the same transport durations and distances apply for the resuspension of sediment.

2.6 Bed Change

Sediment Accretion

2.6.1 In locations where the bed substrate is suitable for cable burial, machine trenching will be undertaken. his trench will be c.1 m wide (up to a maximum of 1.5 m in places) and 1.5 m deep and cable burial will advance at c. 150 m/hr along the route.

2.6.2 At the locations where sediment has been calculated to remain in suspension (locations 1 and 9 of the OCC – see **Section 2.4**), a sediment plume area is possible. In all other locations along the Offshore Cable Corridor, it is assumed that disturbed sediment will immediately resettle to the bed in a very localised area (within tens of metres of the disturbance activity).

2.6.3 For the purposes of this calculation, it was assumed that the rate of sediment disturbance in one hour of trenching is 202.5 m^3/hr ($150\ m/hr \times 1.5\ m \times 1\ m \times 90\% = 202.5\ m^3/hr$), which includes assumption of 10% immediately backfilling into the trench, as per most precautionary case from the BERR (2008) recommendation of disturbance activities.

2.6.4 It was further assumed that this sediment is either released over a continual working period of 6 hours (worst-case extent for duration between low and high slack water) or 1 hour (worst-case deposition thickness in the hour before slack water).

2.6.5 The distance of sediment transport away from the cable route in the 6 hour or 1 hour period was calculated from the tidal current velocity. This was multiplied by a distance of 150m (length trenched per hour), to provide a very crude estimate of the potential total plume area. Horizontal sediment dispersion (which would further increase the area of the plume, but reduce the concentration/ density of it) has not been included, meaning that the sediment deposition thicknesses calculated are likely to be conservative.

2.6.6 **Table 2.7** shows the average sediment deposition thickness associated with the minimum and maximum plume areas at locations 1 and 9 under maximum current conditions (scenario 3, **Table 2.2**) at 1 m and 2 m above the bed. The maximum deposition thickness corresponds to the minimum plume area (minimum current velocity), since the volume of material disturbed during a tide cycle is deposited over a smaller area. Conversely, the minimum deposition thickness corresponds to the maximum plume area (maximum current velocity).

Table 2.7: Sediment Deposition Thickness (Peak Spring Tide)

Location	Distance above bed (m)	Maximum plume area over tidal cycle (km^2)	Minimum plume area after 1hr (km^2)	Maximum plume area sediment deposition thickness (mm)	Minimum plume area deposition thickness (mm)
1	1	12.6	0.2	>0.5	1.0 – 1.5
1	2	13.7	0.2	>0.5	>1.0
9	1	6.5	0.1	>0.5	1.0 – 1.5
9	2	7.0	0.2	>0.5	1.0 – 1.5

2.6.7 The minimum and maximum predicted sediment deposition thickness at locations 1 and 9 under mean spring tide and mean neap tide scenarios were also assessed. The average deposition thicknesses for these scenarios were found to be less than 1 mm.

2.6.8 Sediment deposition thickness calculations above (results presented as **Table 2.7**) assume equal deposition across the plume area (based on the median sediment particle size, d_{50}), therefore results represent an average deposition thickness across the plume area for that particular scenario.

2.6.9 It is noted that the settling velocity of sediment along the cable route varies between 0.01 m/s (fine sand) to 0.27 m/s (gravel). The initial effects on SSC (i.e. the largest concentration changes) from sediment disturbed by cable trenching activities will therefore be short-term (in the order of minutes) and highly localised as the largest fractions of the disturbed sediment settle close to the point of disturbance (and the finest fractions are potentially carried further but also dispersed to far smaller concentrations). This is because the transport calculations are based on the median particle size (d_{50}) which lead to an estimated plume area between 6.5 km^2 and 13.7 km^2 (and the methodology does not include dispersion/ dilution of the plume or consideration of the particle size distribution of the disturbed sediment).

2.6.10 It is also noted that due to the relatively shallow nature of location 1 (compared to offshore section depths) this section will experience significant levels of wave driven sediment mobilisation/transport. Therefore, material deposited following cable installation will tend to be resuspended in a short timeframe (i.e. over a tidal cycle) and a measurable change in bed level is highly unlikely. The magnitude of potential impact on sediment deposition across all sections is deemed negligible.

Scour

2.6.11 In locations where the bed substrate (or other circumstances such as crossing existing cables) means cable burial is not possible, above sea bed level cable protection will be required, principally achieved by rock placement. Theoretical maximum scour depths and lengths (in the direction of wave travel) were estimated using a method for determining scour around submerged structures (Young, et al., 2006).

2.6.12 The assessment of sea bed conditions provides indicative locations for rock placement (or risk to full burial, etc.) – see e.g. Volume 1, Chapter 3: Project Description of the ES - but uncertainty remains in some sections, until construction takes place. In other sections, e.g. in Bideford Bay, there is high confidence that substrates are appropriate for trenching and backfill of existing sediments, hence no rock protection is anticipated. For completeness in this report, calculations were carried for all sections along the cable route. These calculations account for the effects of waves only and are therefore most applicable to the coastal waters sections, and can be considered conservative for deeper sections.

2.6.13 **Table 2.8** gives the maximum estimated scour depth and length due to wave action at each location in winter and summer conditions (scenarios 3 and 4, **Table 2.2**). Note the maximum scour depth would not occur over the full length of the scour hole (**Plate 2.6**).

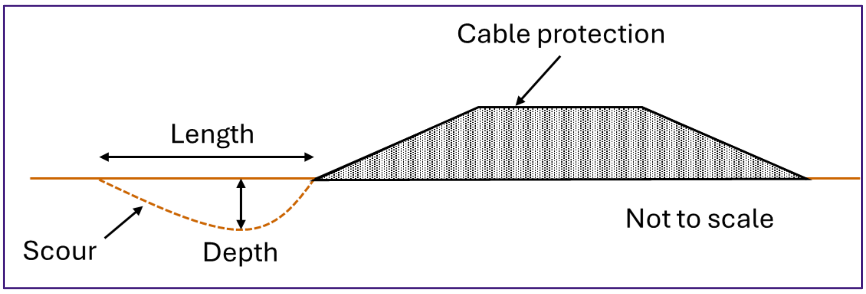

Plate 2.6: Schematic of Scour Length and Depth

2.6.14 The wort-case scour is predicted to occur during winter conditions. The maximum theoretical scour depth is 0.433 m at location 1 and the maximum length is 5.77 m at locations 8-10. These calculations could apply to scour on either side of the rock protection depending on the direction/ magnitude of tidal currents in transporting sediment scoured due to wave action. As above, there is not anticipated to be any rock protection required in Bideford Bay. If the results from Section 1 are discounted, then the maximum scour depth predicted across all sites is considered modest.

Table 2.8: Maximum Scour Depth and Length Under Wave Action Along the Cable Route (all locations, ignoring outline CBRA indications of where rock placement would be required).

Section	Wave Conditions	Maximum Scour Depth (m)	Maximum Scour Length (m)
1	Summer	0.058	2.520
2		0.003	2.520
3		0.000	1.910
4		0.000	1.910
5		0.000	1.910
6		0.000	2.006
7		0.002	2.096
8		0.002	3.000
9		0.002	3.000
10		0.001	3.000
1	Winter	0.433	2.741
2		0.057	2.741
3		0.020	3.951
4		0.015	3.951
5		0.019	3.951
6		0.001	4.154
7		0.094	4.347
8		0.110	5.770
9		0.190	5.770
10		0.117	5.770

2.7 Assumptions and Limitations

2.7.1 Assumptions were made in the sediment transport calculations due to data availability and inherent limitations in the methods/ equations available. Where appropriate, conservative assumptions were applied to give a reasonable worst-case assessment.

2.7.2 The following assumptions were used in the sediment transport calculations:

- Bed shear stress (including thresholds):
  - Waves and currents are acting in the same direction;
  - Waves are monochromatic and non-breaking; and

  - The bed is flat (with no bedforms) and hydrodynamically rough.
- Sediment suspension and resuspension:
  - Sediment settling is not hindered;
  - Sediment dispersion/ dilution of sediment plumes is not considered;
  - Sediment is transported between 1 m and 2 m above the bed in deeper water; and
  - Sediment is not resuspended more than once outside the OCC.
- Bed change (accretion and scour):
  - Sediment grab samples are representative of the sediment throughout the depth of the cable trench;
  - Bed accretion due to suspended sediment transport settling ignores the concentration/ density of the plume and advection and dispersion during transport; and
  - Scour assessment only considers wave action, using equations for a submerged structure.

2.8 Discussion

2.8.1 The sediment transport estimates carried out show that suspended sediment could remain in suspension along approximately 18% of the overall OCC length (sections 1 and 9 - **Plate 2.3**) during peak spring tides only. This corresponds to the sections where the sediment is finest (d_{50} = 0.16 and 0.18 mm respectively). These are also the only locations where sediment can be naturally resuspended and transported further due to wave action (and tidal currents).

2.8.2 Suspended sediment in Bideford Bay (section 1) may travel a maximum distance of up to 15.2 km if it is disturbed at the offshore extent of this section during worst-case wave conditions and peak spring tide currents, but is expected to be dispersed to negligible concentrations at the upper extents of this transport distance. Suspended sediment to the southwest of the Isles of Scilly (in section 9) can travel a maximum distance of up to 7.5 km (depending on the level above the bed).

2.8.3 Sediment that is released from cable trenching activities in sections 1 and 9 is estimated to be deposited with a thickness of up to <1.5 mm depending on the timing of the trenching activities within the tidal cycle and subsequent distance of transport in suspension. Along the remaining length of the OCC, sediment is assumed to settle immediately back in the vicinity of the trench.

2.8.4 The depth of scour around cable protection structures is expected to be up to 0.19 m during winter wave conditions (if no cable protection in assessment section 1 is assumed) and the length of scour up to 5.77 m (at sections 8-10). The limited spatial extent and volume of scour is not expected to have any significant effect on SSC considering any scour would occur over longer timescales (compared to the cable trenching activities for example).

3 CONCLUSIONS

3.1.1 An assessment of potential sediment transport was carried out, principally to support the physical processes ES considerations. Baseline data including sediment sampling, background remote sensing concentrations, modelling of natural disturbance, and waves and currents were collected and used to inform the assessment. The baseline information shows that the sediment along the OCC varies from very fine sands to medium pebbles but is generally fine and medium sands. Typical background surface suspended sediment concentrations vary along the route, ranging from <1 mg/l to >11 mg/l with background concentrations at seabed level expected to be substantially higher due to frequent natural disturbance by wave and current action, particularly closer to shore. Wave and current conditions vary along the OCC and between summer and winter periods.

3.1.2 Construction activities including route preparation and cable burial were considered in the context of assessments carried out for similar schemes. The BERR (2008) review of cabling techniques was used initially to estimate relative sediment disturbance from different construction activities and to inform assumptions used in the assessment. This was supplemented by data from the EA SediChem tool to give predictions of suspended sediment concentration uplifts. Of the construction methods currently proposed, mass flow excavation and water jetting have the highest predicted uplift of up to 400 mg/l (in the short-term/ nearfield).

3.1.3 Semi-empirical calculations carried out for the PEIR were updated to include wave action, sediment resuspension, and scour. The OCC was split into 10 sections (1 being in Bideford Bay and 10 at the offshore extent of the UK OCC route). Semi-empirical calculations were carried out for each section to determine whether sediment could be suspended and transported by waves and currents.

3.1.4 It was determined that sediment in suspension (either naturally or due to construction activities) in sections 1 and 9 will remain in suspension and could travel up to 15.2 km and 7.5 km respectively during a peak spring tide (and worst-case wave conditions) with suspended sediment concentrations expected to reduce with distance from source (and be negligible at the maximum distances stated). The relative concentration/ density of the sediment plume with increasing distance from source cannot be estimated using semi-empirical approaches (and the level of potential sediment dispersal risk associated with the Proposed Development does not merit full numerical modelling – as confirmed during regulator consultations).

3.1.5 The transport of sediment suspended during cable trenching activities was conservatively estimated to be deposited over the bed with a thickness of <1.5 mm depending on the stage of the tidal cycle.

3.1.6 Scour around cable protection installed at locations where the cable cannot be fully buried or to cross existing cables was estimated to occur up to a maximum depth of ~0.19m (depending on the location and wave conditions, and excluding Bideford Bay where no cable rock protection is anticipated).

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