Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects

Appendix 9.7.2 - Export Cable Burial Risk Assessment

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SUMMARY AND CONCLUSIONS

Equinor New Energy Limited are presently leading the project to develop extensions to the existing Dudgeon and Sheringham Shoal offshore wind farms. The proposed cable will run from an offshore substation to a landfall at Weybourne, a distance of approximately 17.5 km. Of this distance, approximately 10 km crosses the Cromer Shoal Marine Conservation Zone (MCZ).

In connection with this project, PACE have been contracted by Equinor to carry out a Cable Burial Risk Assessment (C-BRA) report for an export cable that will connect the Sheringham and Dudgeon Extensions with a landfall near Weybourne on the Norfolk coast. PACE have obtained the assistance of Xodus Group Limited, to provide assistance with the AIS data and processing, and expertise on environmental aspects.

This report has been prepared as Cable Burial Risk Assessment (C-BRA) to consider seabed geology and the external risks to the cable including both natural, anthropogenic and environmental events. The process follows the guidance published by the Carbon Trust and takes into account various guidelines and standards including documents published by Carbon Trust and DNV-GL.

The report finds that the external risks to the cable are relatively low, with limited fishing activity and relatively light shipping traffic and no anchorages that might pose a hazard to cable integrity. Based on this assessment, a depth of lowering of 1.0 m is considered sufficient to achieve an annual probability of damage to the cable due to external aggression of less than 10^{-5}/year. If this depth is relaxed to 0.6 m in chalk, the probability of external aggression remains at approximately 10^{-5}/year. It has therefore been proposed that a target depth of lowering of 1.0 m is proposed, with 0.6 m or greater being acceptable in Chalk.

Consideration has been given to the suitability of different trenching tools. Both ploughs and mechanical trenchers are considered suitable. The preferred plough type is a Sea Stallion, based on the aggressive share rake angle and its successful record on the nearby Dudgeon Export Cable. For mechanical trenchers and hybrid trenchers (able to both cut and jet), there are a number of suitable options, with preference given to the larger tools due to a combination of greater cutting power and track record. Jet trenchers are not considered suitable in the chalk, but may have a benefit where sands are present, and where used to complement a mechanical trencher.

The route crosses the Cromer Shoal MCZ, which has been designed as such to protect the seaweed dominated infralittoral chalk bedrock, which provides an important habitat for a variety of sea creatures to settle and grow. Particular attention has been given to the environmental aspects of cable lay and trenching operations. The report finds that both trenching and external protection will have an adverse impact. Given the status of the zone, and the fact that another cable appears to have been rerouted to avoid crossing the MCZ, we consider that there may be some difficulty in obtaining a permit to install a cable through this area. It is recommended that options are discussed with the relevant authorities (including Natural England and the Marine Management Organisation). A useful exercise may be to perform an environmental assessment of the Dudgeon route to understand how that has recovered following installation of the cable.

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1 INTRODUCTION

Equinor New Energy Limited are presently leading the project to develop two extensions to the existing Dudgeon and Sheringham Shoal offshore wind farms.

In connection with this project, PACE have been contracted by Equinor to carry out a Cable Burial Risk Assessment (C-BRA) report for an export cable that will connect the Sheringham and Dudgeon Extensions with a landfall near Weybourne on the Norfolk coast. PACE have obtained the assistance of Xodus Group Limited, to provide assistance with the AIS data and processing, and expertise on environmental aspects.

This report has considered the external risks to the cable including both natural, anthropogenic and environmental events. The process follows the guidance published by the Carbon Trust and takes into account various guidelines and standards including documents published by Carbon Trust and DNV-GL [5, 6, 16].

An overview of the project area is reproduced in Figure 1-1 [1].

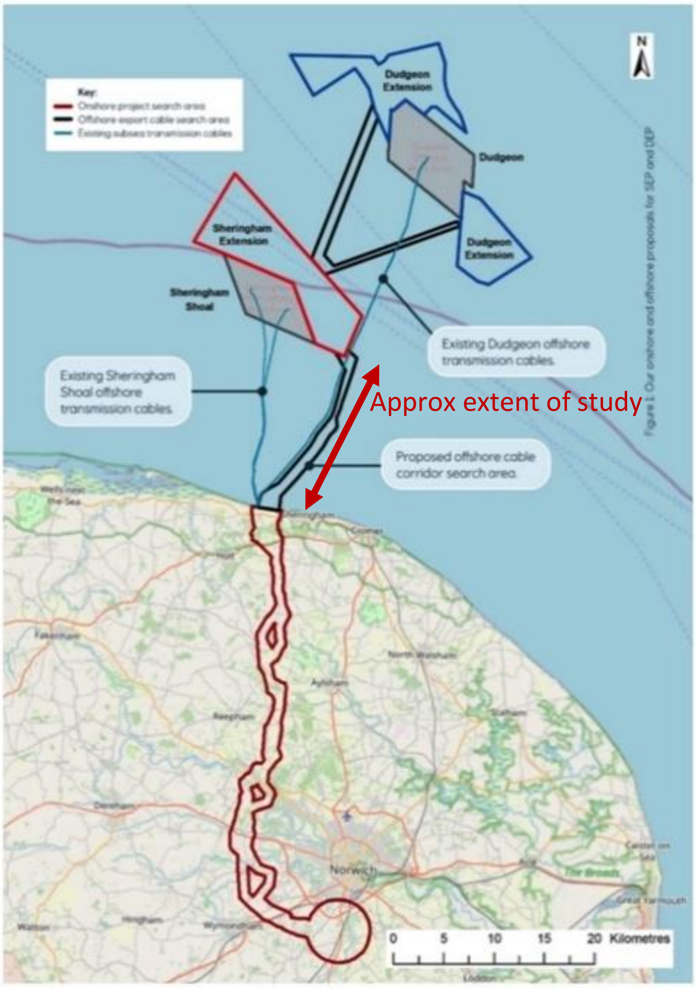

Figure 1-1 : Overview of the Proposed UK Extension Cable Route.

1.1 Abbreviations

AIS	Automatic Identification System
C-BRA	Cable Burial Risk Assessment
CPT	Cone Penetration Test
CPTU	Cone Penetration Test with Pore Pressure Measurement
DNV-GL	Den Norske Veritas Germanischer Lloyd
DoL	Depth of Lowering
DWT	Deadweight Tonnage
FOCI	Features of Conservation Interest
GIS	Geographic Information System
GT	Gross Tonnes
HDD	Horizontal Directional Drilling
IACS	International Association of Classification Societies
ICES	International Council for Exploration of the Sea
KP	Kilometre post
LAT	Lowest Astronomical Tide
MAG	Magnetometer
MBES	Multi-Beam Echo Sounder
MCA	Marine and Coastguard Agency
MCZ	Marine Conservation Zone
NCEL	Naval Civil Engineering Laboratory
OSS	Offshore Substation
OWF	Offshore Wind Farm
PGA	Peak Ground Acceleration
PSD	Particle Size Distribution
ROV	Remotely Operated Vehicle
RPL	Route Position List
SBP	Sub-Bottom Profiler
SOLAS	Safety of Life at Sea
SSS	Side Scan Sonar
UK	United Kingdom
VC	Vibrocore

2 AVAILABLE INFORMATION

The following information has been used to assist with preparation of this report:

1. Equinor: UK Extension Burial Risk Assessment – Invitation to Tender
2. Gardline Limited, UK Wind Extension of Sheringham Shoal and Dudgeon Surveys, Equinor Reference EQ19537 (28/02/2020)
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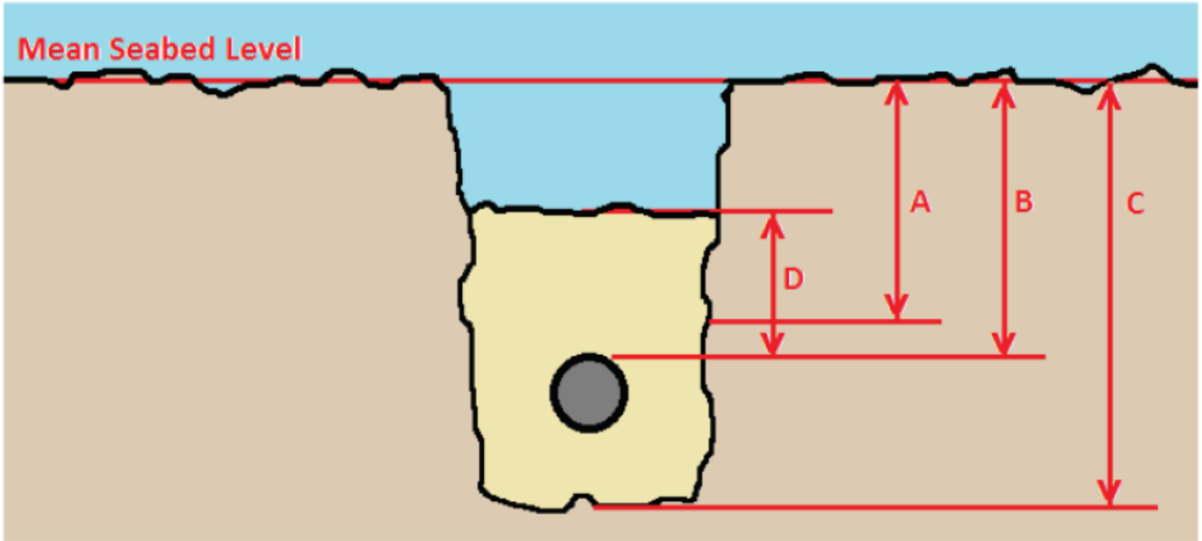
2.1 Cable Details

Full engineering of the cable design has not been completed, however it is expected to have an outside diameter in the range 235 mm to 300 mm and a minimum bend radius of between 3.0 m and 3.5 m.

2.2 Terminology

KP 0 is defined as the OSS and KP 17 is the HDD exit. The landfall at Weybourne is located at KP 17.75.

The depth of lowering and backfill cover over the cable is defined as shown in Figure 2-1.



A **Recommended Minimum Depth of Lowering**
B **Target Depth of Lowering**
C **Target Trench Depth**
D **Depth of Cover**

Figure 2-1 : Definitions used for Depth of Lowering and Cover

3 SEABED CONDITIONS

Assessment of seabed conditions is based on interpretations from a 2019 Gardline geophysical route survey [2] as well as non route-specific vibrocore and CPT logs and laboratory data from a 2013 GEO survey carried out in connection with investigations for the original existing Dudgeon export cable [4].

Seabed conditions along the cable route are described in Appendix A, with an overview provided below.

3.1 Bathymetry

Water depths range from 27 m LAT at the offshore end of the survey route to 0 m LAT at the Weybourne landfall. Seabed gradients are reported to be generally < 1°, but local higher slopes are associated with some seabed bedforms. A bathymetric profile, digitised from Gardline alignment sheets, is shown in Figure 3-1.

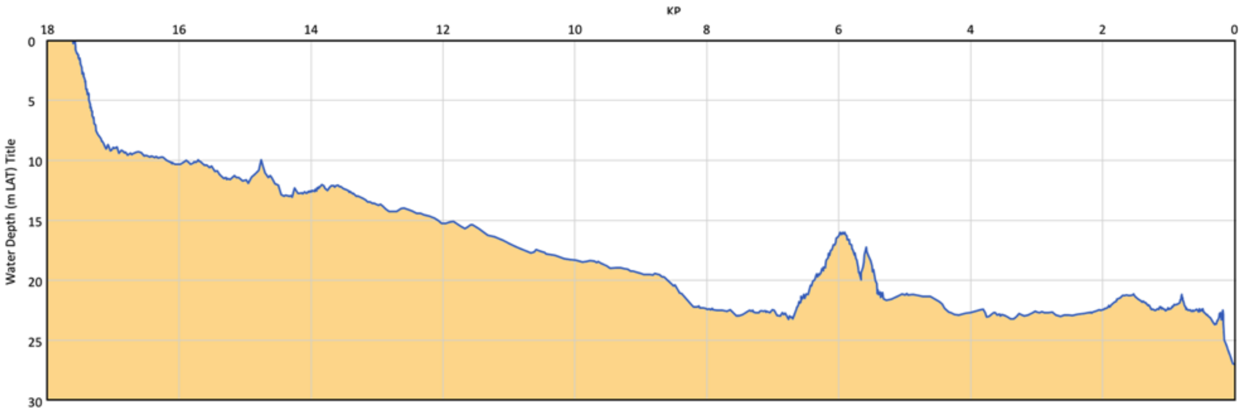


Figure 3-1: Bathymetric profile along the Weybourne route

3.2 Seabed Features

The sea is reported to be relatively smooth and featureless between KP 0 and KP 13.68. Beyond this, the seabed is reported to become "lumpier", with WNW-ESE trending bands of megaripples with crests oriented NW-SE.

The following seabed features have been reported:

- Sheringham Shoal, a seabed high comprising thick sand sequences. The route crosses the southern tip of this feature between KP 5.35 and KP 6.35.

- Megaripples or sand waves. These are reported primarily between KP 5.32 and KP 8.32 in connection with Sheringham Shoal, and between KP 13.71 and KP 17.2. Megaripples have amplitudes of 0.1 m to 0.5 m and wavelengths between 2 m and 16 m. Sand waves have heights up to 2 m and may be either isolated features or have wavelengths between 25 m and 150 m. Gradients of up to 15° may be encountered on the sides of some of these bedforms.

- Seabed Boulders. Seabed boulders are reported with typical heights over seabed ranging between 0.3 m and 0.6 m, with single larger contacts reported. The density of boulders increases from KP 10 and an additional increase in density occurs from KP 13.5. However, Gardline suggests that the increase at KP 13.5 may be due to a closer line spacing and lower side scan sonar range used during the nearshore survey.

- Possible Debris. Single sonar contacts have been interpreted as point or linear debris. A line of magnetic anomalies with associated sonar contacts that cross the route at KP 16.75 has been interpreted as fishing tackle. Magnetic anomalies on the tip of Sheringham Shoal are interpreted as a possible length of cable on the seabed which crosses the route at KP 6.00 and again at KP 6.16.

- Magnetic anomalies. Single anomalies are observed, as well as anomalies that define linear features. Some of these are interpreted to indicate possible linear debris. Lineations of anomalies also correlate with the Sheringham Shoal Export A and B cables.

- Wrecks. Two wrecks were identified during the survey operations at distances of 750 m and 150 m from the current route centreline.

3.3 Seabed Sediment

Seabed sediments are described as Holocene Sand, gravelly Sand or Gravel. This sediment is interpreted, on the basis of the geophysical data, to be thin or patchy over much of the route. Local areas of exposed Quaternary Clay or Sand sediments or Cretaceous Chalk bedrock are expected. Beyond KP 17.23, the seabed has been interpreted to be dominated by chalk outcrop, although available off-route geotechnical and environmental data suggests that a seabed veneer of granular materials may also exist over most of this section.

3.4 Crossings

The out of use Stratos telecom cable is interpreted to cross the route at KP 13.28. This position was determined both from magnetic data and locally on bathymetric and side scan data. An additional crossing of an unknown cable or feature was registered at KP 16.73 in both magnetic and bathymetric data.

4 GEOTECHNICAL PROPERTIES

4.1 Introduction

A geophysical survey along the proposed installation route (MBES, SSS, SBP, MAG) was carried out in 2019 by Gardline [2]. No route-specific geotechnical data are presently available. Off-route vibrocores and CPTUs were carried out by GEO [4] at 20 locations in connection with initial development of the Sheringham and Dudgeon OWFs. Results from thirteen of these locations, at distances between ≈300 m to > 1000 m to the planned export route, have been used to provide an indication of likely soil conditions and for comparison with the geophysical interpretation. The locations of the geotechnical data relative to the planned export cable route is shown in Figure 4-1.

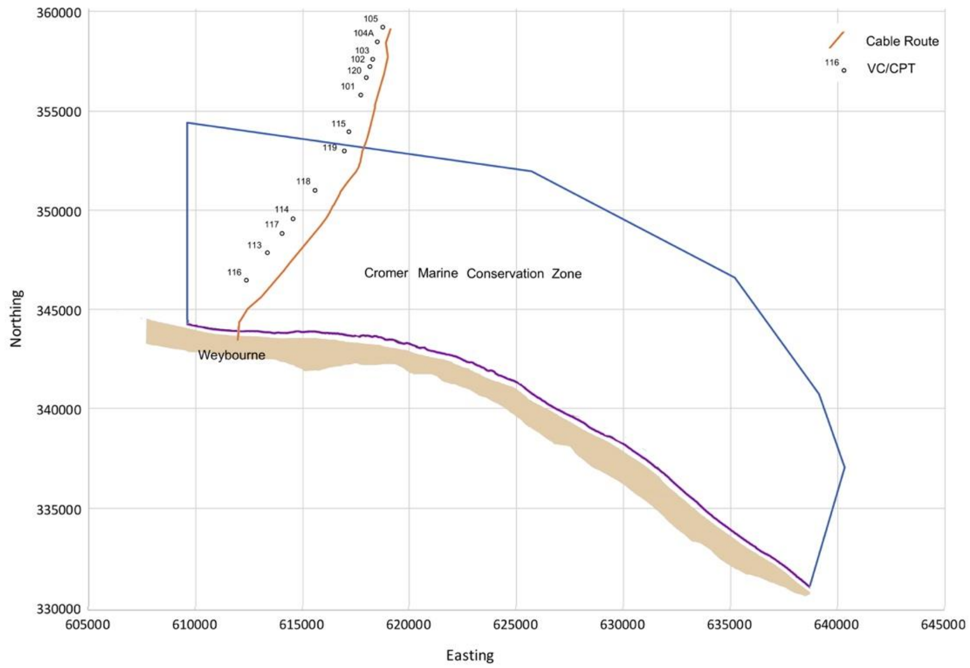


Figure 4-1 : Geotechnical locations relative to cable route

The main soil and rock units interpreted by the geophysical survey are:

- Holocene – sands and calcareous gravels
- Quaternary Soils
  - Botney Cut Formation – Laminated clays and fine sands with occasional peat layers
  - Swarte Bank – poorly sorted gravelly sands and reworked Glacial Till
- Chalk – Cretaceous Chalk bedrock

The expected geotechnical properties of these soil and rock units are discussed below.

A summary of the geophysical interpretation of the route geology is presented in Appendix A. Off-route vibrocore/CPTU soil summaries from the GEO survey are also included together with their approximate distance from the route. Due to the relatively long distances between the test locations and the route, close correlation of the results is not expected. It is, however, notable that from KP 6.5, or south of

Sheringham shoal, Chalk is interpreted to be the predominant unit underlying the Holocene veneer in the geophysical interpretations, whereas the geotechnical samples indicate a more complex sequence of Clay, Sand and Clay Till underlying the Holocene until somewhere between VC 113 and VC 116, corresponding to approx. KP 13.5 and KP 15.1, when a change from Quaternary units to Chalk is observed at depths relevant to trenching operations.

4.2 Holocene Sand and Gravel

On most of the route, the thickness of the Holocene granular veneer sediment is not indicated on the geophysical profile interpretation, so knowledge of the Holocene seabed sediment thickness is limited. It is expected that the veneer will generally be less than approximately 0.5 m, but thicker sections may locally occur without indication on the alignment sheets, due to limitations identifying reflectors at shallow depth in the SBP data. The Holocene veneer thickness is only indicated between KP 0 and KP 0.25, over and near the Sheringham Shoal between KP 5.15 and KP 6.45, between KP 7.55 to KP 8.15, below a bedform at KP 14.75 - KP 14.9 and in connection with a deep channel incised in the chalk between KP 16.2 and KP 17, which is interpreted to be infilled with Holocene granular sediment.

On the basis of the CPT data, uninterpreted and uncorrected for soil type, thin veneers of less than about 0.5 m Holocene sand and gravel have a relative density of very loose to loose, occasionally medium dense. Where thicker sequences are encountered the granular soils may become dense with depth, however at VC 104A, with a thick sequence of 0.8 m sand over gravel to 2.9 m, the calcareous gravel underlying the medium dense sand shows a profile of progressive decrease in relative density.

The sand fraction is expected to be well-sorted fine to medium grained, typically with significant gravel content, as seen in the PSDs from granular soil samples from the existing Dudgeon cable route, shown in Figure 4-2. All samples are of Holocene origin with exception of sample 118 from 1.8 m depth.

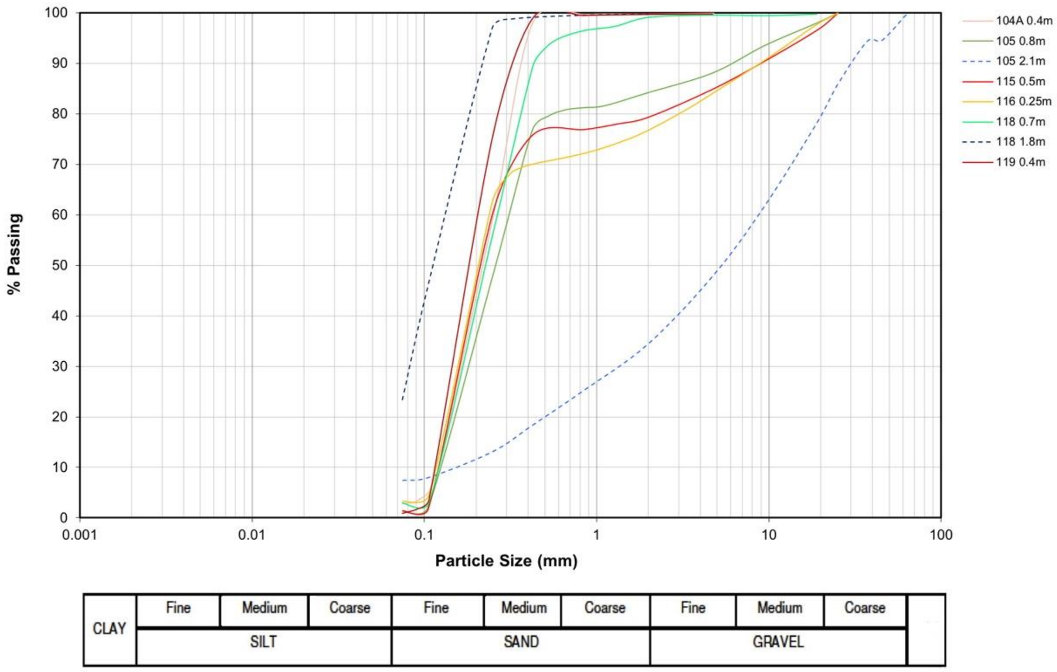


Figure 4-2 : PSD of sand and gravel, Dudgeon OWF data

4.3 Quaternary Soils

Quaternary soils of the Botney Cut Formation and the Swarte Bank Formation have been interpreted to typically underlie the Holocene between the OSS and approximately KP 8.45. As limited data is available and both units, although variable, can have similar characteristics, they have been grouped together. The Botney Cut is expected to comprise laminated Clay and Sand, the Swarte Bank gravelly SAND and reworked TILL. Botney Cut also may locally contain plant remains or PEAT laminae or thin beds of calcareous PEAT.

Only a single PSD test is available for sands within the Quaternary units, location 118 from 1.8 m depth which shows very silty fine Sand, as shown in Figure 4-2. Vibrocore descriptions record the sands to be both fine and fine to medium grain with very low to medium dense relative density.

4.4 Chalk

Chalk bedrock has been interpreted to be present extensively along the route within depths relative to trenching, particularly on the nearshore portion of the route where the Cromer MCZ is crossed.

From KP 8.45 to the end of trenching at the HDD entrance at approximately KP 17, Chalk is interpreted on the geophysical profiles to underlie the Holocene veneer and may form local or extended outcrop at seabed. An exception to this is the incised channel between KP 16.24 and KP 16.99, where granular Holocene sediments have been interpreted. Localised outcrops of chalk are also interpreted between KP 4.6 and KP 5.1 and between KP 6.6 and KP 7.4.

The Chalk bedrock is subdivided into a series of geological sub-units, each with their own strength characteristics. While the units are not well mapped offshore, relatively reliable mapping is available onshore, as shown in Figure 4-3. This suggests that the route will largely cross Paramoudra, Beeston and Weybourne Chalk, which lie at the upper (more recent) limit of the Upper Campanian Chalk sequence.

No detailed strength data is readily available, however strength is related to the porosity of a chalk and Mortimore and Pomerol [10] have provided an assessment of porosity of chalk across south eastern England, which indicates that the area comprises relatively high porosity chalk, as shown in Figure 4-4.

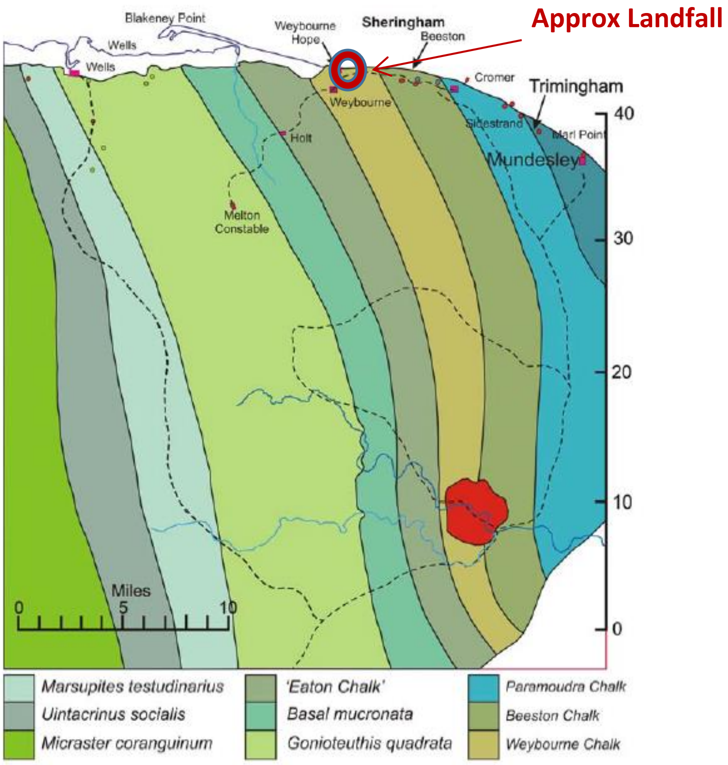


Figure 4-3: Chalk Sub Units in East Anglia (from Peake and Hancock, 1961) [9]

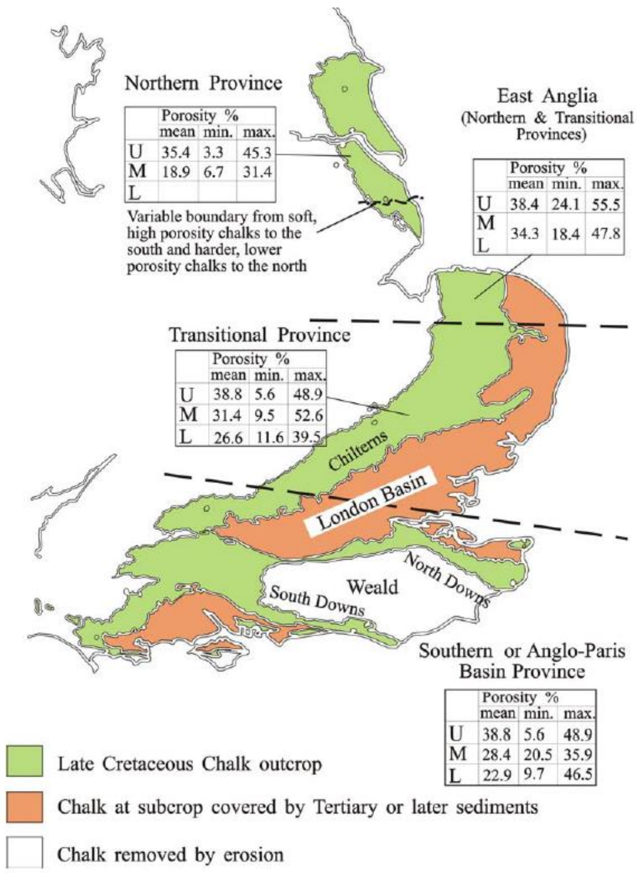


Figure 4-4 Chalk Porosity Across SE England (from Mortimore and Pomerol, 1997) [10]

Based on the reported high porosity of the chalk, plus some limited data from the Dudgeon export cable geotechnical investigation [4], it considered that the Chalk on the study route is Grade D chalk as defined by CIRIA C574 [11]. This classifies the chalk as a structureless material with a relatively low strength. Idealising this as a cohesive type material, an undrained shear strength in the range 100 to 200 kPa may be tentatively considered appropriate in advance of route-specific geotechnical data.

While the chalk mass may be relatively soft, the importance of understanding flints within the chalk has been highlighted by Pyrah et al [12]. Work by Mortimore et al [13] suggests that large flints are particularly prevalent in Paramoudra Chalk, where flints with lengths and diameters greater than 1 m are possible. The Dudgeon export cable investigation did not report flint within the encountered chalk, only black flint in the overlying glacial unit. However, as seen in Figure 4-3, the trends of the chalk units as mapped onshore suggest that different chalk units may be encountered on the present route.

4.1 Expected Geotechnical Parameters

Although no geotechnical testing has been carried out along the proposed cable route, the shallow soil conditions are expected to be similar to those encountered on the earlier Dudgeon cable installation. The range in laboratory test values obtained from vibrocores that can be extrapolated to the planned route are summarised in Table 4-1. Where only a single value is reported, it indicates the presence of a single determination.

Soil Description	d_{50} (mm)	Bulk Density (Mg/m^3)	Dry Density (Mg/m3)	Su (kPa)
SAND, often gravelly or very gravelly, medium dense to dense, fine to medium grain (Holocene)	0.112 - 0.26	1.58	1.3	-
GRAVEL, sandy, calcareous (Holocene/Cretaceous?)	1.161 - 5.229	-	-	-
CLAY, very soft to stiff, with sand layers or laminae, locally with peat laminae or layers (Botney Cut)	0.004 - 0.011	1.07- 2.15	0.69 - 1.88	5 – 105
CLAY TILL, firm to very stiff, gravelly, may contain sharp-edged black flint pebbles (Swarte Bank)	0.009 - 0.014	1.88 - 2.23	1.63 - 1.92	65 – 225
CHALK, expected very weak to weak, no flint described in vibrocore samples (Cretaceous)	0.024 - 0.037	1.92 - 2.24	1.46 - 1.93	100 - 200

Table 4-1 : Summary of expected geotechnical parameters

5 CABLE BURIAL RISK ASSESSMENT

5.1 Shipping Risk Assessment

5.1.1 General

Shipping represents an anchoring hazard to a cable on or in the seabed. Vessels that drop their anchors have the potential to interact with the cables if the anchor is dragged along the cable route or dropped directly on the cable. A ship in transit will not anchor under normal conditions and anchoring normally takes place as part of a managed process such as waiting to enter a port. Anchoring in the study area is expected to be a rare event as the site is not close to any port and is not an area sheltered from the weather, therefore ships are more likely to transit through the area than to anchor.

However, an anchoring hazard remains based on the possibility of the following events:

- Emergency anchoring (where an anchor is deployed to prevent collision or grounding, or following a mechanical failure).
- Accidental anchoring (where an anchor falls unexpectedly from a vessel due to equipment impact or operator error).
- A vessel being anchored inadequately (where an anchor is deployed but drags along the seabed prior to embedment).

Of the above scenarios, emergency anchoring is considered a low risk given the vessel density in the area, and while accidental anchoring cannot be discounted, such anchoring is more likely to occur close to a port where an anchor might be readied for deployment or incorrectly secured following recovery. Anchor dragging is also a low risk given that that anchoring of vessels in the area is unlikely.

However, as an anchor strike on a cable will most probably cause damage to the cable, an assessment of the risk is required.

5.1.2 Marine Traffic Study

A marine traffic assessment has been conducted to analyse the shipping activity in the vicinity of the proposed export cable route.

Automatic Identification System (AIS) is an automatic tracking system used on ships and by marine vessel traffic services for identifying and locating vessels electronically. AIS has been a regulatory requirement since 2004 by virtue of the International Convention for the Safety of Life At Sea (SOLAS) [17]. These regulations require AIS to be fitted aboard all ships meeting any of the following criteria:

- Vessels larger than 300 GT (Gross Tonnes) conducting international voyages.
- Cargo ships larger than 500 GT.
- Passenger ships irrespective of size.

A significant proportion of smaller vessels such as smaller fishing vessels and pleasure craft may carry AIS voluntarily. However, it should be noted that the AIS data set may not accurately assess the movement of these smaller vessels.

The data used for the assessment is based on a 12-month AIS dataset taken between August 2019 and August 2020. This represents the most recent and complete dataset which is available to characterise the shipping activity in the region and across the proposed export cable route.

Data were acquired only from terrestrial receivers as the route is in close proximity to shore and therefore within the coverage area of terrestrial receivers. AIS data were collected within 10 nautical miles of the export cable route and further refined to within a ±250 m corridor in order to give a representative area of marine traffic crossing the route.

5.1.3 Data Analysis

The AIS data were acquired in raw point-based format (representing the transmission and logging of AIS signals from each vessel). Within a GIS based system, vessel tracks are created using the included time stamp fields. The vessel-specific attributes (such as vessel type and DWT) are then reattached to enable further analysis.

The vessel tracks are interrogated in GIS to characterise the marine traffic in the study area. The results are presented in the following sections.

5.1.4 Vessel Type and Density

The categories and the regional distribution of vessel activity in the study area are shown in Figure 5-1 alongside relative vessel density.

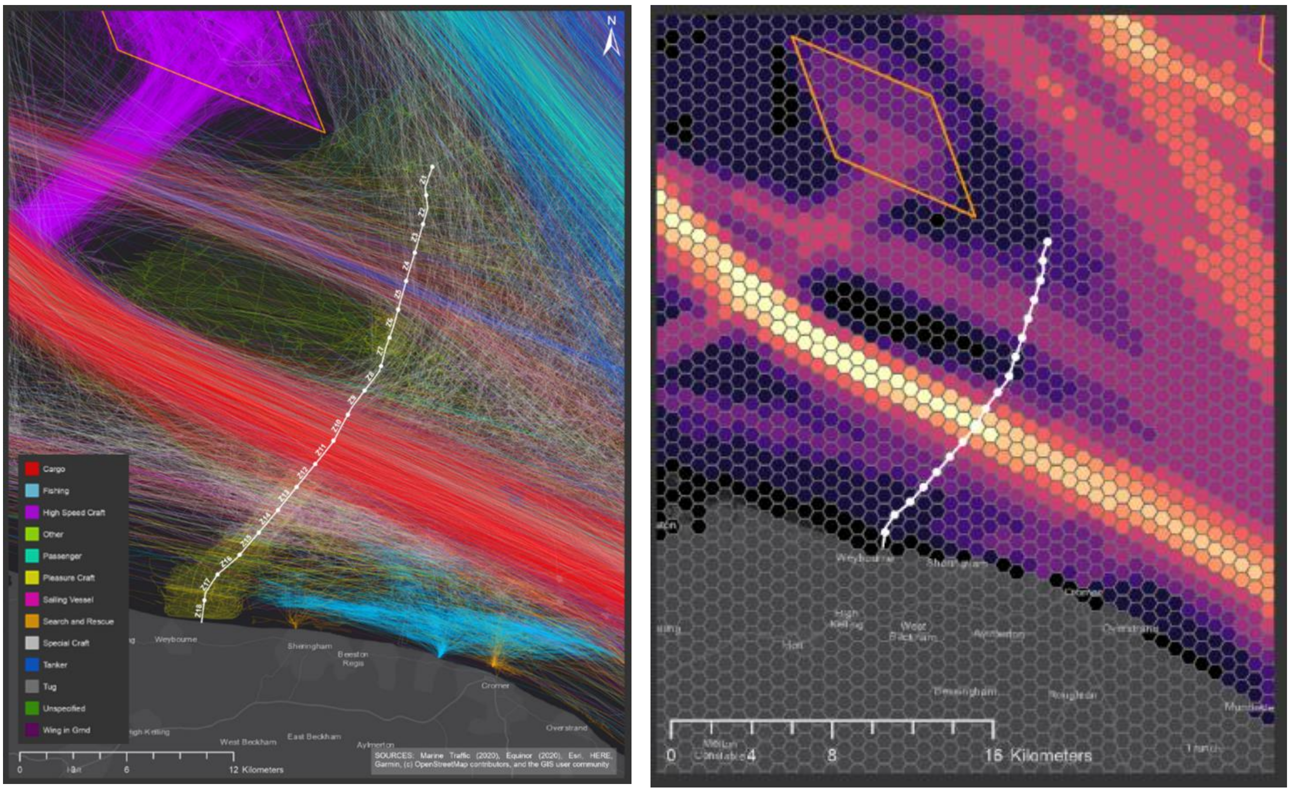


Figure 5-1: Regional Vessel Tracks and Density

A total of 8,831 crossings of the proposed export cable route are identified from the dataset. A primary shipping lane exists at the centre of the proposed route whereby a high volume of cargo vessels is observed. Figure 5-2 presents details of the number of crossings by vessel type, with the route divided into 1 km zones. The use of 1 km zones allows direct comparison between zones, but does not fully align with changes in seabed geology however these have been approximated for the anchor risk assessment.

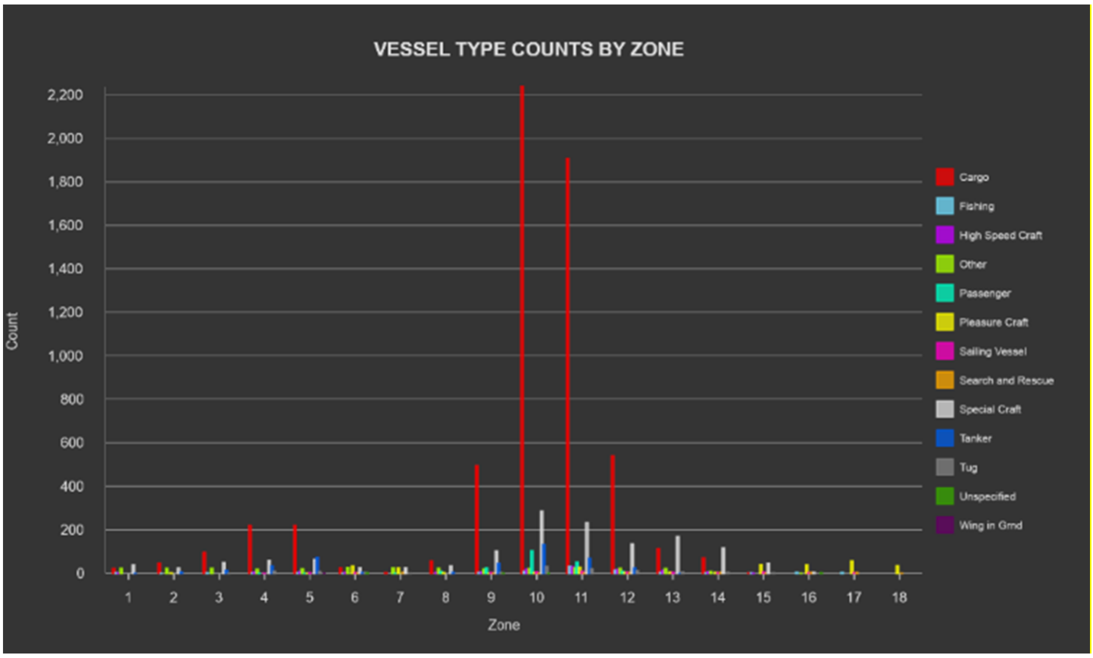


Figure 5-2: Count of Vessel Type per Zone

In total, cargo vessels account for approximately 2/3 of observed vessel traffic, as shown in Table 5-1.

Vessel Type	Total Number of Vessels	Proportion of Total Vessels (%)
Cargo	6057	68.6%
Fishing	86	1.0%
Special Craft	1411	16.0%
Other	305	3.5%
Tanker	412	4.7%
High Speed Craft	124	1.4%
Pleasure Craft	33	0.4%
Search and Rescue	30	0.3%
Tug	106	1.2%
Sailing Vessel	59	0.7%
Passenger	202	2.3%
Unspecified	6	0.1%
ALL	**8831**	**100.0%**

Table 5-1: Number of Vessel Crossings by Type

It is noted that a survey vessel (MMSI 235086211) was identified to have crossed the proposed route multiple times in the data period (this can be seen in Figure 5-1 where it has been classified as 'Pleasure Craft' and follows in close proximity to the proposed route). This data is removed from the assessment as it is not considered to pose an ongoing risk to the proposed export cable.

5.1.5 Vessel Size

Vessel size is an important factor, as this determines the size of anchor used and is thus a controlling factor on the hazard posed to the cable. Figure 5-3 presents a count of vessels by nominal Dead Weight Tonnage (DWT) category. It can be seen that the majority of vessels (85%) are <6,000 DWT, whilst only 2% of vessels are >10,000 DWT.

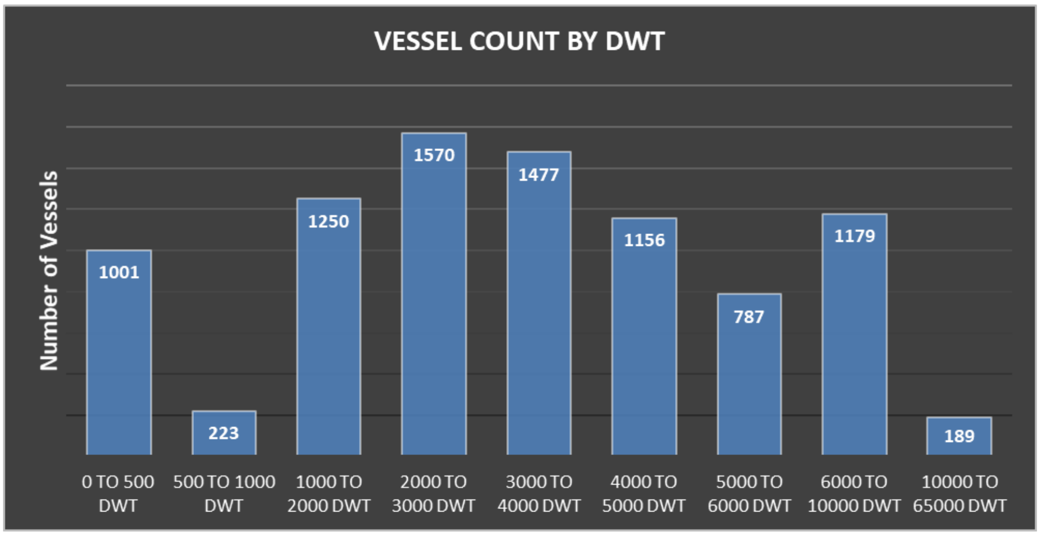


Figure 5-3: Vessel Count by DWT

It is noted that DWT is not recorded in the AIS dataset for a small number of vessels (<10%) and therefore this data has been estimated based on correlations with vessel length.

5.1.6 Vessel Speeds

The speed at which vessels are transiting contributes to the determination of the exposure of the cable in terms of the number of hours per year when a vessel is close enough be a threat.

Figure 5-4 presents an overview of average vessel speed, by vessel category, when transiting across the proposed route.

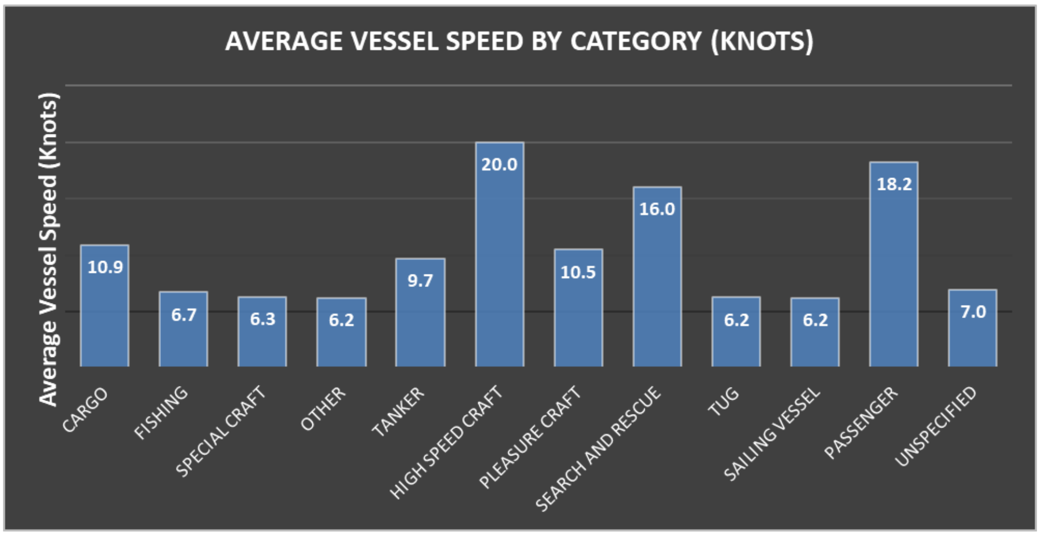


Figure 5-4: Vessel Speed by Type

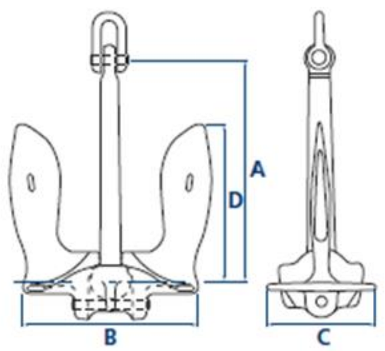
5.1.7 Anchor Size

The results of the AIS processing have included an assessment of different anchor penetration depths, which in turn are related to a combination of anchor size and nature of the seabed geology.

An estimation of anchor size to dead weight tonnage has been developed based on International Association of Classification Societies (IACS) rules [19]. This calculation includes several parameters such as breadth and effective height and therefore, the analysis should be considered to be only an approximation. However, DWT represents between 60% and 70% of the classification value and hence the relationship does provide a reasonable level of correlation. It is also relevant to note that the results correlate well with anchor sizing proposed by Luger [14], and that IACS rules result in broadly similar anchor sizes to classification rules provided by Lloyds and DNV.

From the anchor size, it is possible to estimate the fluke length from standard anchor geometries. Vessels may carry an anchor larger than the recommended minimum size, however, this is offset by assuming the largest possible vessel size for each category. Therefore, this approach is considered appropriate for this assessment.

For this assessment, stockless anchors were assumed as defined by Vryhof in their publication 'Anchor Manual 2010 – The Guide to Anchoring', 2010 [18].



US Navy Stockless					
weight		A	B	C	D
lb.	kg	mm	mm	mm	mm
1000	454	1072	841	521	772
5000	2268	1854	1437	889	1319
10000	4536	2337	1810	1121	1661
15000	6804	2680	2089	1295	1861
20000	9072	2946	2280	1413	2094
25000	11340	3175	2456	1522	2256
30000	13608	3372	2608	1616	2394
35000	15876	3550	2743	1703	2523
40000	18144	3708	2872	1778	2619
60000	27216	4775	3194	2218	3375

Figure 5-5: US Navy Stockless Anchor Dimensions [18]

As an anchor is pulled across the seabed, the flukes pivot and engage into the seabed soil. In most seabed soils, the flukes will open and bite into the seabed, but not penetrate deeply due to the resistance of penetration of the flukes, palm and shank. The depth of penetration of the fluke tip may then be estimated as the fluke length x the tangent of the opening angle, typically 45° for ship anchors. In some hard soils, the flukes may not be able to penetrate at all, while in very soft soils there may be a tendency for the anchor to penetrate to depth as it is dragged.

Assuming the anchor does land correctly on the seabed; the flukes open and penetrate into the seabed and with continued dragging the palm and the shank support the anchor and prevent deep penetration as shown in Figure 5-6. This is an inherent feature of the design of stockless anchors used for merchant vessels, as deep penetration is undesirable and makes recovery difficult as was demonstrated by NCEL (1987) [20]. It also means that there may be a loss of holding capacity if the anchor is continued to be dragged across the seabed, and the depth of penetration may reduce.

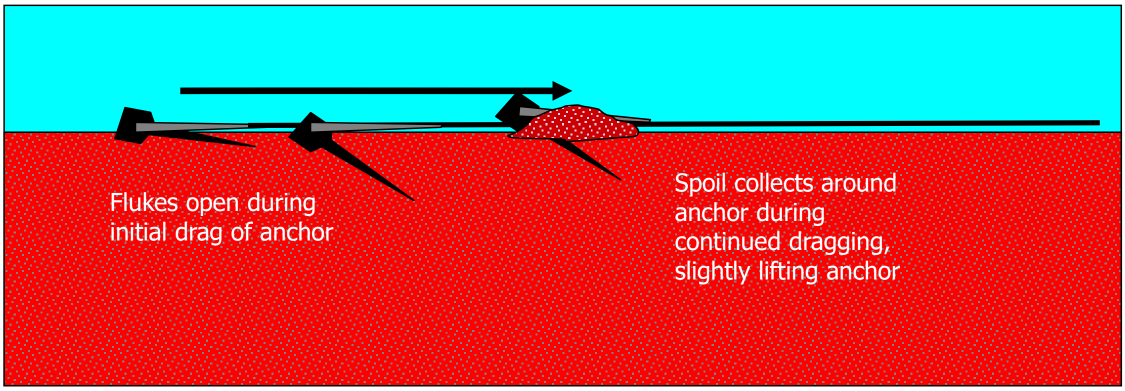


Figure 5-6: Mechanism of Fluke Opening and Continued Drag of Anchor

For the purposes of this project, the fluke opens to its angle of 45° in the Holocene, Botney Cut and Swarte Bank Deposits, however in Chalk, while highly weathered, it is a relatively competent material when compared to sands and firm clays and therefore anticipated to only open to 50% of its full angle.

Figure 5-2 presents a summary of estimated anchor size and fluke length per DWT category.

DWT Range	Estimated Displacement (Te)	Estimated Anchor Size (kg)	Estimated Fluke Length (m)
0 to 500	850	362	1.00
500 to 1,000	1700	584	1.03
1,000 to 2,000	3400	943	1.07
2,000 to 3,000	5100	1248	1.11
3,000 to 4,000	6800	1523	1.15
4,000 to 5,000	8500	1777	1.18
5,000 to 6,000	10200	2015	1.21
6,000 to 10,000	17000	2868	1.31
10,000 to 65,000	110500	10456	2.14

Table 5-2: Estimated Anchor Size and Fluke Length

5.1.8 Anchor Risk

The anchor risk calculation has been performed based on the Carbon Trust Guidance (presented in Appendix B) assuming the cable is surface laid, and for depths of lowering of 0.6 m and 1.0 m. The route has been divided into 1 km zones, and the geology approximated to these zones. As can be seen in Figure 5-7, the risk for a surface laid cable is concentrated in the shipping lane in zones 9 to 12, and particularly 10 and 11. However, with burial to 0.6 m, the risk drops significantly through this section, and only Zone 10 has a high probability of anchor strike as this zone represents the approximately 1 km of sand within the shipping lane. Elsewhere, the presence of chalk seabed prevents anchor penetration to 0.6 m.

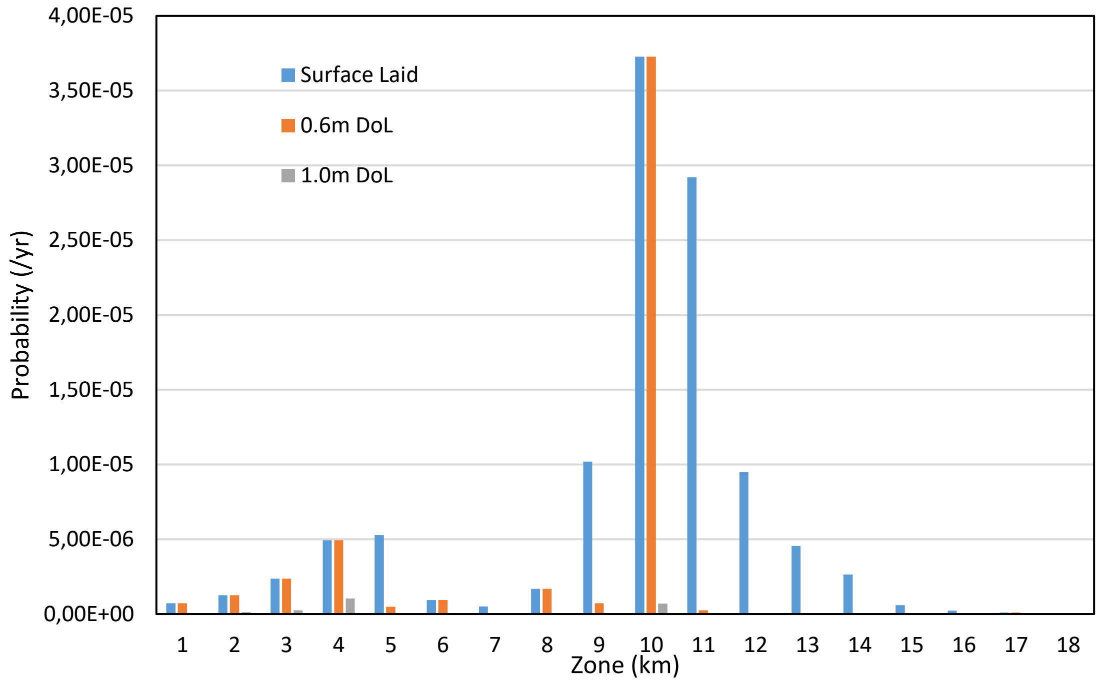


Figure 5-7: Anchor Risk Calculation

To assess the acceptable risk level, reference is made to DNVGL-RP-F107, which is intended for pipelines that have a greater consequence of failure including both economic and environmental risk, however is considered a conservative basis. For cable risk assessment the target is to achieve an annual frequency of anchor contact within Category 1 or 2 (Table 5-3).

Category	Description	Annual Frequency	Return Period
1 (low)	Likelihood of event considered negligible.	$<10^{-5}$	Less than 1 in 100,000 years
2	Event rarely expected to occur.	10^{-4} to 10^{-5}	Between 1 in 10,000 and 1 in 100,000 years
3 (medium)	Unlikely for a single pipeline, but may happen once a year given a large number of pipelines.	10^{-3} to 10^{-4}	Between 1 in 1,000 and 1 in 10,000 years
4	Event individually may be expected to occur during the lifetime of the pipeline. (Typically, a 100 yr storm)	10^{-2} to 10^{-3}	Between 1 in 100 and 1 in 1,000 years
5 (high)	Event individually may be expected to occur more than once during lifetime.	$>10^{-2}$	More than 1 in 100 years

Table 5-3: DNVGL Annual Failure Frequency Ranking

Taking the results obtained from the anchoring risk assessment, the overall annual frequency of anchor contact is presented in Table 5-4 with detailed calculations in Appendix B. As can be seen in this table, there is clear benefit from trenching the cable, with risk reducing incrementally with increasing depth to close to zero risk at a depth of 1.0 m. However, it is recognised that trenching in the chalk may present some challenges and for those sections, reducing the depth of lowering to 0.6 m still achieves a DNV category 1 risk rating, but may prove to be a more realistic target.

An alternative strategy, to help minimise environmental impact in the MCZ may be to adopt a burial depth of 0.3 m in the MCZ and 0.5 m outsize this zone. As shown in Table 5-4 this results in a Category 3 risk rating.

Description	Annual Frequency	DNV Category
Surface Laid (Ignoring Fishing)	1.12E-04	3
0.6 m DoL	5.07E-05	2
1.0 m DoL	2.11E-06	1
0.6 m in Chalk / 1.0 m in Soil Units	3.58E-06	1
0.3 m in MCZ / 0.5 m Outside MCZ	1.07E-04	3

Table 5-4 :Annual Frequency of Anchor Contact

5.2 Fishing Risk Assessment

Commercial fishing is carried out in the area crossed by the UK Extension export cable corridor, although the total activity is very low as can be seen by extraction of fishing vessel navigation tracks from the AIS data in Figure 5-8. These data have been corrected for speed, under the assumption that vessels traveling at speeds of less than 8 knots are likely to be fishing as opposed to transiting. The highest concentration of activity in and around zone 11 appears to be correlated with small fishing boats launched from a concrete slipway at West Runton, the locus of the blue plume west of Cromer observed in Figure 5-8, or from trawling activities in straight line trajectories, that likely include larger vessels of greater than 10 m.

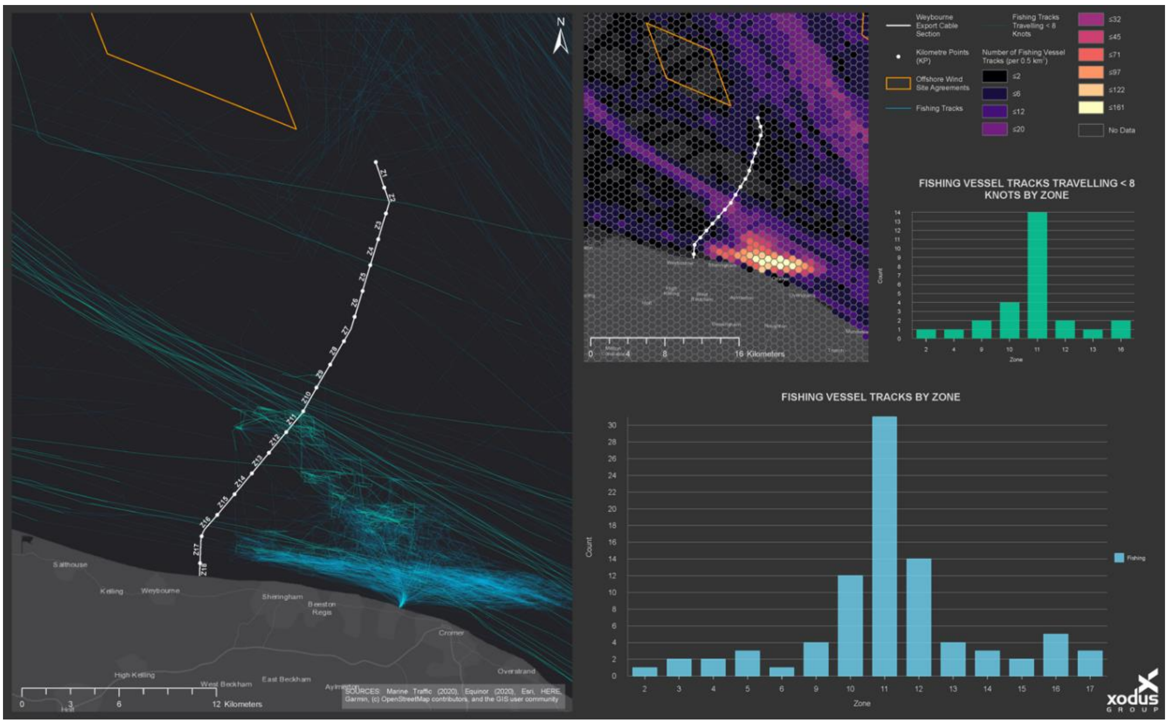


Figure 5-8: Fishing Vessel Tracks based on speed-corrected AIS Data

There is a very limited number of vessels operating in the area with a fishing vessel being reported within the 1st 10 km of route on only thirteen occasions within the 12 month AIS data set, seventeen times in the final 5 km or route to the HDD. The Lola Kate is the most frequent visitor to the area, with a length of 7 m and a beam of 3 m. An example of a slightly larger vessel (length 11 m and beam 4 m) is shown in Figure 5-9.

Figure 5-9: Example of Fishing Vessels Reported in the AIS Data (Serene Dawn MMSI 235096863)

The AIS data have been supplemented by UK Fisheries data for the most recent year available, 2018 [7], which indicate a total of 89 times that fishing vessels have worked (not transited) within ICES Rectangle 35F1, the zone that includes the planned export route. 48% of vessels registered fishing in the zone were < 10 m in length, 52% > 10 m. The distribution of fishing methods employed is illustrated in Figure 5-10. It can be seen that the overwhelming majority of fisheries (96.6%) either employs static gear (pots and traps) or is without seabed contact. Beam trawlers, all >10 m, were recorded three times within the zone, once each for shrimp, lobster and cod. No traditional demersal trawlers were registered fishing in this area during 2018.

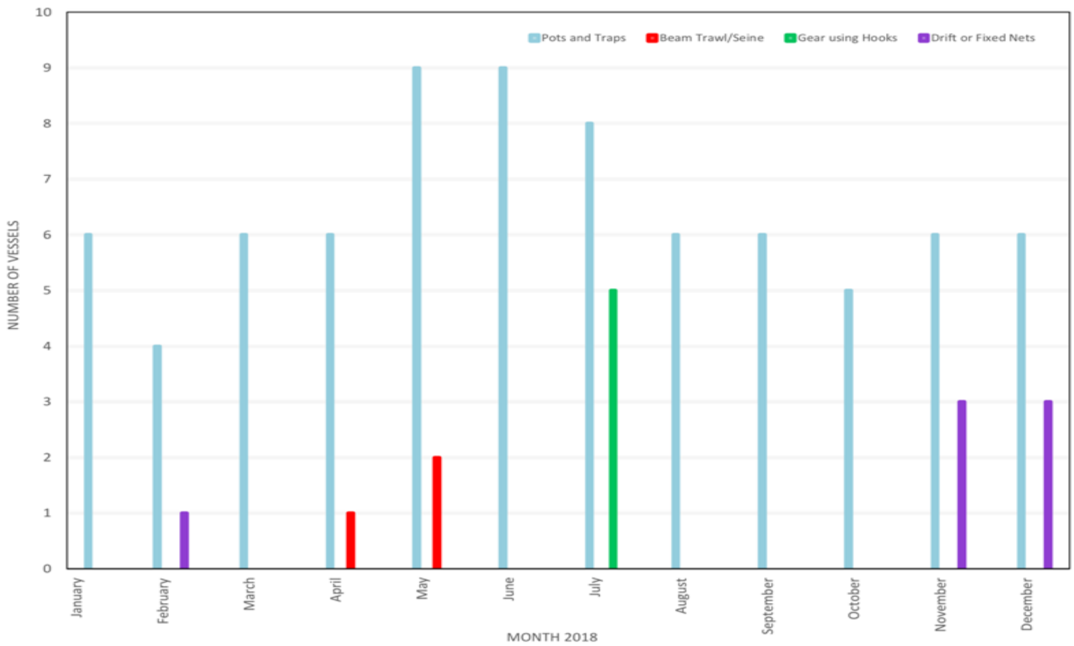


Figure 5-10: Breakdown of type of fisheries on monthly basis, 2018

A wide range of observational and theoretical studies into the penetration of trawling gear into the seabed is available in the literature and is summarised by Linnane et al (2000) [15]. These data indicate that the depth of penetration of trawl beams or otter boards is typically limited to 0.1 m in sands and harder clays, and up to 0.3 m in loose sands and soft clays. For static fisheries, pots and nets are typically anchored with small anchors weighing between 10 kg to 15 kg, principally to allow ease of handling from small vessels. Penetration of this gear into the seabed is also unlikely to exceed a maximum of 0.2 m.

To protect the cable from the threat posed by fishing, the cable must be buried deeper than the penetration of fishing gear. There is no standard methodology to achieve this, however the procedure adopted by PACE on a wide range of projects, is to factor the penetration depth by 1.5 to determine a safe depth of lowering. Where the penetration of fishing gear is small, as is the case along the majority of this route, a fixed minimum value is recommended. Based on work by Shapiro et al (1997) [21], a clear distance of 0.3 m is recommended. Thus, a safe depth of lowering for protection from fishing gear can be recommended as minimum of 0.5 m.

5.3 Natural Hazard Risk Assessment

5.3.1 Seismic Risk

The UK is a region of low seismicity typical of an area not located on a tectonic boundary. Figure 5-11 reproduces a Peak Ground Acceleration (PGA) hazard map for a 2,500 year return period, produced in connection with the Eurocode 8 regulations [8]. PGA is not a measure of magnitude but of ground shaking as recorded by seismic instruments, which is more closely related to ground motion. The area directly off the northern Norfolk coast is expected to have a Peak Ground Acceleration between 0.02 and 0.04 g, which can be translated into a light to moderate perceived shaking with no to very light potential damage.

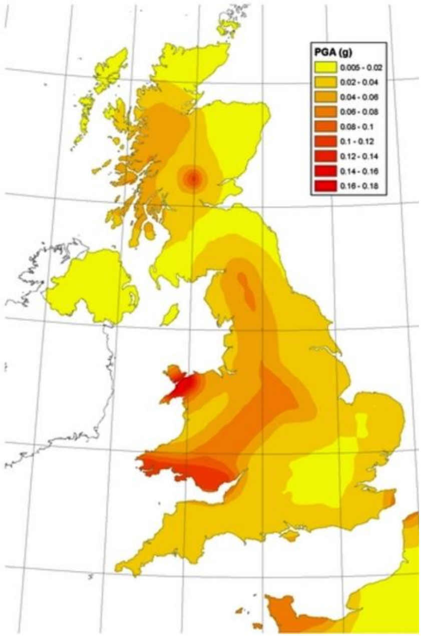


Figure 5-11: UK PGA hazard map, 2,500 year return period

5.3.2 Megaripples and Sand Waves

Both megaripples and sand waves are typically observed as northerly-trending parasitic features associated with other larger features or bedforms, such as the Sheringham Shoal and the sand features extending from the northern flank of the shoal. Some of the sand waves, or the underlying structures are associated with steep local slopes, typically parallel or at low angle to the route.

5.3.1 Areas of Chalk Cobbles / Boulders

Environmental studies (refer to Section 7) and public domain videos recorded within the Cromer Marine Conservation Zone (MCZ) indicate areas of coarse seabed sediment comprising dense concentrations of cobble and / or boulders. If present along the installation route, these areas may be impossible to trench without use of pre-installation clearing. Such work may result in a permanent impact on the seabed immediate to the cable corridor within the Cromer MCZ.

5.4 Burial Recommendations

The assessment of shipping traffic and probability of anchoring has recommended a target depth of lowering of 1.0 m with 0.6 m as a minimum depth. This is anticipated to be achievable from a trenching perspective (as discussed below) and to achieve a DNV Category 1 risk rating. While fishing is infrequent in the area, it is also more than sufficient to provide protection from normal fishing activities.

Consideration has also been given to a strategy of 0.3 m depth of lowering within the MCZ, and 0.5 m beyond the MCZ. As this results in a DNV Category 3 risk rating, and does not significantly reduce the environmental impact as the footprint of trenchers and the trench width is unchanged, this is not recommended.

6 TRENCHING CONSIDERATIONS

6.1 Introduction

A target depth of lowering of 1.0 m, with a proposed minimum of 0.6 m has been recommended based on the Cable Burial Risk Assessment. To achieve the desired cable burial, a variety of trenching techniques and tools are available. This section of the report discusses both the suitability of the different techniques and comments on some specific trenching tools that may be available.

Particular reference is given to the seabed geology along the route and how the trenching operation may contribute to any potential environmental impact.

6.2 Overview of Trenching Techniques

Cable burial methodologies can be divided into three main categories of ploughing, water jetting, and mechanical cutting. Ploughing of power cables has traditionally been completed using cable ploughs; however, pre-cut ploughing methods using a v-shaped plough have been developed and used as an alternative solution. Water jetting includes a number of sub-categories such as ROVs, Mass Flow Excavators, Jet Sleds and Vertical Injectors. Mechanical trenchers comprise a cutting tool using rock picks to form the trench and mounted on either a chain or a cutting wheel. The following sections broadly describe individual methodologies applied and types of machines used for cable burial.

6.2.1 Ploughing

Ploughs are passive burial tools equipped with a share that engages the seabed with the plough being towed by its host vessel across the seabed to form a trench. Ploughs come in two main varieties; displacement ploughs which cut an open V shaped trench in the seabed and are generally used for post lay pipeline burial or pre-cut cable trenching. If it is required to backfill the trench, or spoil heaps left to either side of the trench are unacceptable, a separate backfill plough pass is required. Cable trenching ploughs comprise a thin vertically sided share that cuts through the seabed in a blade-like manner creating a narrow trench.

The process of forming a V shaped trench and the returning the spoil into the trench disturbs a relatively wide corridor along the seabed and may be considered to have a relatively onerous environmental impact. As such they are unlikely to be acceptable for this project and this discussion has focussed on cable ploughs.

A typical cable plough is illustrated in Figure 6-1 and shows the share engaged in the seabed (a beach in this instance). Some spoil does arise from the shearing action of the share but there is relatively limited disturbance to the seabed with some of the spoil falling back into the trench as the plough progresses forwards and the cable is placed at the base of the trench within the share.

Ploughs can trench through a wide variety of soils and are particularly suited to projects where long continuous lengths of cables are to be buried through variable ground conditions.

Figure 6-1: Example of Cable Plough Installing Shore End Cable

Cable ploughs are towed via a bridle from a surface support vessel with cable laying and ploughing being performed either as a simultaneous operation from the cable lay vessel or a post lay trenching operation. In both cases managing the cable slack (amount of cable paid out from the lay vessel) is critical. If the cable is laid with too much slack, a loop can form in front of the plough, which can cause the cable to be damaged as it enters the plough, or in the extreme the plough can 'trip' over the loop. If the cable is laid with too much tension, the cable can be 'pulled' out of the trench behind the plough resulting in shallower than expected burial. In the extreme, the depressor on the plough can be forced open and the cable may escape, resulting in shallow burial or even damage to the outer roving of the cable.

The cable enters the front of the plough via a bell mouth and then passes through the throat of the plough and then onto a radius-controlled depressor within the share body, exiting the plough from the bottom of the share at the base of the trench. Depending on soil type, collapse of the trench may occur quickly once the plough has passed. The main components of a plough and the cable path are illustrated in Figure 6-2.

Depth of share engaged in the seabed is controlled by hydraulically raising or lowering the front skids with most cable ploughs having at least 2 m depth capability. Some of the latest ploughs can achieve a 3 m deep trench depth. It is possible to use the geometrical arrangement between the skid height and the base of the depressor to determine the cable exit point (assumed to be equal to as-built position) thereby potentially saving an additional survey run.

Cable ploughs are suitable across a wide range of soil conditions, including sands and very stiff clays. The main disadvantage of such tools is the relatively high bollard pull required for trenching operations. For cable ploughs this can vary between a few tonnes in very soft clays to 100 tonnes or more in hard soil conditions. This group of ploughs are usually designed for maximum tow forces of between 100 and 150 tonnes and typically require a relatively large tow vessel with adequate bollard pull, or an anchored support barge to provide the necessary tow force.

Progress speeds can vary enormously from 1000 m/hr or more in soft clays to 100 m/hr in very stiff clays and very dense sands or even less in rock.

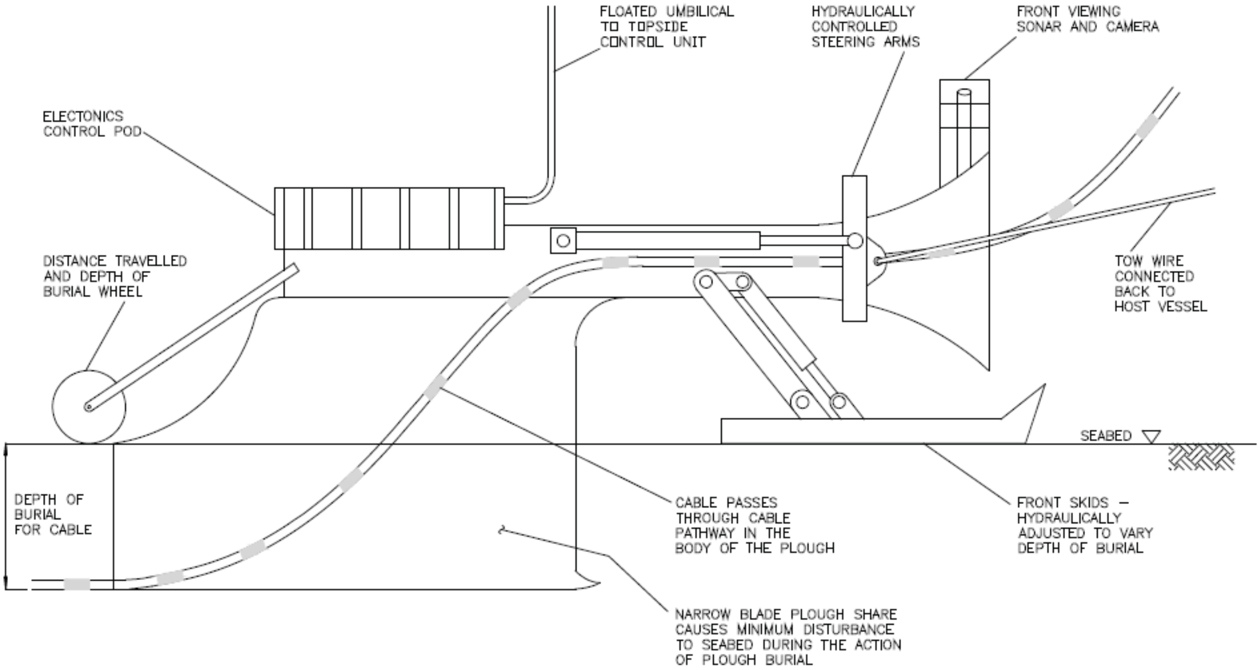


Figure 6-2 : Main Components of a Cable Plough

Some of the latest cable ploughs utilise a number of water jets fitted within the plough share to fluidise material at the leading edge of the share that acts to reduce the required tow force and allows the plough share to penetrate deeper into the seabed. These new multi-depth ploughs have the ability to bury cables up to 3.0 m depth. The water jets are most effective in sands, gravels and weaker clay conditions but have limited use in harder seabed conditions.

As evidenced in Figure 6-1, Figure 6-3 and Figure 6-4, cable ploughs can be operated in dry beach conditions or in very shallow water.

Normally it is not possible to multi-pass with a cable plough, therefore any sections that fail to meet burial specifications cannot be directly remedied using the plough. Often, shallow burial is associated with the plough tending to “ride out” where harder ground conditions are encountered, however any shortfall in protection resulting from less burial is often offset by increased soil resistance to impacting objects, such as fishing gear, without compromising the planned cable integrity.

Figure 6-3 : Hi-plough, pull to offshore

Figure 6-4 : Sea Stallion pulled towards beach

6.2.2 Jet Trenching Tools

Jetting tools excavate a trench by directing jets of water at the seabed. There are, however, a number of sub categories of jetting tools. ROV jet trenchers are the most widely used machines and are self-propelled and able to operate in a wide range of water depths and a variety of ground conditions.

Jetting tools excavate a trench by directing multiple jets of water at the trench face via two jet legs or swords. The jet legs are positioned by either pivoting at the top flange or by a combination of pivoting and vertical translation. The jet legs straddle the cable on the seabed and are lowered to the desired target depth, the cable passing between the legs whilst the trencher moves forward. The cable is usually tracked using an electromagnetic induction system, though other tracking systems are available. Where visibility allows, the cable can be monitored using on-board cameras.

In sand, the material is fluidised and the cable, being of relatively higher density, will settle though the slurry towards the base of the trench. In a seabed of cohesive material, the jetting process cuts through or erodes the clay and spoil is carried out of the trench by the flow of water, aided by backwash jets to the rear of the jet legs. Many modern jetting systems have carefully designed patterns of jet nozzles facing in different directions to maximise the efficiency of the liquefying or eroding action. A typical jet trenching tool used for cable burial is shown as Figure 6-5 and the jetting process is illustrated in Figure 6-6.

There is a large range of trenching ROVs on the market from relatively small cable maintenance machines with approximately 150 kW installed power to much larger specialist pipeline trenching machines with up to 2 MW of installed power. There are also a wide range of track bases and free-swimming options.

For a free swimming ROV, the trencher relies on thrusters to maintain forward progress and to react against the jet nozzles. This can consume a significant portion of the available power in the trencher. In contrast, track base trenchers have a positive contact with the seabed, with the tracks requiring a relatively low power input and the ability to maintain forward progress and position in currents more effectively than a free swimming ROV. Consequently, a track based ROV is generally much more efficient in terms of power requirements than a free swimming ROV.

Figure 6-5 : Example Jet Trencher (Helix T1500)

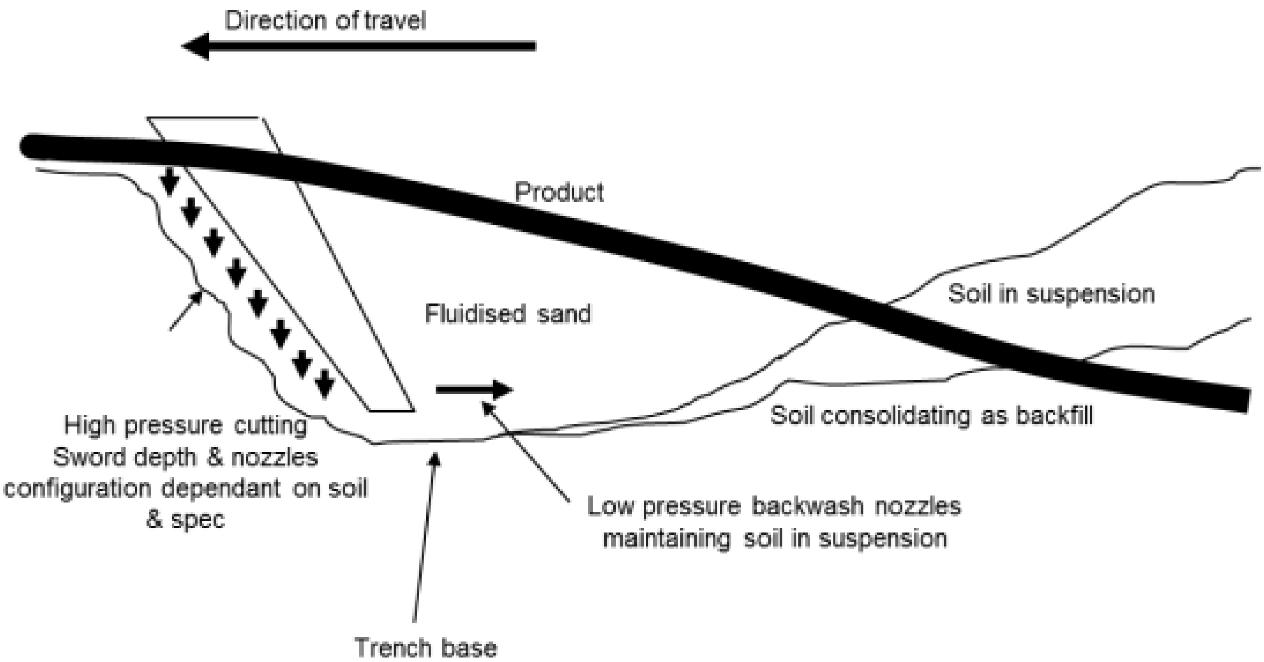


Figure 6-6 : Jet Trenching Process

With jet trenchers, the cable is not picked up off the seabed; this significantly reduces risk of damage to the cable compared to many mechanical trenchers or ploughs, both of which typically require the cable to be passed over rollers and / or through a depressor mechanism. However, the absence of a depressor system means that the cable is not positively placed in the seabed, therefore the depth of the cable is dependent on the settlement of soils out of suspension, the lay tension and the relative density of the cable.

Jet trenching techniques have the advantage of allowing multiple passes over the product to attempt remedial trenching to increase the depth of lowering of the product, should it be required.

Vertical Injectors use the same basic principle as ROV jet trenchers however the ROV element is removed and a large ‘leg’ is fixed to the side of a barge. These tools are typically used for shore approaches and where very deep burial is required in shallow water. Mass or Controlled Flow Excavators, are primarily used for clearing existing trenches, forming a route through sand waves or removing seabed material that has built up around structures. Neither vertical injectors or mass flow excavators are considered appropriate for this project.

6.2.3 Mechanical Trenchers

Mechanical trenchers are self-propelled tracked vehicles and can be divided into wheel cutters and chain cutters. Tracked cable burial vehicles are operated in post-lay burial mode to bury subsea cables that have been previously laid on the seabed and are best suited to stiff clays and very weak rocks which cannot be jetted.

Tracked cable burial vehicles are launched from the support vessel by crane or A-frame. Once lowered to just above the seabed, the pre-laid cable is located using a combination of cable detection, underwater cameras and/or ROV assistance. The tracks are positioned to straddle the cable and then it is loaded into the trencher. The loading procedure varies slightly between machines but almost all examples working in Northern Europe are now diverless. As the vehicle makes forward progress, many have the capability to automatically steer along the line of the cable with an auto tracking capability linked to the cable tracking system fitted to the front of the trencher. Manual control by the operator is also available.

Most cutting tools are equipped with emergency ROV panels so the product can be unloaded in the event of a complete power system failure.

Power is normally delivered to the vehicle via an electrical umbilical, which also carries all the control cables. Some mechanical trenchers have been designed specifically with cable burial in mind whilst others are more suitable for pipeline burial, or are dual purpose.

The cutting mechanism comprises a series of high specification tungsten carbide picks mounted on a rotating chain or on a wheel. They are typically conical in shape and about 25 mm in diameter. It is important that the picks are arranged on the chain or wheel to give the most optimum pattern for cutting, transporting and maintaining a balanced torque across the chain.

Mechanical rock wheel cutters, as the name suggests, have picks mounted on a rotating wheel and cut relatively narrow trenches into stiff clay or rocky seabeds, typically operating in the 1.0 to 1.5 m trench depth range. Progress is dependent on the strength of the seabed soils with typical progress rates in the range of 50 m/hr to 200 m/hr, however slower progress can be experienced, for example, if a large number of cobbles and boulders are encountered. A typical example of this type of trencher is Figure 6-7.

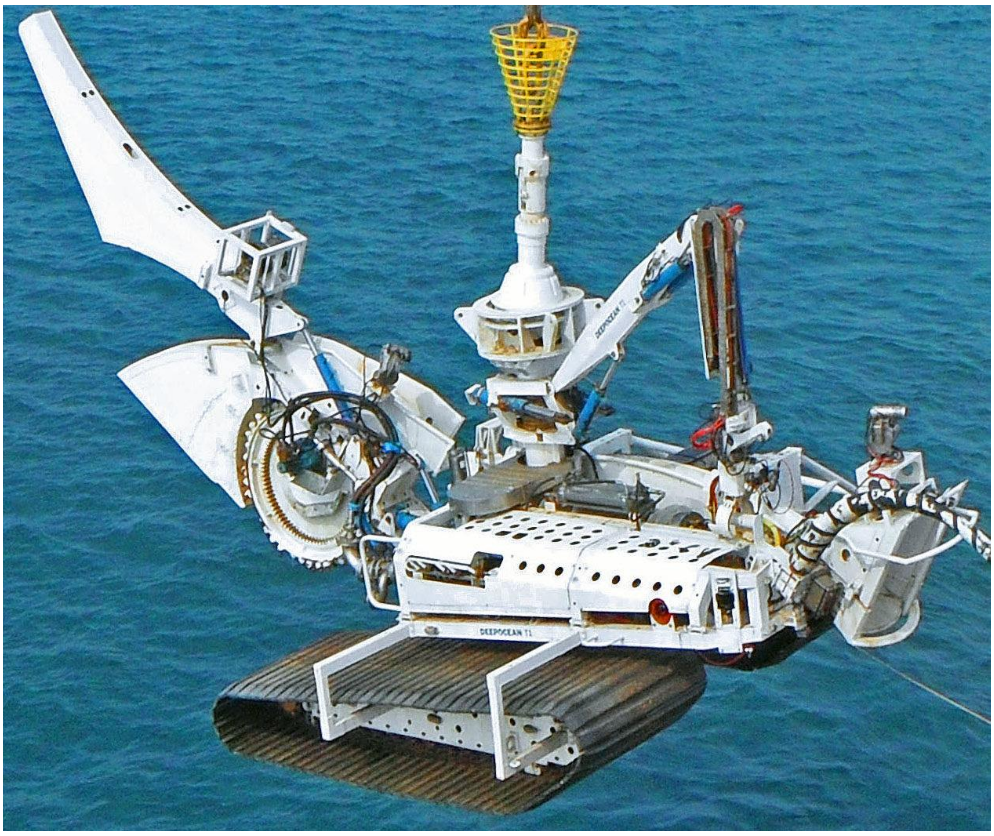


Figure 6-7 : Deepocean / Enshore T1 Trencher

It should be noted that wheel cutters may not be suitable for this project as they are often limited to relatively small cable diameters and minimum bend radii. As the cable for this project is relatively large diameter, this may preclude their applicability.

Mechanical chain trenchers have the cutting picks mounted on a chain rather than a wheel. The operation is similar to a wheel cutter, however they typically cut a wider and deeper trench and are able to handle larger diameter cables. Mechanical chain excavators are typically used to form trenches in the range of 1.5 m to 3.0 m depth. An example mechanical chain trenching tool is shown in Figure 6-8.

For both wheel and chain cutters, the soil excavated by the picks is transported out of the trench by the chain /wheel as appropriate. Most wheel cutters rely on a combination of spoil blades to push the material away from the trench sides, and a depressor mechanism to place the cable to depth in the trench.

In the case of chain cutters, there is usually an educator system to clear spoil off the chain and remove it from the side of the trench. This lifts material into the water column from where it can settle out of suspension either side of the trench.

Figure 6-8 : Helix Robotics's i-Trencher

As noted above, mechanical cutters are most suited to stiff to very stiff clays, cemented sands and weak or very weathered rocks. If the material is relatively free of inclusions such as gravel, cobbles and boulders, then mechanical trenchers generally work well. However, the presence of coarse material within the underlying material, or present as a lag deposit on the seabed clay, can cause problems. In particular, coarse material can become lodged in between the picks or caught in the crumber (the plate on the rear of the cutting chain or wheel). Several trenchers have systems in place to deal with these issues.

Note is also made that, as with cable ploughs, care needs to be taken with the amount of slack present during cable lay.

6.2.4 Hybrid Trenchers

Hybrid trenchers combine a cutting capability, typically a chain, with a jetting capability. For these trenchers, the cutter is normally mounted in the middle of the trencher, with the jet legs to the rear. This allows the chain to be deployed when the jet leg depth cannot be maintained due to hard ground.

Their suitability aligns well with those of chain cutters and jetting tools described above, however they are relatively heavy machines and unlike ROV based jetting tools, they are not suitable for soft clays.

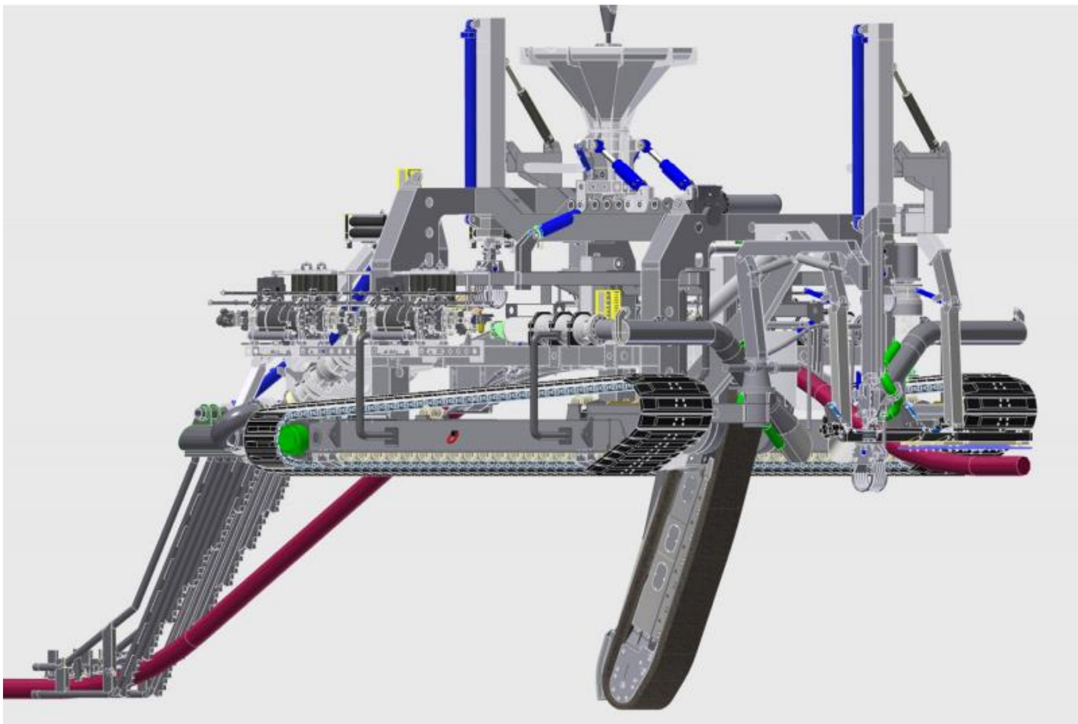


Figure 6-9 : Boskalis CBT2400 (showing relative position of chain and jetting tools)

6.3 Available Trenchers

The nature of the seabed soils, including Chalk, is considered to require the use of either a mechanical trencher or a cable plough. Note is made that the adjacent Dudgeon export cable was ploughed using a Sea Stallion plough operated by VBMS (now Boskalis). A relatively consistent depth of between 1.5 m and 2.0 m was achieved along the route, with only shore sections having a burial depth of less than 1.0 m.

Given the expected predominance of Chalk along the route, a conventional jet trencher is not considered to be practical, unless mobilised as part of a combined spread with a mechanical trencher.

This section of the report describes some of the specific trenching tools which may be offered for this project and are currently known to be operating within Northern Europe. The list is not exhaustive but is believed to cover the main trenching tools operating in the region.

6.3.1 Sea Stallion Cable Ploughs

These ploughs were originally developed as telecom cable ploughs by The Engineering Business (now IHC) and grew in size and capability to handle larger cables and deeper depths of lowering. As noted above, a plough of this type was successfully used for the adjacent Dudgeon Cable. Examples are currently in the service of Boskalis.

The ploughs benefit from a steeply raked share (Figure 6-10) which has the advantage of pulling the plough aggressively into the seabed and displacing the soil upwards, maximising the depth achieved. Tow forces are likely to be in the range 100 to 150 te and depths in excess of 1.0 m are achievable.

As the cable is placed in the seabed through the share, with good operating practices (avoiding excessive forward pitch) burial should be reliably achieved.

Figure 6-10 : Sea Stallion Plough

6.3.2 HD-3 Plough

HD-3 ploughs were developed by SMD to meet the requirement for trenching of large diameter cables and typically have a depth capability up to 3 m, however they are well capable of operating at shallower depth of lowering, with an articulated chassis to keep the tow line close to the seabed. Examples are offered by Enshore, Global Marine Systems, Prysmian and Boskalis.

A difference with the HD-3 plough when compared to the Sea Stallion is the less aggressive rake angle of the share with a near vertical rake on some share. The intention is to displace some soil sideways rather than upwards, as achieved with the Sea Stallion. In theory this should reduce disturbance to the seabed, but the difference between the two plough, taking into account other factors such as skid area, is likely to be small.

As with the Sea Stallion, the cable is placed through the share, however the near vertical share has less tendency to pull the plough into the seabed and this can result in the plough riding out if hard soils are encountered.

Figure 6-11 : HD-3 Plough

6.3.3 Q Series Trenchers

The Q1400 and 1600 trenchers were developed by SMD, with two Q1400 being operated by Global Marine Systems, and Van Oord operating a Q1600 (Figure 6-12). The tools are designed around a cutting chain which can be interchanged for a jetting system. For this project it is envisaged that the cutting tool would be the main tool deployed, however trench collapse may result in reduced burial where sand is present. For any such sections, remedial jetting is likely to be practical, but this may require a port call.

Figure 6-12 : SMD Q1600 (Van Oord Deep Dig-It

6.3.4 SMD Cable Burial Tractors / Hybrid Trenchers

SMD have built a series of hybrid trenchers, generally referred to as Cable Trenchers (CBT) ranging from T2 built in the 1990's and now operated by Enshore, through CBT1100 and CBT1200 (one is now named SeaRex and operated by Prysmian, Figure 6-13), to CPT2400 recently built by SMD for Boskalis (Figure 6-9). T2 has a power output of approximately 700 hp, and the others give their power output in their naming, hence there are significant differences in the power outputs of these trenchers. For the geology anticipated on this project, T2 may prove slightly underpowered, and CBT2400 has ample power.

Figure 6-13 : Prysmian SeaRex

With their combined chain cutting and jetting capability, these tools are in some ways ideally suited to this project, being able to cut into the chalk and any stiff clays that may be encountered, and switching to jetting in sands. In practice it may be simpler to simply run the cutting chain throughout the route, with the jet legs engaged to maintain any material falling into the trench in suspension.

6.3.5 Helix Robotics Solutions i-Trencher

The Helix i-Trencher (Figure 6-8) was originally built by The Engineering Business as a pipeline trencher but is now mainly used for cable trenching. It has a centrally mounted chain cutter with eductors to remove spoil. It is well capable of forming the trench having approximately 1700 hp and has successfully trenched in rocky seabed appreciably harder than anticipated on this project.

It is normally mobilised with a jet trenching spread, (T1500) which provides a solution in sands and for remedial trenching, should that be required. On this project, it is expected that it would complete the full length of the cable and, while some sands are present, little remedial work would be required.

6.3.6 Enshore T3200

The Enshore T3200 (Figure 6-14) is one of the largest trenchers currently available with a track record of trenching in chalk on the Race Bank Export cable and the Nemo Interconnector. With 3200 hp of installed power it is a step larger than other trenchers and has more than sufficient power to trench the cable. The trencher is also able to jet while cutting, in a manner similar to the hybrid machines discussed above.

Figure 6-14 : Deepocean T3200

6.4 Trencher Selection

To assist in the choice of trenchers, a selection matrix has been developed. This takes the key project requirements and rates the ability of the different trenchers to meet these requirements, scoring them on the basis of 1 to 5. Their importance is weighted between 1 and 3, and the values summed with the most suitable trencher achieving the highest score.

Note is made that this selection matrix has only considered technical aspects of the trenchers; commercial factors are not considered.

The results are presented in Table 6-1 and it can be seen that the top scoring trencher is the Sea Stallion plough. This is due to a combination of factors including the limited footprint on the seabed, the expectation that the trench will largely infill and the proven capability in the relevant seabed soils.

T3200 and then i-Trencher are the next highest scorers. The ability to trench in the anticipated seabed conditions and track record assist their scores, but the relatively large footprint and the dispersal of soil over a wider area of the seabed are negative factors.

The HD-3 ploughs are likely to be effective tools, but the depth may be impacted in chalk and there is little known track record for these tools in such soil conditions. The smaller Q-Series and hybrid trenchers achieve lower scores due to potential difficulty trenching in the chalk and particularly flint, an open trench and lack of a known track record in similar conditions.

Item No.	Criteria	Weighting	Trencher							Comments
			Sea Stallion	HD-3	Q-Trencher	SeaRex	CBT2400	i-Trencher	T3200	
1	Ability to trench in Chalk	3	5	3	3	3	4	5	5	Trenching in chalk is key for this project
2	Ability to trench through flints	2	3	2	2	2	3	3	5	Flints may be encountered in the chalk but are expected to be most frequent offshore where soil deposits overlie the chalk.
3	Ability to trench in sands / firm clays	2	4	4	4	4	4	3	4	Sands and firm clays will need to be trenched offshore.
4	Footprint on seabed	2	3	3	3	3	2	2	1	Footprint will affect the environmental impact
5	Dispersal of spoil	1	4	4	3	3	3	3	3	Dispersal of spoil by eductors or similar is undesirable environmentally.
6	Nature of remaining trench	2	4	4	3	3	2	2	1	An infilled trench is to be preferred for environmental considerations.
7	Track record of similar projects	2	5	3	2	2	2	4	5	Experience in similar geology is preferred.
-	Total	-	57	45	40	40	41	46	50	-

Table 6-1 : Trencher Selection Matrix

Typical performance for cable ploughs is anticipated to be in the region of 150 to 250 m/hr for, with a tow force in the range 100 to 150 te for depths in the range 0.6 m to 1.0 m. In the case of mechanical and hybrid trenchers, speeds are likely to be 150 to 200 m/hr in chalk, with a potential to increase to 200 to 250 m/hr where sand is predominant.

7 ENVIRONMENTAL CONSIDERATIONS

7.1 Introduction

Cable trenching and/or the installation of external protection may cause disturbance and / or destruction to infauna and epifauna located within the area surrounding the cable. It is expected that the trench area will be up to 0.8 m wide and up to 1.5 m deep in most areas. Where external protection measures such as rock placement or concrete mattresses are utilised, the footprint of the berms or mattresses is expected to be in the region of 6 m in width. In most cases, seabed disturbance relating to cable installation works will be limited to an overall width of 3 to 5 m centred on the cable. However, this footprint may be up to 10 m for trenching equipment with large track widths. Note that for trenching tools, the footprint on the seabed is the over-riding concern, not the trench depth.

Benthic organisms may be directly impacted by physical disturbance of the seabed or increased suspended sediment rates, as well as indirectly affected by the loss of important habitat types. In 2019, Natural England and JNCC published advice on the key sensitivities of habitats and Marine Protected Areas in English waters to offshore wind farm cabling [27]. The advice highlights the key pressures of cable installation activities which include:

1. Habitat structure changes – removal of substratum;
2. Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion;
3. Changes in suspended solids – reducing water quality;
4. Smothering and siltation rate changes;
5. Abrasion/disturbance of the substrate on the surface of the seabed;
6. Changes in water flow altering sediment transport pathways; and
7. Physical change to another seabed/sediment type.

The magnitude of impact resulting from the pressures listed above will depend on which cable trenching and protection techniques are employed, as well as the sediment types located along the proposed cable corridor.

This section of the CBRA compares the environmental impacts associated with the various cable trenching and protection techniques being considered for the Dudgeon and Sheringham Shoal offshore wind farm extension export cable (Section 7.3). An overview of how these impacts may vary across different sediment types observed along the cable corridor is also provided (Section 7.4). Particular focus is placed on the potential environmental impacts on the Cromer Shoal Marine Conservation Zone (MCZ), which overlaps with the export cable (Section 7.5).

7.2 Key Resources

Key resources used to undertake this environmental assessment include:

- BERR (2008) Review of Cabling Techniques and Environmental Effects Applicable to the Offshore Wind Farm Industry.
- Natural England and JNCC (2019) Advice on key sensitivities of habitats and Marine Protected Areas in English Waters to offshore wind farm cabling within Proposed Round 4 leasing areas.
- NIRAS (2015) Subsea Cable Interactions with the Marine Environment – Expert Review and Recommendations Report.
- DNV (2016) Subsea Power Cables in Shallow Water.
- RPS Group (2019) Review of Cable Installation, Protection, Mitigation and Habitat Recoverability; and

- OSPAR (2012) Guidelines on Best Environmental Practice (BEP) in Cable Laying and Operation.
- Natural England (2018a) Natural England Offshore wind cabling: ten years of experience and recommendations.
- Natural England (2018b). Natural England Conservation Advice for Marine Protected Areas – Cromer Shoal Chalk Beds MCZ.
- Royal Haskoning DHV (2020) Cromer Shoal Chalk Beds MCZ Environmental Constraints.
- DEFRA (2016) Cromer Shoal Chalk Beds MCZ – Feature Maps.

7.3 Environmental Impacts Associated with Different Cable Trenching and Protection Techniques

Due to the varying sediment types observed along the cable corridor, various trenching and external protection techniques are being considered for the cable installation. As described in Section 3 and 4, it is expected that marine sediments are likely to be present as a thin veneer across the majority of the cable corridor (between KP 8.45 and KP 17), with Cretaceous Chalk expected to underlie the Holocene veneer with areas of local or extended outcrop. It is expected that a plough or a mechanical trencher will be the most viable option for cable burial in these areas due to the presence of a chalk substrate. Alternative means of cable burial may be achieved in the areas of sandier sediment between KP 8.45 and the Offshore Substation (OSS), such as ploughs, jet trenchers or hybrid trenchers.

The environmental impacts associated with these different cable trenching techniques are described below. An overview of the advantages and disadvantages of the various trenching techniques and cable protection measures being considered for the Sheringham Shoal and Dudgeon extension export cable is provided in Table 7-1. This is followed by Table 7-2 which ranks the trenching and protections measures as having a low, moderate or high impact in reference to the key pressures outlined in Section 7.1. Key differences in trenching and cable protection techniques is provided below.

7.3.1 Seabed Disturbance

Different cable trenching techniques cause varying degrees of seabed disturbance. Firstly, the method of trenching will influence how much sediment is removed (relating to pressures 1 and 2 listed in Section 7.1). For instance, ploughing allows for spoil to fall back into the trench, with only a small amount of sediment removed and jetting techniques may also allow for fluidised sediments to re-settle within the trench. Conversely, mechanical trenchers and hybrid trenchers, increase the volume of direct sediment removed from the trench with a lower potential for natural backfilling to occur (Figure 7-1).

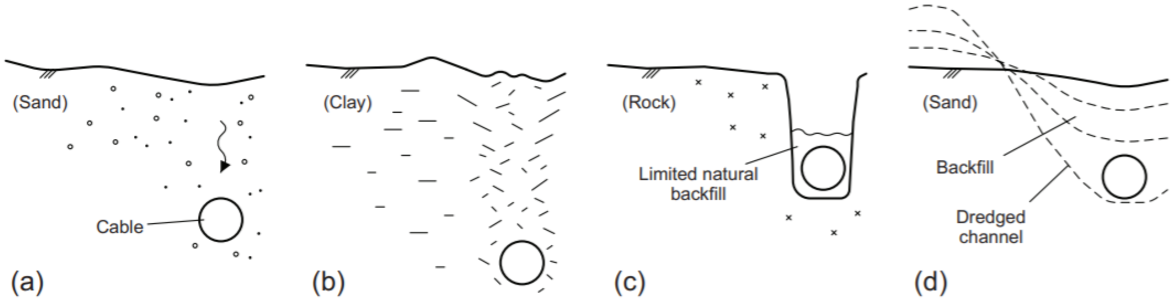


Figure 7-1 : Protection of cable through burial. (a) Jetting/fluidisation, (b) ploughing, (c) mechanical cutting, (d) open trench dredging (DNV, 2016) [24]

7.3.2 Sediment Resuspension

Secondly, the degree of sediment resuspension (relating to pressures 3 and 4 in Section 7.1) will also vary between trenching techniques, with this typically being highest for chain cutters which utilise an eductor system to clear spoil from the chain and along the sides of the trench. Sediment resuspension rates from jet trenchers, which fluidise sediments using direct jets of water, are considered to be lower than chain cutters, but higher than ploughs. Ploughs lift wedges of soil from the trench before lowering the cable into the trench, allowing the trench to backfill naturally with the displaced wedges of soil, with sediment disturbance for this technique being kept to a minimum. It should be noted that for all trenching techniques, the degree of sediment resuspension, how long this sediment will remain suspended, and how far it will spread will be highly dependent on sediment type, as well as local tidal and wave conditions. However, sediment resuspension associated with cable installation will generally be short-term and localised, minimising the potential for adverse environmental impacts.

7.3.3 Physical Change to the Seabed/Sediment Type

Thirdly, the method of cable protection will directly influence the degree and nature of physical change to the seabed/ sediment type (relating to pressure 7 in Section 7.1). Generally, the preferred protection method for cables is trenching, with burial under natural sediments, which may be achieved through fluidisation, natural backfill, or through post-lay burial (e.g. backfill plough). As discussed in Section 7.4.1, trenching through areas of softer sediment (e.g. sand) typically constitutes as a temporary change, with recoverability of the seabed being possible in most cases. However, trenching through areas of rocky substrates (including chalk), will form a permanent scar on the seabed with no ability for the rocky substrate to regenerate, even when sufficient burial under natural sediments is achieved. This would constitute as a change in the seabed with a permanent loss of rocky habitat. Additionally, depth of burial may not be achieved in some cases. Within these areas, it may be necessary to use alternative means of cable protection (e.g. rock placement) which would also lead to a physical change to the seabed type, with the potential loss of important benthic habitats. Where external cable protection is used, the footprint of seabed disturbance will typically be greater than what is observed for burial under natural sediments with no recoverability of the habitat achievable.

An alternative to cable trenching or burial is to surface lay cables with protection measures such as rock placement, concrete mattresses or articulated half shells (Figure 7-2). This is preferred over trenching when the ground conditions make trenching particularly onerous, or at crossings of other cables or pipelines (see Section 7.1). Although this minimises the degree of sediment displaced (minimising impacts related to pressures 1 - 4 in Section 7.1), this would constitute as a direct physical change in the seabed type, with a large area of benthic habitat likely to be lost. An alternative external protection measure to rock placement or concrete mattresses is articulated half shells. These are generally more expensive to install but have a lower seabed footprint in comparison to rock placement or concreate mattresses. These may be utilised in environments which are highly sensitive to cabling impacts.

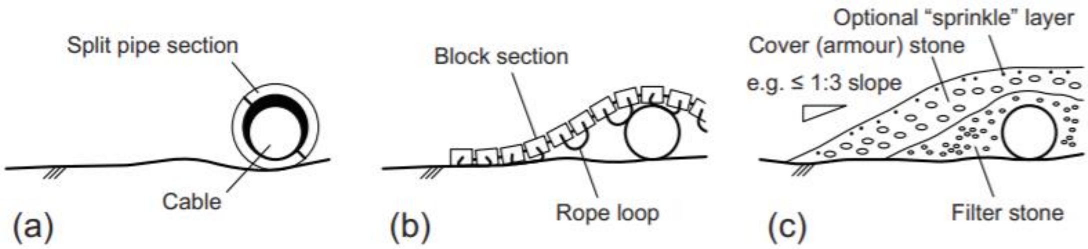


Figure 7-2 : Cable protection. (a) tubular product (e.g. articulated half shells), (b) mattress, (c) rock placement (DNV, 2016) [24]

Table 7-1 Advantages and Disadvantages of Different Cable Trenching and Protection Techniques

Technique	Sediment Type where this equipment is utilised	Environmental Advantages	Environmental Disadvantages
Trenching Techniques			
Ploughs	• Sands, silts, gravels and clays.	• Lower levels of sediment resuspension compared with other trenching techniques; and • Potential for natural backfill.	• Difficult to manage any ride out (reduced depth) and only remedial option may be rock placement; • Physical abrasion to seabed resulting from front skids; and • Potential to create side berms along the trench from displaced spoil.
Jet Trenchers	• Sand, silts, gravels and clays.	• Potential for natural backfill.	• Moderate levels of sediment resuspension which could cause smothering impacts or decreases in water quality; and • Physical abrasion to seabed resulting from tracks (5 – 10 m wide).
Mechanical Trenchers/ Hybrid Trenchers	• Hard substrates (e.g. stiff clays, chalks).	• Can be utilised in harder substrates which are less amenable to other trenching techniques.	• High levels of sediment resuspension which could cause smothering impacts or decreases in water quality; • Lower potential for natural backfill, increasing risk of remedial rock placement/backfill ploughing; • Permanent changes to the substratum if used in rocky areas; and • Physical abrasion to seabed resulting from wide tracks associated with this equipment type (5 – 10 m wide).
Protection measures			
Surface lay with no protection	• Hard substrates which prohibit cable trenching.	• Lower seabed disturbance with no removal of substratum necessary; and • No sediment resuspension.	• Risk to other sea users (anchoring) or fishing activities; • Risk to cable integrity; • Potential abrasion to seabed surface in mobile environments;

Technique	Sediment Type where this equipment is utilised	Environmental Advantages	Environmental Disadvantages
Concrete Mattresses/ Rock Placement	• Hard substrates where depth of cover is not achieved.; • Hard substrates which prohibit cable trenching (surface laid cables).; and • Cable/pipeline crossings.	• No removal of substratum necessary (applicable to surface laid cables only); • Potential for artificial reefs to form in the long-term; • Reduced impacts to other sea users and fisheries; and • Limited sediment resuspension.	• Potentially large reduction in habitat extent with physical changes to seabed/ sediment type. This will increase the footprint of the infrastructure to approx. 6 m wide. • Potential to cause scour around berms in high tidal flows.
Articulate half shells	• Hard substrates which are protected and/or highly sensitive to cabling impacts.	• No removal of substratum necessary; and • Smaller seabed footprint (approx. 0.5 m diameter) in comparison to concrete mattresses and rock placement.	• Small reduction in habitat extent; and • May result in snagging risk to other sea users and commercial fisheries.

Table 7-2 Assessment of Trenching and Protection Measures Against Key Pressures for Cable Installations

Pressure	**Assessment for Technique - Low =** Low impacts expected/ more favourable, **Moderate** = Moderate impacts expected, **High =** High impacts expected/ less favourable	
> Habitat structure changes – removal of substratum	Ploughs	**Moderate**
	Jet Trenchers	**Moderate**
	Mechanical Trenchers/ Hybrid trenchers	**High**
	Surface lay with no protection	**Low**
	Concrete Mattresses/ Rock placement	**Low**
	Rock dump	**Low**
	Articulate half shells	**Low**
> Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion	Ploughs	**Low to Moderate**
	Jet Trenchers	**Moderate**
	Mechanical Trenchers/ Hybrid Trenchers	**High**
	Surface lay with no protection	**Low**
	Concrete Mattresses/ Rock Placement	**Low**
	Articulate half shells	**Low**
> Changes in suspended solids – reducing water quality	Ploughs	**Low**
	Jet Trenchers	**High**
	Mechanical Trenchers/ Hybrid Trenchers	**High**
	Concrete Mattresses/ Rock Placement	**Low**
	Articulate half shells	**Low**
> Smothering and siltation rate changes	Ploughs	**Low**
	Jet Trenchers	**Moderate**
	Mechanical Trenchers/ Hybrid Trenchers	**High**
	Surface lay with no protection	**Low**
	Concrete Mattresses/ Rock Placement	**Low**
	Articulate half shells	**Low**

Pressure	Assessment for Technique - **Low =** Low impacts expected/ more favourable, **Moderate** = Moderate impacts expected, **High =** High impacts expected/ less favourable	
> Abrasion/disturbance of the substrate on the surface of the seabed	Ploughs	**Moderate**
	Jet Trenchers	**Moderate**
	Mechanical Trenchers/ Hybrid Trenchers	**High**
	Surface lay with no protection	**Moderate**
	Concrete Mattresses/ Rock Placement	**High**
	Articulate half shells	**Low**
> Changes in water flow altering sediment transport pathways	Ploughs	**Low**
	Jet Trenchers	**Low**
	Mechanical Trenchers/ Hybrid Trenchers	**Low**
	Surface lay with no protection	**Low**
	Concrete Mattresses/ Rock Placement	**Moderate**
	Articulate half shells	**Low**
> Physical change to another seabed/sediment type	Ploughs	**Low**
	Jet Trenchers	**Low**
	Mechanical Trenchers/ Hybrid Trenchers	**Moderate (if trench infill cannot be achieved)**
	Surface lay with no protection	**Low**
	Concrete Mattresses/ Rock Placement	**High**
	Articulate half shells	**Low**

7.4 Environmental Impacts Along the Cable Corridor

7.4.1 Environmental Impacts Associated with Different Sediment Types

The sediment types located along the cable corridor are described briefly in Section 3 of this CBRA. Sediments along the cable corridor are expected to be primarily SAND, gravelly SAND or GRAVEL, and this is expected to be present as a thin veneer across the majority of the route with exposed Quaternary CLAY or SAND sediments or CHALK. The nearshore area is primarily CHALK outcrop. There are also areas of mobile sediment including sandwaves and megaripples located along the cable corridor.

As detailed in Section 4, it is expected that the Holocene veneer will be less than 0.5 m deep for the majority of the route. Towards the OSS, it is expected that Quaternary soils will mostly be comprised of CLAY, SAND and reworked TILL with only small areas of CHALK at trenchable depths. However, towards the nearshore end of the export cable (from KP 8.45 to KP 17), CHALK is expected to underlie the Holocene veneer with areas of local or extended outcrop, with the exception of KP 16.2 to KP 17, where an incised channel exists, infilled with granular sediment.

The export cable overlaps with the Cromer Shoal Chalk Beds MCZ, and chalk features identified along the cable corridor in areas overlapping with the boundaries of the Cromer Shoal MCZ are designated as 'subtidal chalk' within this protected site. It is likely that the sand sediment types coincide with 'subtidal sand' feature of this MCZ and that the gravelly sand/gravel may represent the 'subtidal coarse sediment' and 'subtidal mixed sediment' protected features of this protected site [30]. The impacts on this MCZ are assessed separately in Section 7.5, with the general impacts associated with the sediment types observed in along the cable corridor described below to capture any impacts to these habitat types that lie outwith the boundaries of the designated site.

The environmental impacts associated with the sediment types observed along the cable corridor are as follows:

- **Sand** – Sandy sediments have a good ability to recover from cabling impacts and it is likely that infill will occur rapidly following ploughing or trenching. Likely that sediments will settle in the immediate vicinity of the cable trench. Options for cable trenching and burial within sandy areas include ploughs, jet trenchers and hybrid trenching, impacts associated with these techniques are described in Table 7-1 and Table 7-2.
- **Gravel** – Gravel also has a relatively good ability to recover from cabling impacts, although a shallow trough may be left following infill. However, overall it is expected that benthic species will be able to recover from cabling impacts fairly quickly. Likely that sediments will settle in the immediate vicinity of the cable trench. Likely options for cable trenching and burial within gravel areas include ploughs, jet trenchers and hybrid trenchers, impacts associated with these techniques are described in Table 7-1 and Table 7-2.
- **Clay** – In soft clays, infilling is likely to occur rapidly. However, a permanent scar is likely in stiffer clays, with limited recoverability of this type of habitat. However, it is acknowledged that this habitat type is relatively species poor. In softer clays, the volume of sediment resuspended may be high and this will be much greater than in stiffer clays. Ploughs, jet trenchers and hybrid trenchers will likely be suitable for softer clays with mechanical cutters most suitable for cohesive clays. Impacts associated with these techniques are described in Table 7-1 and Table 7-2.

- **Chalk** – Likely that a permanent scar will be left in the seabed with limited recoverability. Direct disturbance to epifauna and flora inhabiting chalk habitat. Potential for a high volume of sediment resuspension. Likely that only mechanical trenchers or ploughs will be appropriate trenching techniques within chalk habitat along the cable corridor. Impacts associated with these techniques are described in Table 7-1 and Table 7-2. Impacts associated with the subtidal chalk designated within the Cromer Shoal MCZ are discussed in Section 7.5.

The sandy and gravel areas located closer to the OSS are not considered to be of any particular environmental sensitivity with recoverability of these habitat types considered probable for most trenching techniques. Although these sediment types may be sensitive to external cable protection measures such as concrete mattresses or rock placement. The greatest concern from an environmental perspective is the large overlap with areas of chalk along the cable corridor, the majority of which is likely to be located within the Cromer Shoal Chalk Beds MCZ. This habitat type is particularly sensitive to removal of substratum and disturbance to substratum below and above the surface of the seabed [26]. It is generally advised that all chalk habitats are avoided during cable installation works where possible [25], due to the slow recovery of this habitat type and the fact that it will never achieve morphological recovery from cabling impacts. The trenching activities within areas of chalk will likely require mechanical cutting trenching or ploughing techniques, given the thin layer of marine sediment expected, and this will cause irreversible damage to the chalk habitat, as described above. Rock placement in this area would also constitute as a loss of this rare habitat type. An alternative to these cabling techniques would be to utilise articulated half shells. This would minimise the area of seabed disturbance to approximately 0.5 m width, with no direct loss of substratum.

There are also several areas of sandwave and megaripples located along the cable corridor and it is noted that an Annex I sandbank habitat lies across the width of the coastline adjacent to the export cable (Figure 7-3). The sandbank area is likely associated with the ‘subtidal sand’ feature designated within the Cromer Shoal MCZ. This sand feature is considered to be relatively species poor due to the mobile nature of the area but is particularly sensitive to changes in physical seabed type as a result of the introduction of hard substrate which would cause a loss in the extent of this feature [26]. Mobile sediments may also cause cables to become exposed over time if they are not sufficiently buried.

Figure 7-3 : Annex I sandbank habitat located along the coastline adjacent to the export cable*.

*The existing Sheringham Shoal and Dudgeon offshore wind sites and export cables are provided for reference.

7.4.2 Areas of Reduced Burial

Cable burial is the preferred method of protection for the export cable and this is intended to be achieved through natural infill of the trench over time via sediment transport processes. If this is not achieved, a remedial jetting pass may be performed. However, it is acknowledged that there are areas of hard substrate along the cable corridor, including areas of chalk outcrop, and this may lead to difficulties in achieving the target depth of cover. If depth of cover cannot be achieved, protection measures such as rock placement may be required, and this is common for offshore wind export cables in chalk habitats [25]. As mentioned in Section 7.3, rock placement is generally less favourable in comparison to burial under natural sediment as it results in a physical change of the seabed and a wide area (up to 6 m) of habitat loss. Moreover, it is also acknowledged that if ploughs are used, this could also result in shallow depth of lowering, due to issues around 'ride out' when hard substrates are encountered, and this may also have to be remediated with rock placement. The use of articulated half shells within the areas of exposed chalk outcrop would reduce the extent of habitat loss and eliminate any risks associated with depth of burial not being achieved.

7.5 Cromer Shoal Chalk Beds MCZ

The cable corridor passes through the western end of the Cromer Shoal Chalk Beds MCZ, as designated in Figure 7-4. Although the extant Sheringham Shoal and Dudgeon windfarm export cables are located within the Cromer Shoal Chalk Beds MCZ, these were consented prior to the designation of the Cromer Shoal Chalk Beds MCZ in 2016. Importantly, these extant cables (as well as the telecommunication cable and the pipelines associated with the Bacton Gas Terminal) have already resulted in a reduction of the extent and distribution of the designated features (especially the rock and chalk qualifying features which will not recover from cabling impacts). As such, trenching through the rock and chalk features for the Dudgeon and Sheringham Shoal offshore wind farm extension export cable would further reduce the extent and distribution of these features, as a result of cumulative effects with the extant cables and pipelines which lie within the MCZ. A useful exercise may be to perform an environmental study along the route of the Dudgeon cable to assess long term impact of the trenching operation there. Consideration could also be given to the same exercise on the Sheringham cable, however it is known there were several issues encountered during installation of this cable, which will have caused relatively extensive disturbance of the seabed.

It should be noted that the Hornsea 3 export cable was re-routed around this MCZ during the consenting process, due to issues regarding the sensitive benthic features within this site (particularly the sensitive chalk bed features). Therefore, it is expected that cabling through this area will present significant challenges from a consenting perspective, and there is risk that a cable corridor through the site would be blocked by the regulator, leading to abortive route development work. As such it is recommended that the export cable is routed to avoid this site, unless confirmation from the regulator can be obtained to state that routing through the site would be consentable.

Nevertheless, an environmental assessment of going through the Cromer Shoal Chalk Beds MCZ is provided below.

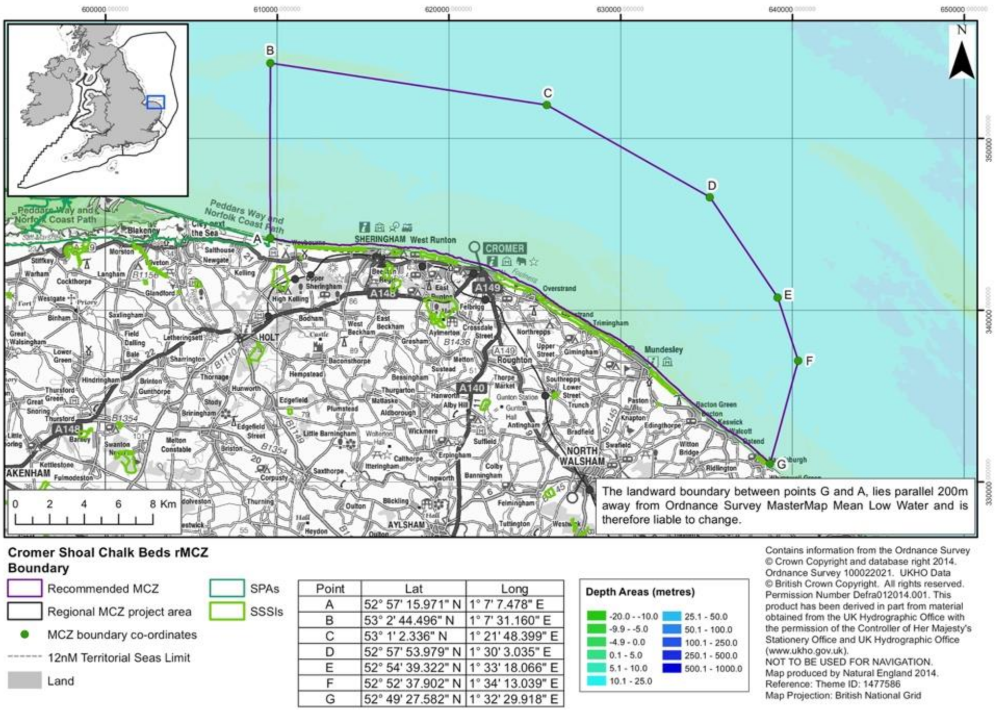


Figure 7-4 : Boundary limits of the Cromer Shoal Chalk Beds MCZ

The Cromer Shoal Chalk Beds MCZ covers a 321 km^2 area. It is designated primarily for broadscale habitat features, but is also for two Features of Conservation Interest (FOCI)[1] (Table 7-3).

[1] FOCI are habitats or species known to be threatened, rare or declining in our seas.

Protected Feature	Type of Feature
High energy circalittoral rock	Broadscale marine habitat
High energy infralittoral rock	Broadscale marine habitat
Moderate energy circalittoral rock	Broadscale marine habitat
Subtidal coarse sediment	Broadscale marine habitat
Subtidal mixed sediment	Broadscale marine habitat
Subtidal sand	Broadscale marine habitat
Peat and clay exposures	FOCI
Subtidal chalk	FOCI
North Norfolk Coast assemblage of subtidal sediment features and habitats	Feature of geological interest

Table 7-3 : Cromer Shoal Chalk Beds MCZ Qualifying features
(Royal Haskoning DHV, 2020)

A map of the broadscale habitat features designated within the Cromer Shoal Chalk Beds MCZ is provided in Figure 7-5 and a map of the FOCI features designated within the Cromer Shoal Chalk Beds MCZ is provided in Figure 7-6. The cable corridor overlaps with subtidal coarse sediment, subtidal sand sediments, subtidal mixed sediments and subtidal chalk designated features within this MCZ. The presence of these features likely coincides with the presence of sandy, sandy gravel and chalk features observed within the geophysical survey of the route [2]. Other designated features of this MCZ are primarily located outwith the cable corridor.

Royal Haskoning DHV [30] undertook an initial assessment on the key cable installation constraints for the features designated within the MCZ. The assessment here will focus on potential impacts relating to the overlapping designated features, expanding on the assessment provided Royal Haskoning DHV [30]. The key sensitivities of the designated features in the vicinity of the cable corridor are provided in Table 7-4 with a comparison of the various trenching and protection techniques provided below. This section draws upon the assessments provided in Section 7.3 and 7.4.

7.5.1 Mechanical Trenchers/ Hybrid Trenchers

Chalk is potentially present at trenchable depths across a wide area of the cable corridor that overlaps with the Cromer Shoal Chalk Beds MCZ, and as such, mechanical trenchers are likely to be the most viable trenching technique within this section of the export cable. Jet trenchers are unlikely to be a viable option given that chalk beds are a hard substrate, while the use of ploughs may be possible in some areas depending on the competence and shear strength of surficial and subcropping chalk. As described in Section 7.4.1, mechanical trenchers are likely to have a considerable environmental impact on the subtidal chalk feature within the MCZ as this would result in permanent irreversible damage to this feature, with subtidal chalk being highly sensitive to removal of substratum. Subtidal chalk also has a medium sensitivity to physical abrasion below and above the seabed.

Mechanical trenchers have large tracks which may cause physical abrasion of the surface of the seabed, and the cutting action is likely to cause a large degree of disturbance below the seabed (see Section 7.3 for more detail). Subtidal chalk is regarded as being highly vulnerable to infrastructure development, and the extent of the chalk beds within the Cromer Shoal Chalk Beds MCZ have already been reduced by existing trenched Sheringham Shoal and Dudgeon windfarm export cables. Trenching within this area would further reduce the extent and quality of this sensitive habitat.

Subtidal coarse sediment, subtidal mixed sediments and subtidal sand are likely to be less sensitive to trenching impacts with some recoverability of these habitat types expected. However, mechanical trenchers have a lower likelihood of the trench infilling and a greater degree of disturbance of the substratum below and above the seabed compared with other trenching techniques (see Section 7.3), which these features have a 'not sensitive to medium sensitivity' to.

7.5.2 Ploughs

Ploughs may be a viable option where chalk is present at a trenchable depth provided it is weathered, and as detailed above may also facilitate cable burial in areas of soil deposits. If used within chalk beds, ploughs will have equal or greater environmental impacts to mechanical trenchers, since the surface abrasion resulting from the contact between the plough's skids and the seabed will have a similar footprint to a trencher's tracks, while also resulting in disturbance and permanent loss of the competent chalk substratum. However, it is noted that plough cut trenches are generally slightly narrower than those cut using a mechanical trencher, as such these impacts will be lower. Ploughed trenches also generally have a shallower profile than those cut by a trencher, resulting in an increased risk of remedial backfilling or the placement of additional external protection being required to achieve the desired level of protection, which would further increase the adverse impacts on the chalk beds. Ploughs do result in less sediment entering the water column than mechanical and jet trenching, and the consequential impacts of reductions in water quality and sediment deposition are also reduced. However, these impacts are considered to be temporary, and as such this reduction is unlikely to offset the increased permanent loss of the chalk substratum.

Where ploughs are used outwith chalk beds, such as where subtidal sand, subtidal coarse and mixed sediments are present, environmental impacts are expected to be reduced in comparison to the use of mechanical trenchers. This due to the fact that in these granular substrates, the substratum is only disturbed not destroyed by the plough. Therefore, the fact that the majority of the displaced material will be deposited within or in the immediate vicinity of the trench (rather than being ejected in the case of a mechanical trencher) means the recovery time of the seabed is reduced, thus reducing the environmental impact.

Finally, it should be highlighted that where ploughing is unsuccessful, the placement of external protection is often the only remediation option available. This can result in significant adverse effects on the qualifying features of the designated site (as detailed in section 7.5.4), which needs to be considered when evaluating the consenting risk associated with the use of ploughs.

7.5.3 Jet Trenchers

For areas where chalk is not present at a trenchable depth, such as where subtidal sand, subtidal coarse and mixed sediments are present, jet trenching is likely to be a more favourable trenching technique. This is because the removal of habitat substratum and the physical abrasion below and above the seabed will likely be lower than from both mechanical trenching techniques and ploughing, which the qualifying features of the MCZ have a 'medium sensitivity' to (see Section 7.3). It is noted that jet trenchers have an increased potential to result in the resuspension of solids compared to ploughs (although lower than mechanical trenchers). However, as stated above, since this impact is temporary, the reduction in seabed disturbance impacts outweighs the increased water quality impacts. Therefore, on balance, in areas where the substrate permits the use of jet trenching, this tool represents the best environmental option due to the reduced disturbance of the seabed, and associated reductions in habitat recovery time [25]. This also applies to hybrid trenchers in jetting mode, with the caveat that the tracks tend to be larger than typical of a jet trencher.

7.5.4 Concrete Mattresses and Rock Placement

Cable protection is also not favourable for the majority of the features protected within the Cromer Shoal Chalk Beds MCZ. Although subtidal chalks features are not sensitive to physical changes in seabed type, the use of cable protection measures such as concrete mattresses or rock placement would reduce the extent of this habitat type (berm width of up to 6 m). In addition, subtidal mixed, subtidal coarse and subtidal sand sediments are highly sensitive to physical change resulting from the introduction of hard substrate, and these protective measures would also reduce the extent of these habitat types. Thus, concrete mattresses and rock placement should be avoided where possible.

7.5.5 Surface laying the cable (with no protection)

Surface laying of the cable with no protection could provide a potential option which reduces the potential for impacts relating to the removal of substratum, and disturbance below the seabed. However, abrasion above the seabed may still occur, which subtidal mixed sediments, subtidal chalk and subtidal sand have a ‘not sensitive to medium’ sensitivity to. However, this would drastically reduce any loss of habitat extent. This does however, present issues regarding snagging risk for the shipping and navigation and fishing industry and would increase the risk of third-party damage of the cable, together with damage from scour. The possible use of unprotected surface laying would need to be subject to further consideration from both an engineering perspective (on-bottom stability), together with key stakeholders including Natural England, the MCA and commercial fishing representatives.

7.5.6 Articulated Half Shells

Articulated half shells would provide an alternative, which similar to cable laying with no protection, would avoid any impacts associated with loss of substratum and disturbance below the seabed, as well as providing some external cable protection. Impacts may still exist in terms of physical abrasion to the surface of the seabed, but the area of habitat loss is drastically reduced in comparison to trenching through features designated within this MCZ. The use of articulated half shells would still present a snagging risk to commercial fishers and other sea users. As such, stakeholder engagement will be required to consider the acceptability of this option, as well as detailed engineering considerations.

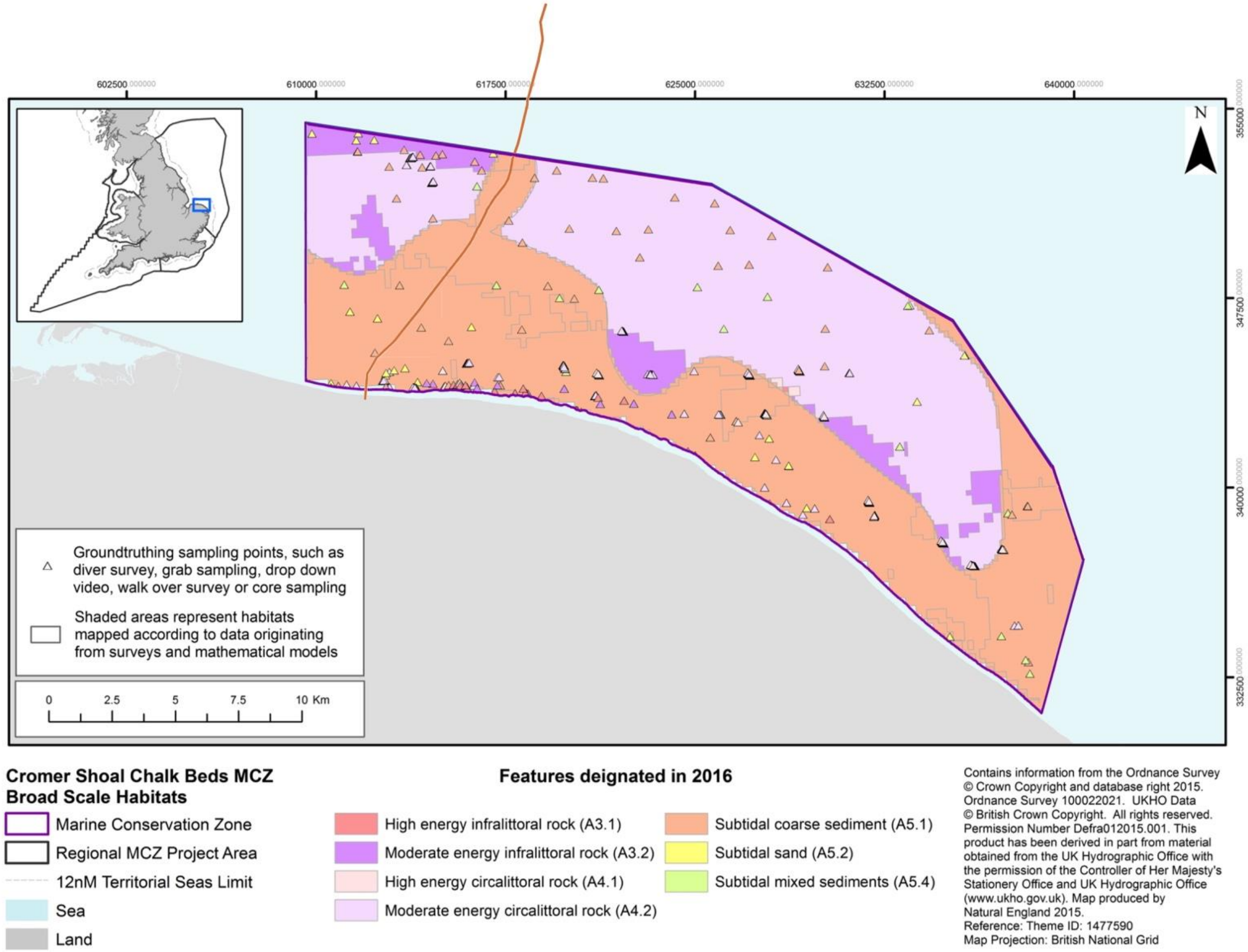


Figure 7-5 : Broadscale Habitat Features Designated within the Cromer Shoal Chalk Beds MCZ (DEFRA, 2016)

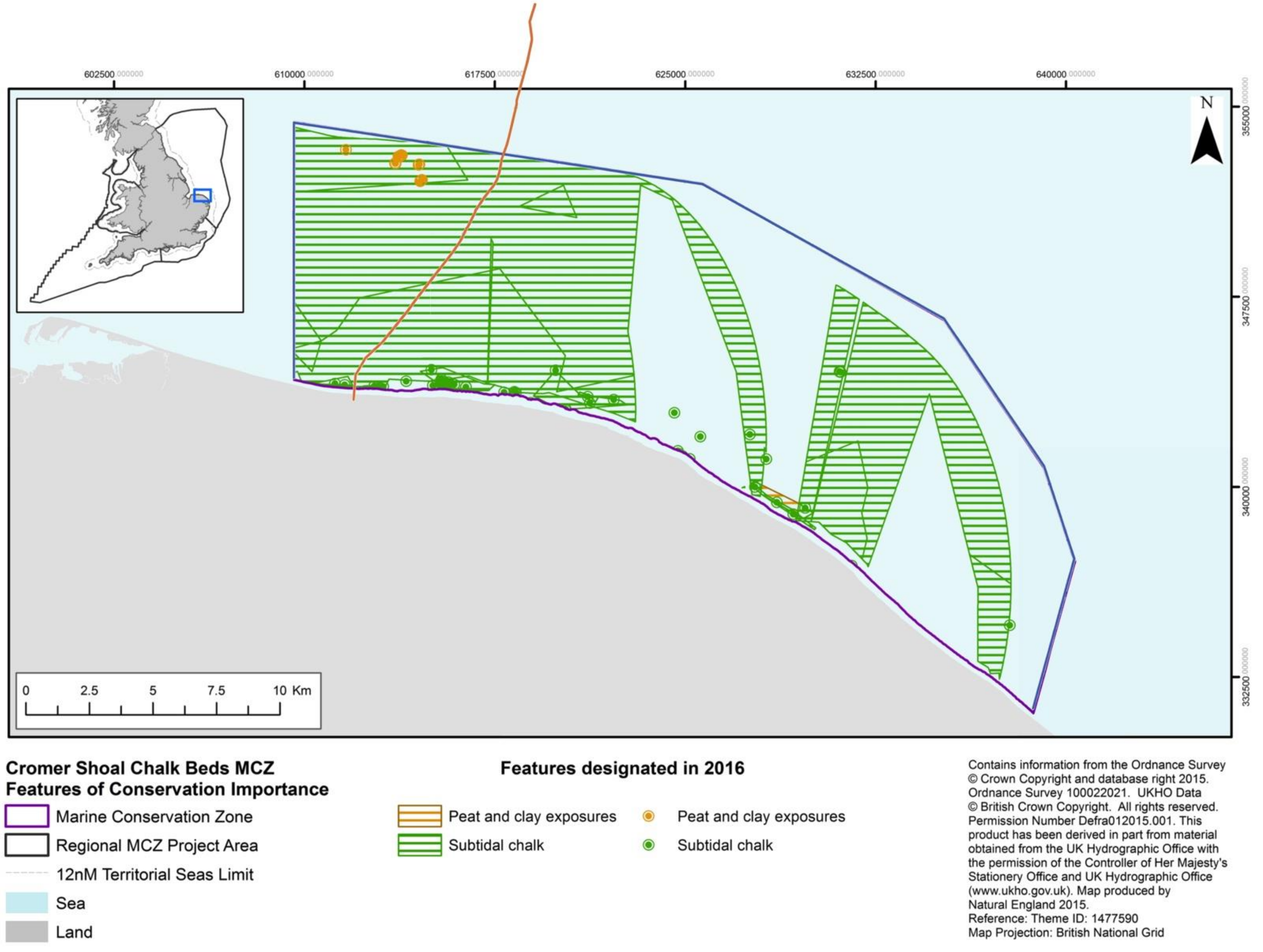


Figure 7-6 : FOCI features designated within the Cromer Shoal Chalk Beds MCZ (DEFRA, 2016)

Table 7-4 : Cromer Shoal Chalk Beds MCZ Cable Installation Constraints (Natural England, 2018a; Royal Haskoning DHV, 2020)

Designated Feature	Description of Feature within MCZ	Sensitivities to Cabling Pressures
Subtidal Coarse Sediments	Subtidal coarse sediment has a wide distribution covering 60 % of the MCZ. This sediment type is dominant beyond the chalk reef and is the dominant sediment type within the offshore area of the MCZ, with only small areas of mixed sediment interrupting the distribution. This habitat type is bordered by subtidal sand or mixed sediments to the north and south. This sediment is primarily composed of empty shells and fragments, and pebbles interspersed with fine sediments. This habitat type is present across all of the export cable area that overlaps with the MCZ boundary (Figure 7-5).	Habitat structure changes – removal of substratum – **Medium** Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion – **Not sensitive to Medium** Changes in suspended solids – reducing water quality – **Not sensitive** Smothering and siltation rate changes – **Not sensitive to Low** Abrasion/disturbance of the substrate on the surface of the seabed - **Not sensitive to low** Changes in water flow altering sediment transport pathways- **Not Sensitive** Physical change to another seabed/sediment type - **High**
Subtidal Mixed Sediments	Subtidal mixed sediment occurs as a thin patch midway through the site, and in smaller patches along the south east portion of the site. This sediment is composed of a mix of muddy gravelly sands with cobbles and pebbles. This habitat type is likely to be present in localised areas along the cable corridor (Figure 7-5).	Habitat structure changes – removal of substratum – **Medium** Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion –**Medium** Changes in suspended solids – reducing water quality – **Not sensitive** Smothering and siltation rate changes – **Not sensitive to Medium** Abrasion/disturbance of the substrate on the surface of the seabed - **Medium** Changes in water flow altering sediment transport pathways- **Not Sensitive** Physical change to another seabed/sediment type - **High**
Subtidal Chalk	The subtidal chalk feature extends across the majority of the MCZ. Subtidal chalk present as chalk outcrop is primarily recorded close to shore, however, there are likely to be areas where chalk bedrock is covered by a thin veneer sand or coarse/mixed sediment with chalk still present within a trenchable depth. This habitat type is present across all of the export cable area that overlaps with the MCZ boundary (Figure 7-6).	Habitat structure changes – removal of substratum – **High** Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion –**Medium** Changes in suspended solids – reducing water quality – **Low** Smothering and siltation rate changes – **Low** Abrasion/disturbance of the substrate on the surface of the seabed - **Medium** Changes in water flow altering sediment transport pathways- **Not Sensitive** Physical change to another seabed/sediment type – **Not Relevant**
Subtidal Sand	Subtidal sand has a limited distribution within the site, restricted to areas of the southern, western and northern borders, where patches of sand tend to occur in large linear expanses. This habitat type is likely to be present in localised areas of the cable corridor (Figure 7-5).	Habitat structure changes – removal of substratum – **Medium** Penetration and/or disturbance of the substratum below the surface of the seabed, including abrasion –**Low to Medium** Changes in suspended solids – reducing water quality – **Not sensitive to Low** Smothering and siltation rate changes – **Not Sensitive to Low** Abrasion/disturbance of the substrate on the surface of the seabed - **Not sensitive - Medium** Changes in water flow altering sediment transport pathways- **Not Sensitive** Physical change to another seabed/sediment type – **High**

APPENDIX A – TRENCHING AND GEOLOGY ASSESSMENT

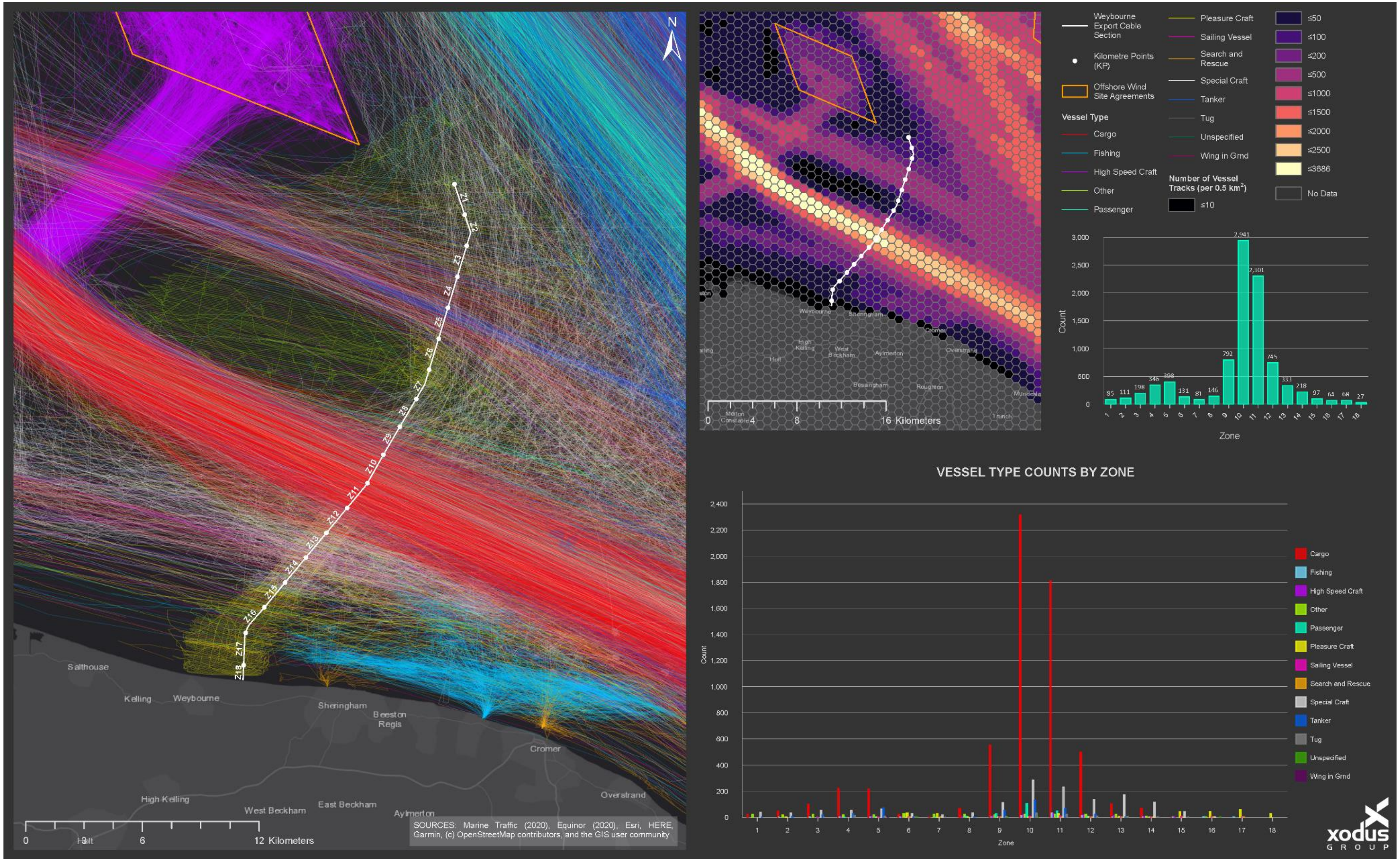
Survey Chart KP		Geophysical Interpretation				Geotechnical			Geological Risk (within 20 m of route)
KP From	KP To	Length (m)	Water Depth m LAT)	Seabed	Geophysical Interpretation to 2 m bsb	Sample ID (existing Dudgeon route, offset to West))	Approx. Distance from Route (m)	Summary description of soils from vibrocores	
0.00	0.15	150	27- 25	Gravelly SAND, shoaling seabed	Approx. 1m SAND and GRAVELS (HOL) over CHALK	105	320 WNW	0-1.5 m fine-medium SAND 1.5-1.6 m gravelly CLAY 1.6-2.3 m very sandy GRAVEL > 2.3 m muddy CHALK, su ~100 kPa	
0.15	1.10	950	25 - 22	SAND, with possible local CLAY exposure Single NNE-trending sandwaves or megaripples, features up to 2 m in height. These bedforms are present in association with a low curving ridge structure	Very thin to locally absent SAND and GRAVELS (HOL) over laminated CLAY and fine SAND (BCT)	104A	350 WNW	0-0.8 m fine-medium SAND 0.3-2.9 m (end) calcareous GRAVEL	Megaripples Sandwaves Cross-track slopes near KP 0.23
1.10	2.13	1030	21.3 - 22.5	Gravelly SAND, slightly irregular seabed	Very thin to locally absent SAND and GRAVELS (HOL) over CLAY and fine SAND (BCT)	103	640 WNW	0-0.3 m very gravelly fine-medium SAND 0.3-1.5 m (end) firm to stiff CLAY TILL	
2.13	4.35	2220	22.5 - 23	Gravelly SAND, slightly to locally irregular seabed	Very thin to locally absent SAND and GRAVELS (HOL) over CLAY and fine SAND (BCT). Local highs of gravelly coarse SAND and reworked TILL (SWB). Near KP 2.9 possible high of CHALK to within 1.5 of seabed	102 120 101	650 WNW 690 WNW 730 WNW	102: 0-0.3 m gravelly med. SAND with calc peat layer 0.11-0.18 m, 0.3-0.5 m very soft CLAY 0.5-0.9 m fine-medium SAND 0.9-2.3 m firm-stiff CLAY TILL 120: 0-1.1 firm CLAY w sand pockets and laminae (BCT) 101: 0-0.3m very soft CLAY 0.3- 0.5m f-m SAND w/ peat laminae 0.5-1.8m firm CLAY TILL 1.8-1.9 m fine-medium SAND 1.9-2 m firm CLAY TILL	
4.35	4.52	170	22.5 - 21.5	Gravelly SAND, gently shoaling seabed	Very thin to locally absent SAND and GRAVELS (HOL) over gravelly coarse SAND and reworked TILL (SWB)	none			
4.52	5.30	780	~21.5	Gravelly SAND, approx. flat seabed	Thin < 1 m to absent SAND and GRAVELS (HOL) over possible CHALK near or at seabed (lack of interpreted reflectors)	none			
5.30	6.35	1050	21.5 - 14.5	GRAVEL. becoming SAND with megaripples and 2 single large sand waves to ~3 m height between KP 5.4 and KP 6.2 as eastern tip of Sherinham Shoal is crossed	SAND and GRAVEL or SAND (HOL) At start of section 1 - 1.5 m, increasing to >2 m from ~KP 5.4. Underlain by CHALK	115	850 WNW	0-0.8m very gravelly calc. medium-coarse SAND 0.8-3.1m very soft CLAY, from 2.55m w/sand laminations (BCT)	Megaripples Sandwaves Cross-track slopes (KP 5.45-5.65) Magnetic anomalies
6.35	7.46	1110	20 - 23	SAND, seabed slightly irregular with megaripples	0 to < 2 m SAND (HOL) over CHALK, possible local BCT at start of section	119	800 WNW	0-1.1m fine-medium SAND 1.1-2.2m over very soft organic CLAY/SILT 2.2-2.5m fine-medium SAND 2.5-2.7m soft CLAY, w/sharp flint pebbles 2.7-3.0m soft gravelly calc CLAY TILL	
7.46	8.45	990	23 - 20.5	Gravelly SAND with megaripples, seabed shoaling with small megaripples	Channel in underlying CHALK with infill of CLAY and fine SAND (BCT) , overlain by up to ~1m SAND and GRAVEL (HOL). Chalk may be encountered at ends of section	none			Chalk below BCT at basin edges
8.45	13.60	5150	20.5 - 12	Gravelly SAND, seabed gently shoaling with occasional undulations	Thin or absent HOL veneer over CHALK	118 114 117 113	1000 NW 1100 NW	118: 0-1.0m fine-medium SAND 1.0-2.1m very silty calc fine SAND with laminae of silt and gravel. sand (plant remains) 2.1-2.4m fine-medium SAND, wood fragments 114: 0-0.5m very gravelly, calc fine-medium SAND	KP 11.89 Mag contact on route KP 12.14 Boulder 0.5-0.6 m height KP 13.36 Crossing location of MAG anomalies associated with existing infrastructure

Survey Chart KP		Geophysical Interpretation				Geotechnical			
KP From	KP To	Length (m)	Water Depth m LAT)	Seabed	Geophysical Interpretation to 2 m bsb	Sample ID (existing Dudgeon route, offset to West))	Approx. Distance from Route (m)	Summary description of soils from vibrocores	Geological Risk (within 20 m of route)
							1100 NW 1100 NW	0.5-1.7m stiff-very stiff gravelly CLAY TILL 117: 0-0.2m very sandy, calc. GRAVEL 0.2-1.6m very soft CLAY w/ sand laminations (BCT) 113: 0-0.3m very gravelly fine-medium SAND 0.3-1.5 stiff becoming firm gravelly calc CLAY TILL	KP 13.54 Boulder 0.3 - 0.4 m in height
13.60	16.24	2640	12 - 10 (10 m LAT at KP 16.19)	Complex seabed comprising WNW-ESE-trending alternating belts of SAND and Gravelly SAND with areas of megaripples	Unknown but expected variable thickness of Holocene granular sediments over CHALK, or possibly locally CLAY	116	965 NW	0-0.3m gravelly fine-medium SAND 0.3-2.9m silty CHALK, at top very variable su from 100 to ~600 kPa. Below ~0.6 m, relatively constant 100-200 kPa	Seabed boulders common up to 0.6 m in height at end of section (KP16.05-16.16,area of large boulders up to 2 m Areas of megaripples or sandwaves Mag anomaly on route at KP 15.45
16.24	16.99	750	10 - 9.5	Similar seabed to preceding section	Deep channel with interpreted SAND and GRAVEL infill	none			Areas of very slightly shoaling seabed with megaripples/sandwaves. KP 16.74 Crossing location of MAG anomalies associated with existing infrastructure ~KP 16.85-16.9 Several magnetic anomalies
16.99	17.20	210	9.5 - 5.5	Similar seabed to preceding section	Unknown but expected variable thickness of Holocene granular sediments over CHALK	none			Megaripples / sandwaves, crests running subparallel to route
17.20	17.75	553	5.5 - 0.0	SAND or gravelly SAND, absent to very thin except at landfall	Subcropping CHALK	none			Steeply shoaling, irregular seabed Seabed boulders

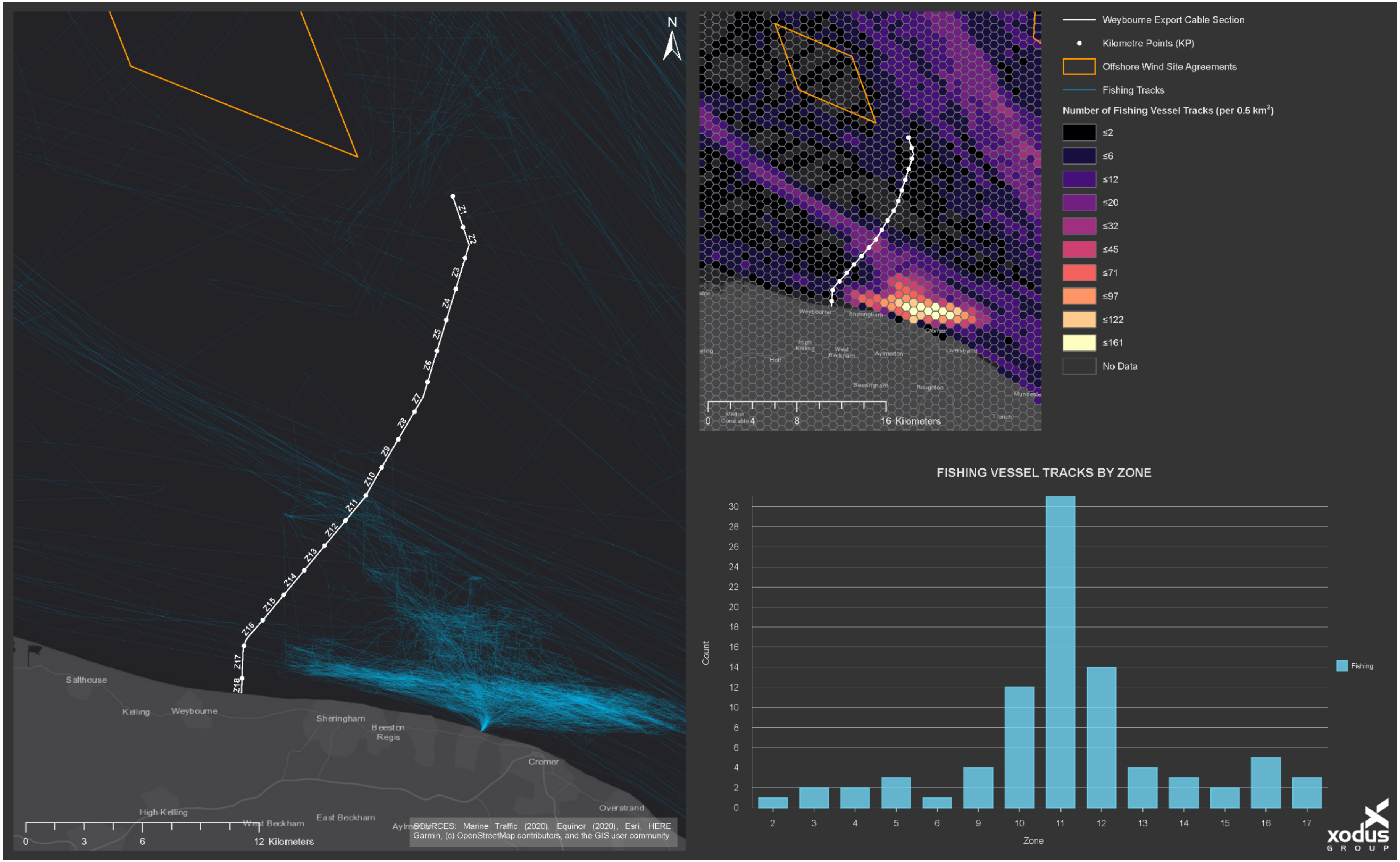
APPENDIX B – AIS DATA ANALYSIS AND RISK ASSESSMENT

- **AIS DATA ASSESSMENT**
- **ANCHOR RISK METHODOLOGY**
- **PROBABILITY ASSESSMENT**

AIS DATA – ALL SHIPPING



AIS DATA – FISHING VESSELS



ANCHOR RISK METHODOLOGY

The probabilistic method used to quantify the risk to the cable from all vessels is taken from the Carbon Trust Cable Burial Risk Assessment Methodology [5] and supporting guidance documentation [6].

The method evaluates the exposure of the cable to external threats by considering the amount of time a vessel spends within a critical distance of the cable and the probability that a vessel might have an incident that requires the deployment of an anchor.

The calculation for the probability of a cable strike is given by:

$$P_{strike} = P_{traffic} \cdot P_{wd} \sum_{1}^{No.ships\ in\ Section} \frac{D_{ship}}{V_{ship} \cdot 8760 hrs\ per\ year} \cdot P_{incident}$$

Where:

$P_{traffic}$	: probability modifier based on the tolerable level of risk
P_{wd}	: probability modifier for nature and depth of seabed
V_{ship}	: ship speed (metre/hr)
D_{ship}	: distance travelled by ship in area under consideration (metre)
$P_{incident}$	: probability of incident occurring for that vessel size and type (/year)
8760 hrs	: factor to annualise the results

The basis for determining each of the variables described in the equation for P_{strike} is described as follows:

- Ptraffic: is intended as a probability modifier based on a tolerable level of risk agreed with stakeholders. In this instance, a tolerable level of risk is not defined and the results of the assessment shall be used to quantify perceived risk, hence $P_{traffic} = 1$.
- Pwd: is a probability modifier based on the seabed profile and water depth, as these factors will influence the navigation of vessels and the likelihood of an incident resulting in the use of an anchor in an emergency. In this instance the water depth/profile is a “wide shipping channel with shallow water at margins”, therefore a probability modifier of 0.5 is adopted along the full length of the route.
- Vship: The ship speed when the anchor is deployed (m/s), taken from the AIS data analysis.
- Dship: is the distance travelled by the vessel when it is close enough to the cable to be a threat. A ship is only a threat if it deploys an anchor and drags it on to the cable. The drag distance can be estimated using an energy absorption calculation based on the vessel’s weight, speed and anchor holding capacity in the anticipated conditions. In this instance Dship has been calculated according to the following formula:

$$D_{ship} = \frac{m \cdot V_{ship}^2}{4 \cdot UHC}$$

Where:

Dship: Distance (in metres) travelled by the anchor in order to be a threat to the cable m: Vessel mass (deadweight + ship light weight), usually taken as displacement (tons)

Vship: The ship speed when the anchor is deployed (m/s)

UHC: Ultimate holding capacity of the anchor (ton-force). UHC is dependent on the anchor type, size, weight and the soil characteristics.

Pincident: DNVGL-RP-F107, probability of machinery breakdown is 1.75×10^{-1} per year per vessel (2×10^{-5} per hour per vessel).

- No. ships in section: is calculated based on the described AIS data processing methodology.

ANCHOR RISK CALCULATION – Based on 1.0 m depth of lowering

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Full Route
0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	14 - 15	15 - 16	16 - 17	17 - 17.454	Full Route
SAND	SAND	SAND	SAND	CHALK	SAND	CHALK	SAND	CHALK	SAND	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	SAND	CHALK	
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
0.00E+00	1.16E-07	2.63E-07	1.03E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.98E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.11E-06
0	8,640,117	3,805,946	966,616	0	0	0	0	0	1,432,078	0	0	0	0	0	0	0	0	473,640
CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1

Vessel Type	DWT (Te)		Probability of Anchor Depoyment in the Vicinity of the Cable																	
	Min	Max	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 17	Zone 18
			Note 3																	
Cargo	0	500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	500	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	1000	2000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2000	3000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3000	4000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4000	5000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5000	6000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6000	10000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	10000	65000	0.00E+00	7.35E-08	2.21E-07	9.92E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.98E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tanker	0	500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	500	1000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	1000	2000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2000	3000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3000	4000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4000	5000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5000	6000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6000	10000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	10000	65000	0.00E+00	4.22E-08	4.22E-08	4.22E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

ANCHOR RISK CALCULATION – Based on 1.0 m in soil / 0.6 m in Chalk depth of lowering

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Full Route
KP	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	14 - 15	15 - 16	16 - 17	17 - 17.454	Full Route
Dominant Soil Type	SAND	SAND	SAND	SAND	CHALK	SAND	CHALK	SAND	CHALK	SAND	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	SAND	CHALK	
Selected DOL (m)	1.0	1.0	1.0	1.0	0.6	1.0	0.6	1.0	0.6	1.0	0.6	0.6	0.6	0.6	0.6	0.6	1.0	0.6	
Total Probability (1/yrs)	0.00E+00	1.16E-07	2.63E-07	1.03E-06	4.83E-07	0.00E+00	0.00E+00	0.00E+00	7.31E-07	6.98E-07	2.57E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-06
Overall Return Period (yrs)	0	8,640,117	3,805,946	966,616	2,069,287	0	0	0	1,367,639	1,432,078	3,887,068	0	0	0	0	0	0	0	279,094
DNV Category	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1

Vessel Type	DWT (Te)		Number of Vessels (2019-2020)		Probability of Anchor Depoyment in the Vicinity of the Cable																	
	Min	Max	Zone 17	Zone 18	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 17	Zone 18
			Note 4		*Note 3*																	
Cargo	0	500	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	500	1000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	1000	2000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2000	3000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3000	4000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4000	5000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5000	6000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6000	10000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	10000	65000	0	0	0.00E+00	7.35E-08	2.21E-07	9.92E-07	4.41E-07	0.00E+00	0.00E+00	0.00E+00	4.78E-07	6.98E-07	2.57E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tanker	0	500	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	500	1000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	1000	2000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2000	3000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3000	4000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4000	5000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5000	6000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6000	10000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	10000	65000	0	0	0.00E+00	4.22E-08	4.22E-08	4.22E-08	4.22E-08	0.00E+00	0.00E+00	0.00E+00	2.53E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

ANCHOR RISK CALCULATION – Based on 0.5 / 0.3 m depth of lowering

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Full Route
KP	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	14 - 15	15 - 16	16 - 17	17 - 17.454	Full Route
Dominant Soil Type	SAND	SAND	SAND	SAND	CHALK	SAND	CHALK	SAND	CHALK	SAND	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	SAND	CHALK	
Selected DOL (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Total Probability (1/yrs)	7.21E-07	1.26E-06	2.37E-06	4.95E-06	1.08E-06	9.31E-07	0.00E+00	1.68E-06	1.02E-05	3.73E-05	2.92E-05	9.50E-06	4.55E-06	2.64E-06	5.95E-07	2.24E-07	9.29E-08	0.00E+00	1.07E-04
Overall Return Period (yrs)	1,386,688	795,216	421,176	202,211	922,476	1,074,243	0	596,718	98,133	26,828	34,246	105,258	219,771	378,365	1,679,413	4,463,076	10,767,697	0	9,323
DNV Category	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 2	CAT 2	CAT 2	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 1	CAT 3

Vessel Type	DWT (Te)		Number of Vessels (2019-2020)		Probability of Anchor Depoyment in the Vicinity of the Cable																	
	Min	Max	Zone 17	Zone 18	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 17	Zone 18
			Note 4		*Note 3*																	
Cargo	0	500	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.16E-09	0.00E+00	0.00E+00	0.00E+00	2.58E-09	0.00E+00	0.00E+00	0.00E+00	2.58E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	500	1000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.41E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.82E-08	9.41E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	1000	2000	0	0	1.29E-08	2.59E-08	1.04E-07	1.04E-07	0.00E+00	1.29E-08	0.00E+00	1.17E-07	5.31E-07	3.86E-06	4.08E-06	9.32E-07	4.27E-07	1.55E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2000	3000	0	0	1.25E-07	1.88E-07	4.07E-07	6.26E-07	0.00E+00	4.70E-08	0.00E+00	1.88E-07	1.60E-06	6.64E-06	7.14E-06	2.94E-06	7.36E-07	7.83E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3000	4000	0	0	1.70E-07	2.83E-07	5.67E-07	9.64E-07	0.00E+00	7.09E-08	0.00E+00	3.40E-07	2.75E-06	7.81E-06	4.55E-06	7.23E-07	1.28E-07	4.25E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4000	5000	0	0	4.04E-08	1.35E-07	1.75E-07	2.83E-07	0.00E+00	8.09E-08	0.00E+00	9.43E-08	1.15E-06	4.76E-06	3.48E-06	1.52E-06	1.48E-07	4.04E-08	1.35E-08	0.00E+00	0.00E+00	0.00E+00
	5000	6000	0	0	0.00E+00	1.37E-08	8.22E-08	3.83E-07	0.00E+00	5.48E-08	0.00E+00	2.74E-08	8.35E-07	5.02E-06	2.78E-06	3.70E-07	1.37E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6000	10000	0	0	0.00E+00	1.51E-08	1.51E-08	4.54E-07	5.60E-07	0.00E+00	0.00E+00	1.97E-07	8.78E-07	4.60E-06	3.77E-06	7.27E-07	3.03E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	10000	65000	0	0	0.00E+00	7.35E-08	2.21E-07	9.92E-07	4.41E-07	0.00E+00	0.00E+00	0.00E+00	4.78E-07	6.98E-07	2.57E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tanker	0	500	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	500	1000	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.26E-08	2.09E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	1000	2000	0	0	0.00E+00	1.17E-08	5.86E-08	3.52E-08	0.00E+00	0.00E+00	0.00E+00	1.17E-08	5.86E-08	2.93E-07	2.11E-07	1.52E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2000	3000	0	0	0.00E+00	2.69E-08	6.72E-08	4.03E-08	0.00E+00	1.34E-08	0.00E+00	1.34E-08	2.15E-07	2.42E-07	9.41E-08	1.34E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3000	4000	0	0	0.00E+00	0.00E+00	3.18E-08	6.37E-08	0.00E+00	1.59E-08	0.00E+00	0.00E+00	4.78E-08	4.30E-07	1.27E-07	9.55E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4000	5000	0	0	0.00E+00	1.72E-08	1.72E-08	2.23E-07	0.00E+00	1.72E-08	0.00E+00	3.44E-08	3.44E-07	7.91E-07	4.64E-07	5.16E-08	1.72E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5000	6000	0	0	0.00E+00	3.30E-08	1.65E-08	8.26E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.26E-08	6.61E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6000	10000	0	0	2.02E-08	4.05E-08	4.05E-08	2.02E-08	4.05E-08	4.05E-08	0.00E+00	2.02E-08	2.02E-08	6.07E-08	2.02E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	10000	65000	0	0	0.00E+00	4.22E-08	4.22E-08	4.22E-08	4.22E-08	0.00E+00	0.00E+00	0.00E+00	2.53E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00