Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects

Appendix 9.7.1 - Interim Cable Burial Study

August 2022
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Glossary of Acronyms

BGS	British Geological Society
CBRA	Cable Burial Risk Assessment
CBT	Cable Burial Tractors
CPT	Cone Penetrometer Test
CSCB	Cromer Shoal Chalk Beds
CSIMP	Cable Specification, Installation and Monitoring Plan
DCO	Development Consent Order
DEP	Dudgeon Offshore Wind Farm Extension Project
DML	Deemed Marine Licence
DOW	Dudgeon Offshore Wind Farm
EIA	Environmental Impact Assessment
HDD	Horizontal Directional Drilling
hr	Hour
ICBS	Interim Cable Burial Study
km	Kilometre
KP	Kilometre Point
kW	Kilowatt
LAT	Lowest Astronomical Tide
m	Meter
MBES	Multibeam Echo Sounder
MCZ	Marine Conservation Zone
MW	Megawatt
OWF	Offshore Wind Farm
ROV	Remotely Operated Vehicle
SBP	Sub Bottom Profiler
SEP	Sheringham Shoal Offshore Wind Farm Extension Project
SLB	Simultaneous Lay and Burial
SOW	Sheringham Shoal Offshore Wind Farm
SSS	Side Scan Sonar
TOP	Top of Product
VC	Vibrocore

Glossary of Terms

Dudgeon Offshore Wind Farm Extension Project (DEP)	The Dudgeon Offshore Wind Farm Extension site as well as all onshore and offshore infrastructure.
Horizontal directional drilling (HDD)	Trenchless technique used to install cables – in this case referring to the installation of the export cables at the landfall.
Landfall	The point at the coastline at which the offshore export cables are brought onshore, connecting to the onshore cables at the transition joint bay above mean high water.
Dudgeon Offshore Wind Farm Extension Project (DEP)	The Dudgeon Offshore Wind Farm Extension onshore and offshore sites including all onshore and offshore infrastructure.
DEP offshore site	The Dudgeon Offshore Wind Farm Extension consisting of the DEP wind farm site, interlink cable corridors and offshore export cable corridor (up to mean high water springs).
DEP onshore site	The Dudgeon Offshore Wind Farm Extension onshore area consisting of the DEP onshore substation site, onshore cable corridor, construction compounds, temporary working areas and onshore landfall area.
DEP North array area	The wind farm site area of the DEP offshore site located to the north of the existing Dudgeon Offshore Wind Farm
DEP South array area	The wind farm site area of the DEP offshore site located to the south of the existing Dudgeon Offshore Wind Farm
DEP wind farm site	The offshore area of DEP within which wind turbines, infield cables and offshore substation platform/s will be located and the adjacent Offshore Temporary Works Area. This is also the collective term for the DEP North and South array areas.
Offshore export cable corridor	This is the area which will contain the offshore export cables between offshore substation platform/s and landfall, including the adjacent Offshore Temporary Works Area.
Offshore export cables	The cables which would bring electricity from the offshore substation platform(s) to the landfall. 220 – 230kV.
Sheringham Shoal Offshore Wind Farm Extension Project (SEP)	The Sheringham Shoal Offshore Wind Farm Extension onshore and offshore sites including all onshore and offshore infrastructure.
SEP offshore site	Sheringham Shoal Offshore Wind Farm Extension consisting of the SEP wind farm site and offshore export cable corridor (up to mean high water springs).
SEP onshore site	The Sheringham Shoal Wind Farm Extension onshore area consisting of the SEP onshore substation site, onshore cable corridor, construction compounds, temporary working areas and onshore landfall area.
SEP wind farm site	The offshore area of SEP within which wind turbines, infield cables and offshore substation platform/s will be located and the adjacent Offshore Temporary Works Area.
The Applicant	Equinor New Energy Limited

SUMMARY

Equinor New Energy Limited is leading the project to develop extensions to the existing Sheringham Shoal Offshore Wind Farm (SOW) and Dudgeon Offshore Wind Farm (DOW), known as the Sheringham Shoal Offshore Wind Farm Extension Project (SEP) and Dudgeon Offshore Wind Farm Extension Project (DEP). The export cables will run from an offshore substation(s) to a landfall at Weybourne, a distance of approximately 17.5km from the boundary of the SEP wind farm site. Of this distance, approximately 10km crosses the Cromer Shoal Chalk Beds Marine Conservation Zone (CSCB MCZ). Consideration of cable burial and any requirement for external cable protection within the MCZ is a key component of the environmental impact assessment (EIA) and the associated MCZ assessment.

The aim of this Interim Cable Burial Study (ICBS) is to consider the available geophysical, geotechnical and environmental information to identify the extent of the export cable corridor that passes through the MCZ that is likely to be able to be buried without the need for remedial external cable protection.

The ICBS has been informed by a preliminary Cable Burial Risk Assessment (CBRA) (PACE Geotechnics, 2020), which considers sea bed geology and the external risks to the cables including both natural, anthropogenic and environmental events in order to determine the recommended depth of lowering (burial). The CBRA establishes that the external risks to the cables are relatively low, with limited fishing activity and relatively light shipping traffic and no anchorages that might pose a hazard to cable integrity.

A geological assessment by the British Geological Society (BGS) (Dove and Carter, 2021) of the export cable corridor shallow sub-surface has also been undertaken, with the primary objective of mapping the “Top Chalk” and the “Top Peat” as well as general mapping of the subsurface units and sea bed characteristics. Alongside this, data from the existing SOW and DOW have been assessed to help draw comparisons between soil conditions and burial performance on those projects.

Consideration has also been given to the suitability of different trenching tools, with both ploughs and mechanical trenchers being considered suitable for the installation of the SEP and DEP export cables. The preferred plough type is a Sea Stallion (a non-displacement plough), based on the aggressive share rake angle and its successful record installing the nearby DOW export cables.

Based on the risk assessment in the preliminary CBRA, BGS geological assessment, comparisons with SOW and DOW and the available trenching tools, the ICBS concludes that a target burial depth of 1.0m to TOP is considered sufficient and suitable to obtain an acceptable level of protection along the export cable corridor and to achieve the required overall cable safety level. The actual required burial depth of the cables will vary along the route depending on the final selected cable corridor and soil conditions, which will be further assessed in the pre-construction phase.

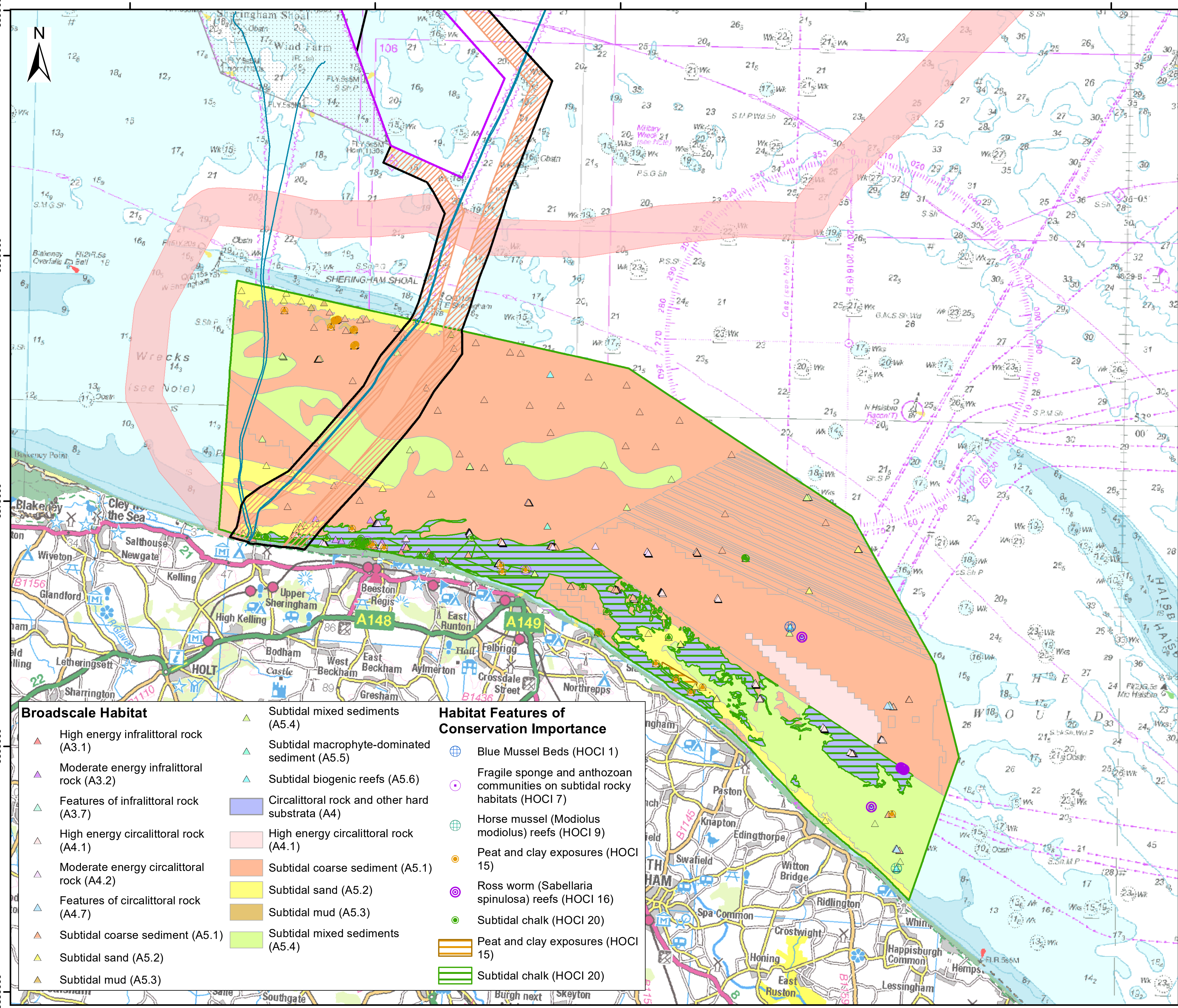
Pending the final route engineering studies that will be carried out pre-construction, the project has included a total allowance for remedial external cable protection of up to 100m for each of the two export cables where they pass through the MCZ (N.B this in addition to the 100m per cable required at the horizontal directional drilling exit points). The ICBS will

be further updated once interpretation of the 2021 geotechnical survey results has been completed.

INTERIM CABLE BURIAL STUDY

1 Introduction

1. Equinor New Energy Limited (the Applicant) is leading the development of SEP and DEP. The export cables will connect the wind farm sites to a landfall at Weybourne, a distance of approximately 17.5km from the boundary of the SEP wind farm site. Of this distance, approximately 10km crosses the CSCB MCZ.
2. This ICBS has been prepared to identify the extent of the export cable corridor that passes through the MCZ that is likely to be able to be buried without the need for remedial external cable protection. The ICBS forms part of the **Outline CSCB MCZ Cable Specification, Installation and Monitoring Plan (CSIMP)** (document reference 9.7), which has been produced to provide clarity on how and when information from detailed engineering studies undertaken prior to the start of construction will be used to inform the cable installation process, as well as how the works will be controlled by the Development Consent Order (DCO).
3. A final CSIMP will be submitted to the Marine Management Organisation prior to construction of SEP and DEP, and is secured in appropriate deemed marine licence (DML) conditions within the **Draft DCO** (document reference 3.1).
4. The study has considered the outcomes of the preliminary CBRA, BGS geological assessment, comparisons with the SOW and DOW export cable installation and the available trenching tools.
5. An overview of the export cable corridor and features of the MCZ area is shown in **Figure 1-1** below.



Sheringham Shoal and Dudgeon Extension Projects

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Figure 1-1 Overview of Export Cable Corridors and the CSCB MCZ Features

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Appendix 9.7.1: Interim Cable Burial Study

Application Doc. no.: 5.6

Legend:

- Sheringham Shoal Offshore Wind Farm Extension Project Wind Farm Site
- Offshore Cable Corridors
- Existing Offshore Wind Farm Export Cable
- Offshore Temporary Work Area
- Existing Offshore Wind Farm
- Cromer Shoal Chalk Beds Marine Conservation Zone (MCZ)
- Hornsea P3 Corridor

Coordinate Reference System: WGS 1984 UTM Zone 31N
Transformation WGS84: OSGB_1936_To_WGS_1984_7

0 4.5 9 km
0 2.5 5 Miles

Scale: 1:150,000 Scale at size: A3

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2 Site Description

6. Assessment of sea bed conditions is based on interpretations from the 2019 Gardline geophysical survey of the proposed SEP and DEP export cable corridor, as well as vibrocore and cone penetrometer test (CPT) logs and laboratory data from a 2013 GEO survey carried out in connection with investigations for the existing DOW export cables.

7. Water depths range from 27m (Lowest Astronomical Tide (LAT)) at the offshore end of the survey route to 0m LAT at the Weybourne landfall. Sea bed gradients are reported to be generally < 1°, but local higher slopes are associated with some sea bed bedforms. A bathymetric profile along the Weybourne route is shown in **Plate 2-1** with the seaward boundary of the CSCB MCZ at approximately kilometre point[1] (KP) 8.

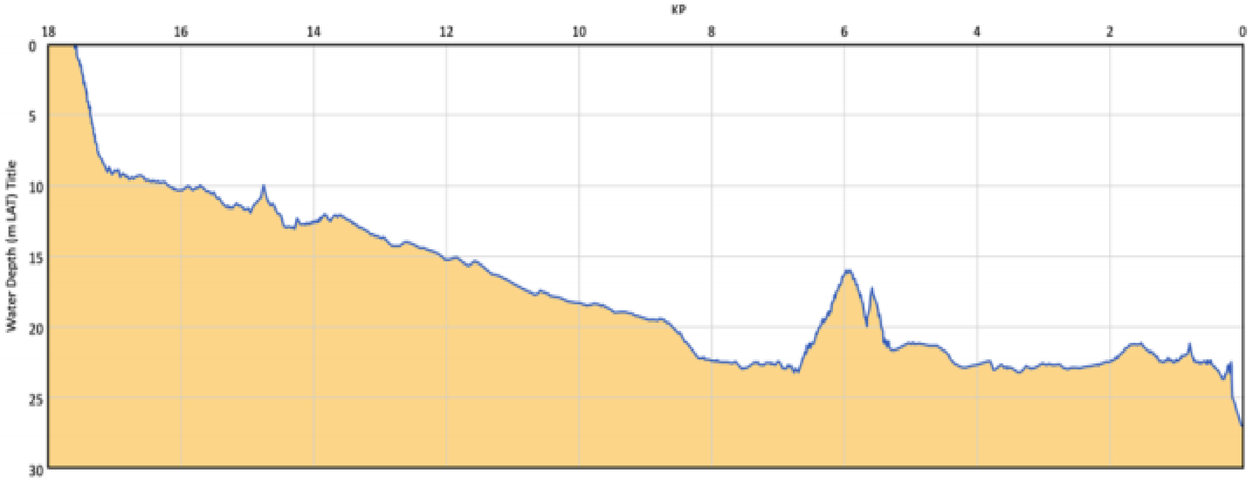

Plate 2-1: Bathymetric Profile Along SEP and DEP Export Cable Corridor

2.1 Sea bed Features

8. The following sea bed features have been interpreted along the wider export cable corridor:

- Sheringham Shoal, a sea bed high comprising thick sand sequences. The route crosses the southern tip of this feature between KP 5.35 and KP 6.35.
- Mega ripples 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. Mega ripples have amplitudes of 0.1m to 0.5m and wavelengths between 2m and 16m. Sand waves have heights up to 2m and may be either isolated features or have wavelengths between 25m and 150m. Gradients of up to 15° may be encountered on the sides of some of these bedforms.

[1] All KPs stated in this document are based on this definition i.e. the landfall at approximately KP18 to the SEP wind farm site at approximately KP0.

- Sea bed boulders. Sea bed boulders are reported with typical heights over sea bed ranging between 0.3m and 0.6m, with single larger contacts reported. The density of boulders increases from KP 10 and an additional increase in density occurs from KP 13.5.
- 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 gear. Magnetic anomalies on the tip of Sheringham Shoal are interpreted as a possible length of cable on the sea bed 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. Line actions of anomalies also correlate with the two existing Sheringham Shoal export cables.
- Wrecks. Two wrecks were identified during the survey operations at distances of 750m and 150m from the current route centreline.
- An 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.

2.2 Sea Bed Sediments

9. Sea bed 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, sand or Cretaceous chalk bedrock are expected. Beyond KP 17.23, the sea bed has been interpreted to be dominated by chalk outcrop, although available off-route geotechnical and environmental data suggests that a sea bed veneer of granular materials may also exist over most of this section.

10. The sedimentary processes operating in the CSCB MCZ have been assessed in Royal HaskoningDHV (2020). A layer of gravelly sand/sandy gravel is interpreted as a lag deposit on top of the subcropping chalk bedrock. The transport potential of this sediment layer is zero or very low. In areas characterised by Holocene sand the surface of the sand unit is mobile under existing tidal conditions, and so can erode, transport and deposit depending on the physical processes. The mobility of the Holocene sand is supported by the existence of megaripples across its surface in places. This indicates that there is a possibility that movement of this sediment may result in exposure or burial of the underlying geological units, including chalk. Given the thickness of the Holocene sands (generally up to 3m where it occurs from 500m to 4.5km offshore, and up to 2m, locally to 6m, in the seaward 2km of the cable corridor inside the MCZ), it would only be possible for movement of the feather edges (where the sediment is thin and could all move), to generate new sea bed substrate, including the potential to expose previously buried chalk if present directly below the sand layer without a static gravelly sand/sandy gravel layer in between.

11. The 2019 geophysical data indicates that areas where there is potential for subtidal chalk to be exposed are of very limited extent within the offshore export cable corridor.

12. A study has been performed by BGS with a scope of work to undertake a geological assessment of the shallow sub-surface for the export cable corridor for this project. The primary objective was to map the “Top Chalk” and the “Top Peat”. See further details in **Section 2.3**.

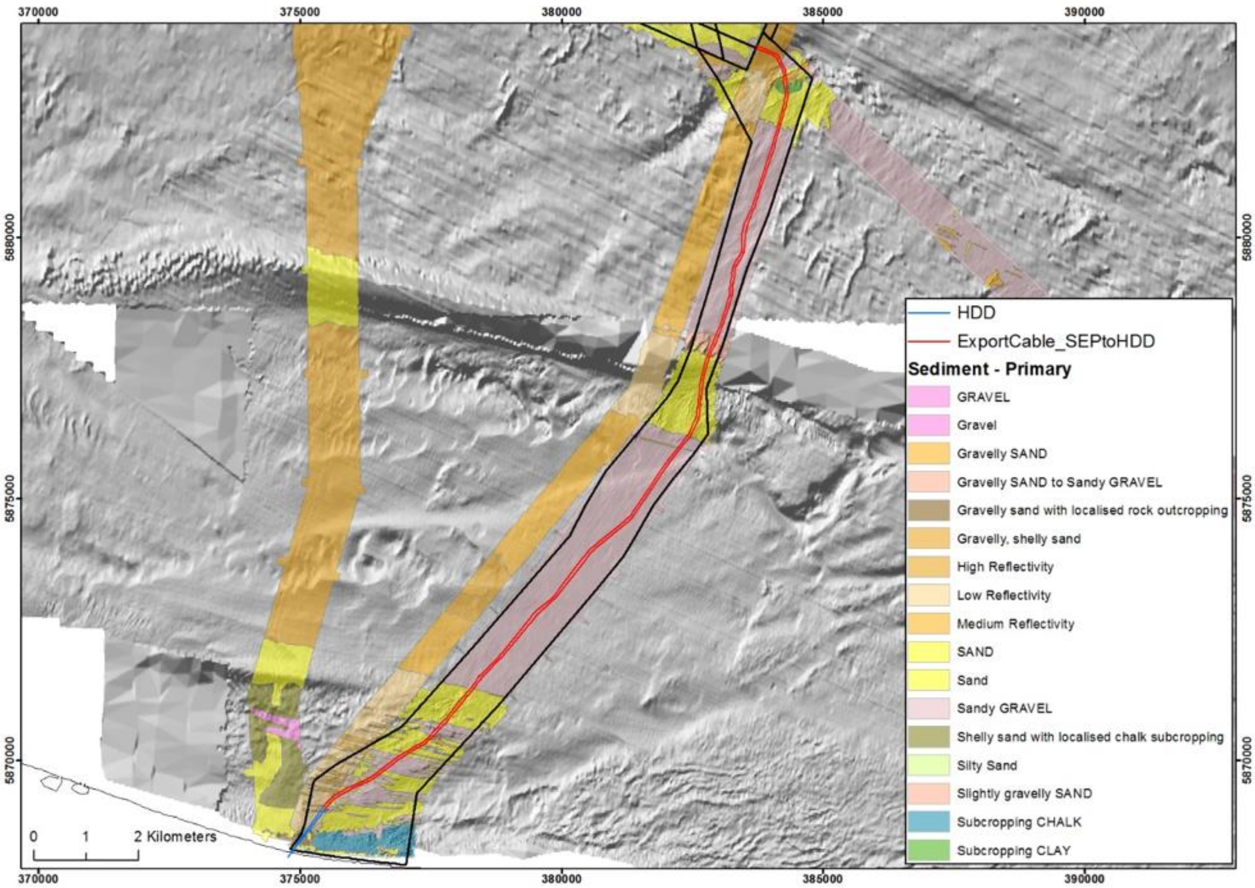

Plate 2-2: Sea Bed Sediment Distribution (Gardline, 2019) Along Indicative Cable Route

2.3 Geotechnical Properties

13. The geophysical survey carried out by Gardline in 2019 along the proposed SEP and DEP export cable corridor included Multi Beam Echo Sounder (MBES), Side Scan Sonar (SSS), Sub Bottom Profiler (SBP) and Magnetometer. No route-specific geotechnical data are presently available for SEP and DEP, however analysis is currently underway of geotechnical data collected in Q4 2021 with this document to be updated once the results are available. Off-route vibrocores (VCs) and CPTs were carried out by GEO in 2013 at 20 locations in connection with the development of the existing SOW and DOW. Results from thirteen of these locations, at distances between approximately 300 m to > 1,000 m to the export cable corridor, 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 corridor are shown in **Plate 2-3**.

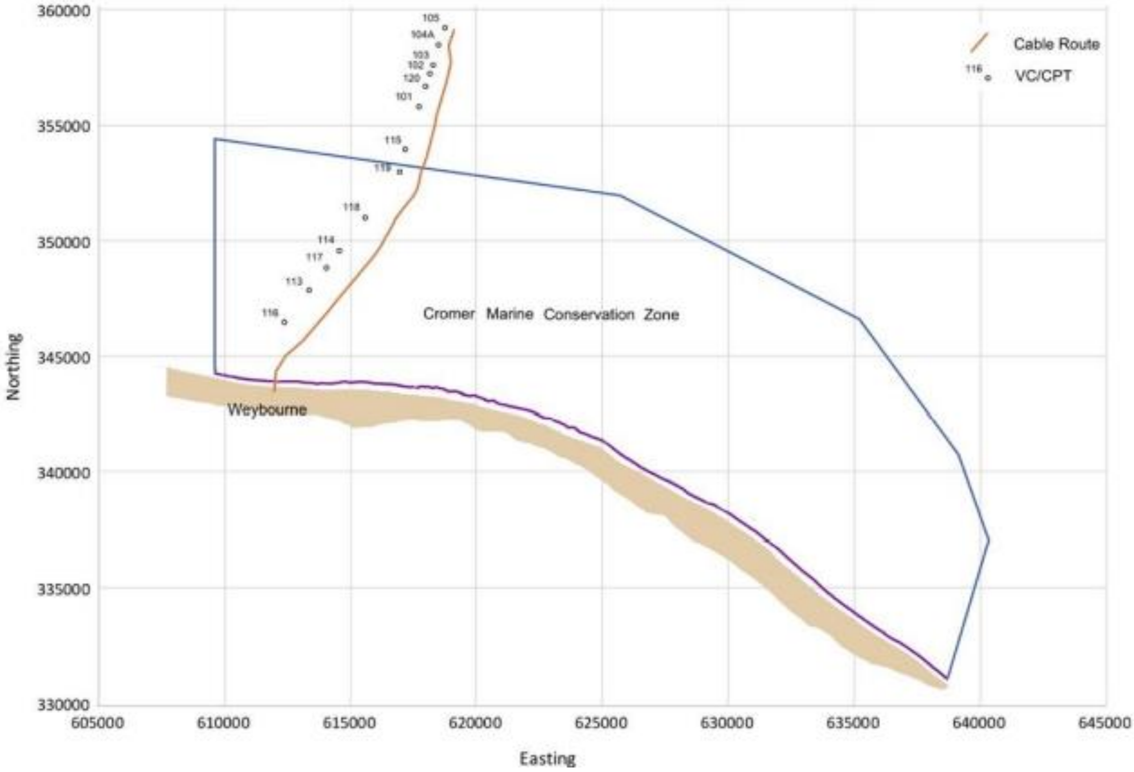

Plate 2-3: DOW Geotechnical Sampling Stations Relative to the Proposed SEP and DEP Export Cable Corridor

14. 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; and
- Chalk – Cretaceous chalk.

15. The expected geotechnical properties of these soil and rock units are discussed below and a summary of the geophysical interpretation of the route geology is presented in **Annex B Geophysical Interpretation**. Off-route VC and CPT 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 clays and sands underlying the Holocene, until somewhere between VC 113 and VC 116 (corresponding to approximately KP 13.5 and KP 15.1) when a change from Quaternary units to chalk is observed at depths relevant to trenching operations.

16. Subcropping chalk bedrock has been interpreted to be present extensively along the route within depths relevant to trenching, particularly on the nearshore portion of the route where the MCZ is crossed. From KP 8.45 to where trenching will be completed at the Horizontal Directional Drilling (HDD) exit point (at approximately KP 17), chalk is interpreted on the geophysical profiles to underlie the Holocene veneer and may form local or extended outcrop at sea bed. 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.

17. Previous BGS mapping (BGS, 1985, 1986; Cameron *et al*., 1992; in Dove and Carter, 2021) indicates Cretaceous chalk to be the only bedrock unit to be present along the full length of the export cable corridor, below a variable thickness of Quaternary and Holocene sediments. The quaternary sediment cover is of benefit to cable burial. Mortimore (2014) (in Dove and Carter, 2021) indicates that different chalk stratigraphic units may be encountered along the length of the cable corridor (**Plate 2-4**), and sampling of chalk within DOW suggests potential variability in chalk characteristics as a result of variable weathering (ranging from putty/rubble to high-density chalk) (Mellet *et al*., 2013; in Dove and Carter, 2021). It is noted that the shallow chalk platform also forms the basis for the recently established CSCB MCZ, with the chalk itself serving as a key benthic habitat where it is outcropping in the nearshore area.

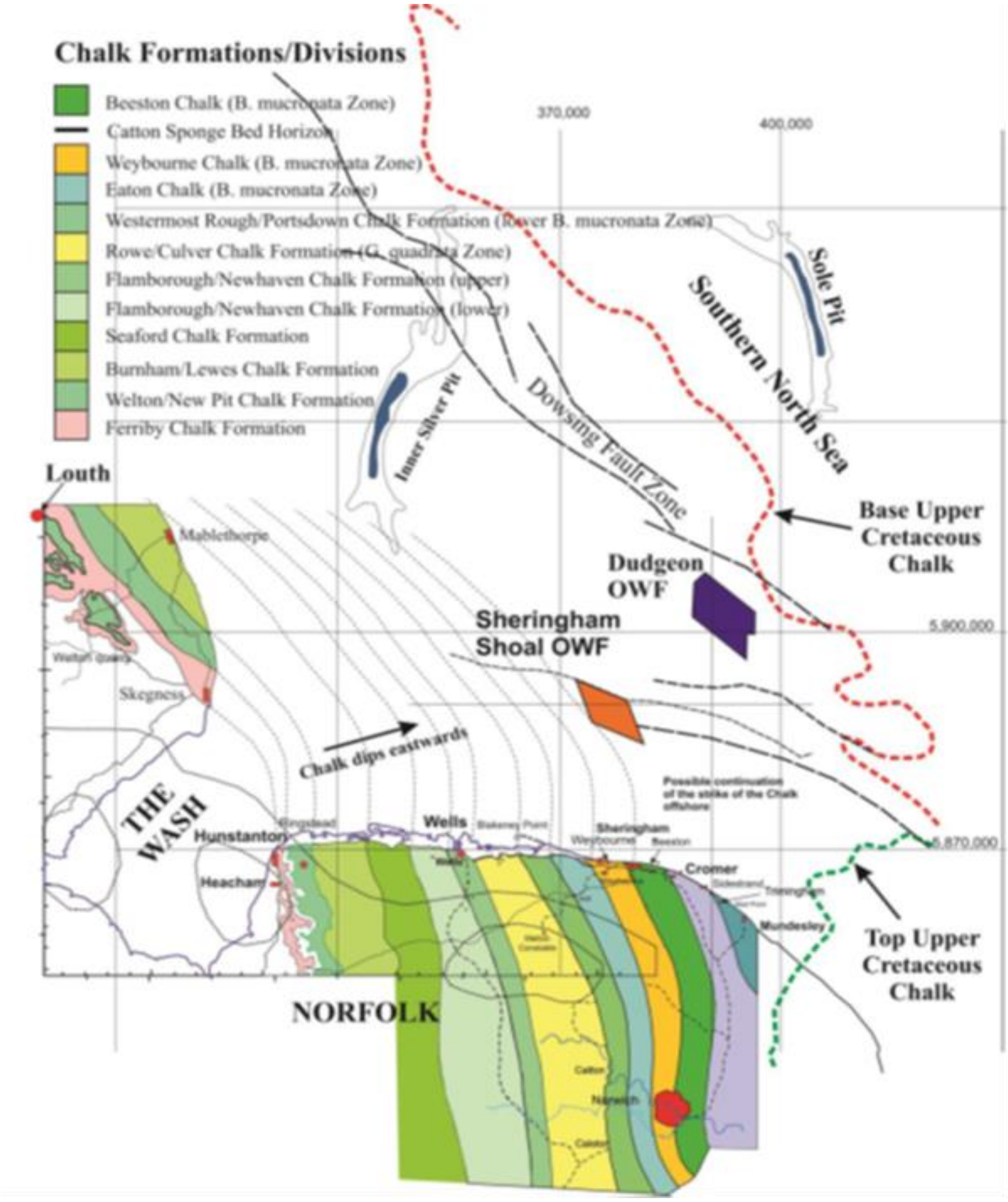

Plate 2-4: Project Offshore Chalk Stratigraphy by Mortimore (2014) (in Dove and Carter, 2021)

[redacted]

3 Burial Tools

18. To achieve the target cable burial depths, a variety of trenching techniques and tools are available. This section discusses both the suitability of the different techniques and comments on some specific trenching tools that may be available for use on SEP and DEP.

19. 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 also been developed. Water jetting includes a number of sub-categories such as Remotely Operated Underwater Vehicles (ROVs), mass flow excavators, jet sleds and vertical injectors. Mechanical trenchers comprise a cutting tool using rock picks to form the trench, mounted on either a chain or a cutting wheel. These methodologies and their suitability are discussed further below.

3.1 Ploughing

20. 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. 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 1,000m/hr or more in soft clays to 100m/hr in very stiff clays and very dense sands or even less in rock.

21. Normally it is not possible to make more than one ‘pass’ with a cable plough, therefore any sections that fail to meet burial specifications cannot be directly remedied using the plough. In such cases, protection by rock placement or jetting are the most common methods used for remedial protection. 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 cable integrity.

22. Ploughs are passive burial tools equipped with a ploughshare that engages the sea bed with the plough being towed by its host vessel across the sea bed to form a trench while burying the cable. They come in two main varieties: displacement and non-displacement. Displacement ploughs cut an open V shaped trench in the sea bed 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 backfilling pass is required. The process of forming a V shaped trench and returning the spoil into the trench disturbs a relatively wide corridor along the sea bed and may be considered to have a relatively onerous environmental impact. As such they are not preferred for this project.

23. In contrast, a typical non-displacement cable plough is illustrated in **Plate 3-1**, showing the ploughshare engaged. Some spoil does arise in this instance from the shearing action of the share but there is relatively limited disturbance caused, with the majority of sediment falling back into the trench as the plough progresses forwards and the cable is placed at the base of the trench within the share. These 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.

Plate 3-1: Example of a Non-Displacement Cable Plough (Photo Credit: Boskalis)

24. 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, infilling of the trench may occur quickly once the plough has passed. The depth of share engaged in the sea bed is controlled by hydraulically raising or lowering the front skids with most cable ploughs having at least 2m depth capability. Some of the latest ploughs can achieve a 3m 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 which would otherwise be needed to confirm burial depth.

25. The nature of the sea bed soils in the SEP and DEP export cable corridor, including subcropping chalk, is considered to require the use of either a mechanical trencher (see below) or a cable plough. Note is made that the adjacent DOW export cables were ploughed using a Sea Stallion non-displacement plough operated by VBMS (now Boskalis), as described below. A relatively consistent depth of between 1.5m and 2.0m was achieved along the route, with only nearshore sections having a burial depth of less than 1.0m. Given the expected predominance of subcropping 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.

3.1.1 Sea Stallion Non-Displacement Cable Plough

26. Non-displacement ploughs (shown in **Plate 3-2**) 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 DOW export cables. Examples are currently in the service of Boskalis. The ploughs benefit from a steeply raked share which has the advantage of pulling the plough aggressively into the sea bed and displacing the soil upwards, maximising the depth achieved. Tow forces are likely to be in the range 100 to 150 tonnes and depths in excess of 1.0m are achievable. As the cable is placed in the sea bed through the share, with good operating practices (avoiding excessive forward pitch) burial should be reliably achieved.

Plate 3-2: Sea Stallion Cable Plough (Photo Credit: Boskalis)

3.1.2 HD-3 Plough

27. HD-3 ploughs (shown in **Plate 3-3**) 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 sea bed. 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. 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 sea bed and this can result in the plough riding out if hard soils are encountered.

Plate 3-3: HD-3 Plough (photo credit: Prysmian Group)

3.2 Water Jet Trenching Tools

28. Jetting tools excavate a trench by directing jets of water at the sea bed. 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 sea bed 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 sea bed of cohesive material, the jetting process cuts through or erodes the sediments 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 in **Plate 3-4**.

Plate 3-4: Example of a Water Jet Trenching Tool (Photo Credit: Helix Energy Systems)

29. There is a large range of trenching ROVs on the market from relatively small cable maintenance machines with approximately 150 kilowatts (kW) installed power to much larger specialist pipeline trenching machines with up to 2 megawatts (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 sea bed, 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.

30. With jet trenchers, the cable is not picked up off the sea bed, which 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 sea bed, 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.

31. 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 approaches to shore 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 sea bed material that has built up around structures. Neither vertical injectors or mass flow excavators are considered appropriate for this project.

3.3 Mechanical Trenchers

32. Mechanical trenchers (example shown in **Plate 3-5**) 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 sea bed 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 sea bed, 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 that 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.

33. 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 25mm 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 sea bed types, typically operating in the 1.0 to 1.5m trench depth range. Progress is dependent on the strength of the sea bed 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.

Plate 3-5: Example of a Mechanical Trencher (Photo Credit: DeepOcean)

34. Mechanical chain trenchers (as shown in **Plate 3-5**) 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 1.5m to 3.0m depth. 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.

35. As noted above, mechanical cutters are most suited for 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.

3.4 Hybrid Trenchers

36. Hybrid trenchers (as shown in **Plate 3-6**) 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.

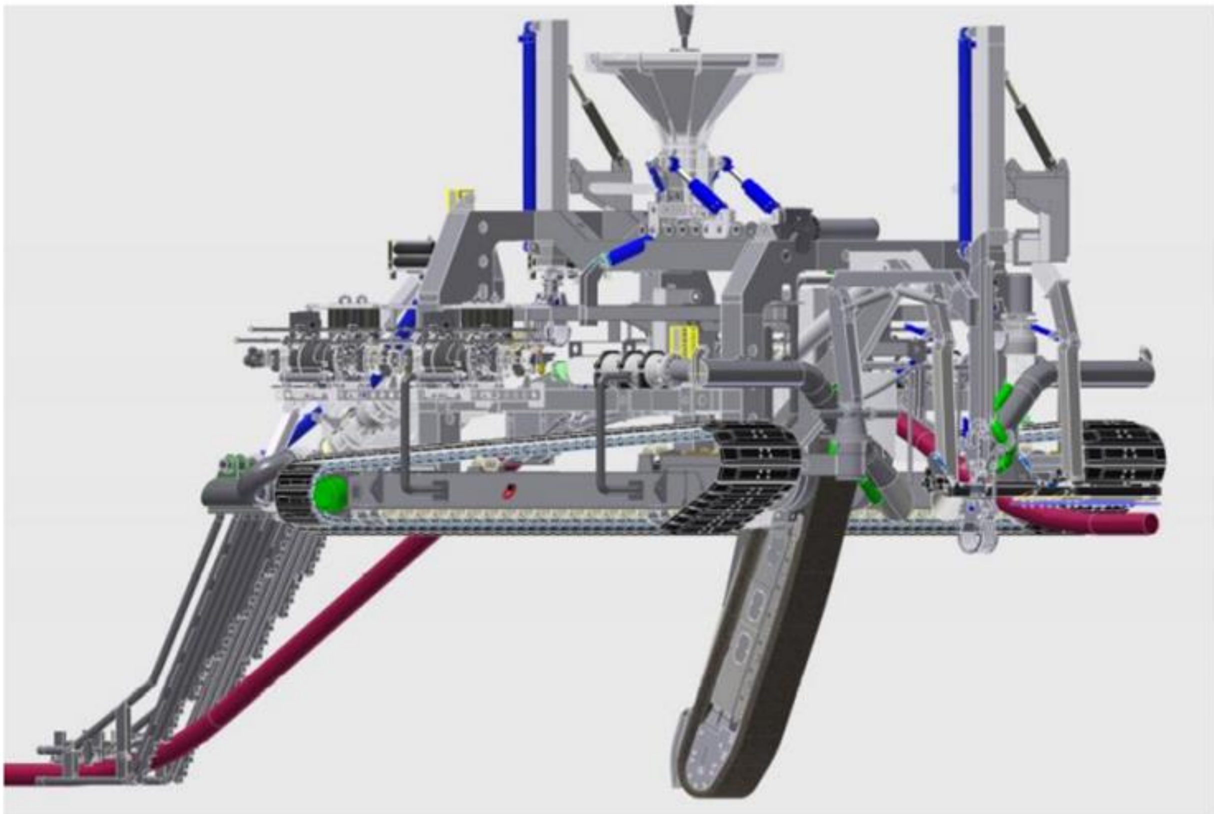

Plate 3-6: Example of a Hybrid Trencher (Photo Credit: Boskalis)

3.4.1 Q Series Trenchers

37. The Q1400 and Q1600 trenchers (example shown in **Plate 3-7**) were developed by SMD, with two Q1400s being operated by Global Marine Systems, and Van Oord operating a Q1600 machine. The tools are designed around a cutting chain which can be interchanged for a jetting system. 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 to change the equipment from cutting to jetting mode.

Plate 3-7: Q Series Trencher (Photo Credit: Van Oord)

3.4.2 SMD Cable Burial Tractors (CBT) / Hybrid Trenchers

38. SMD have built a series of hybrid trenchers, generally referred to as CBT ranging from the T2 built in the 1990s and now operated by Enshore, through to CBT1100 and CBT1200 (one is now named SeaRex and operated by Prysmian, (**Plate 3-8**)), to CPT2400 recently built by SMD for Boskalis. T2 has a power output of approximately 700 horsepower (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 along the SEP and DEP export cable corridor, T2 may prove slightly underpowered, and CBT2400 has ample power.

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

Plate 3-8: Cable Burial Tractor/Hybrid Trencher (Photo Credit: Prysmian Group)

3.4.3 Helix Robotics Solutions i-Trencher

40. The Helix i-Trencher (**Plate 3-9**) was originally built as a pipeline trencher but is now mainly used for cable trenching. It has a centrally mounted chain cutter with educators to remove spoil. It is well capable of forming the trench having approximately 1,700 hp and has successfully trenched in rocky sea bed 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 should be required.

Plate 3-9: Helix Robotics Solutions i-Trencher (Photo Credit: Helix Energy Systems)

3.4.4 T3200

41. The T3200 (**Plate 3-10**) is one of the largest trenchers currently available with a track record of trenching in chalk on the Race Bank Offshore Wind Farm (OWF) export cable corridor 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 export cables for SEP and DEP. The trencher is also able to jet while cutting, in a manner similar to the hybrid machines discussed above.

Plate 3-10: T3200 (Photo Credit: DeepOcean)

[redacted]

4 Preliminary Ranking of Burial Tools

42. A selection matrix (**Table 4-1**) was developed to assist with the initial evaluation of the available trenchers described in **Section 3** taking account of the conclusions of the CBRA (PACE Geotechnics, 2020) (**Table 4-2**). The matrix 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. It should be noted that at this stage the selection matrix has only considered technical and environmental aspects of the trenchers; commercial factors have not been considered.

43. It can be seen that the top scoring trencher is the Sea Stallion non-displacement plough. This is due to a combination of factors including the limited footprint on the sea bed, the expectation that the trench will largely infill (as evidenced by the DOW export cables post-construction monitoring (MMT, 2018a-c)) and the proven capability in the same sea bed soil types. The T3200 and i-Trencher are the next highest scorers. Their ability to trench in the anticipated sea bed conditions and track record assist their scores, but the relatively large footprint and the potential dispersion of soil over a wider area are potentially negative factors. The HD-3 ploughs are likely to be effective tools, but the depth may be impacted in subcropping 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 subcropping chalk and particularly flint, an open trench and the lack of known track record performing in similar conditions.

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

45. Ploughs may be a viable option where subcropping chalk is present at a trenchable depth provided it is weathered (weathered chalk strata is found sub-cropping close to sea bed, presumably resulting from repeated exposure during Quaternary glacial/sea level cycles). In general, 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 sea bed will have a similar footprint to a trencher's tracks. However, it is noted that sea bed disturbance from a plough is likely to be reduced compared to a mechanical trencher. Non-displacement ploughs 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. Where ploughs are used 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 is due to the fact that in these granular substrates, the substratum is disturbed but not completely displaced as would be the case with alternative burial techniques. Therefore, the fact that the majority of the disturbed sea bed material will be redeposited within or in the immediate vicinity of the trench (rather than being ejected in the case of a mechanical trencher) means that the recovery time of the sea bed is likely to be reduced, thus reducing the overall environmental impact.

Table 4-1: Burial Tool Selection Matrix

Item No.	Criteria		Trencher							Comments
		Weighting	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 is chalk in 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 sea bed	2	3	3	3	3	2	2	1	Footprint will affect the environmental impact
5	Dispersal of spoil	1	4	4	3	3	2	2	1	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

Item No.	Criteria		Trencher							Comments
		Weighting	Sea Stallion	HD-3	Q-Trencher	SeaRex	CBT2400	i-Trencher	T3200	
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 4-2: Advantages and Disadvantages of Different Cable Trenching and Protection Techniques (PACE Geotechnics, 2020)

Technique	Sediment Type where this equipment is utilized	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 sea bed resulting from front skids; and • Potential to create side berms along the trench from displaced spoil.
Jet Trenchers	• Sands, 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 sea bed resulting from tracks (5 – 10m 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 sea bed resulting from wide tracks associated with this equipment type (5 – 10m wide)

Technique	Sediment Type where this equipment is utilized	Environmental Advantages	Environmental Disadvantages
Protection Measures			
Surface Lay with no Protection	• Hard substrates which prohibit cable trenching.	• Lower sea bed disturbance with no removal of substratum necessary; and • No sediment resuspension.	• Risk to other sea users (anchoring) or fishing activities; • Risk to cable integrity; and • Potential abrasion to sea bed surface in mobile environments.
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 sea bed / sediment type. This will increase the footprint of the infrastructure to approximately 6m wide; and • 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 sea bed footprint (approximately 0.5m 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.

5 Experience from Sheringham Shoal and Dudgeon

46. Export cable burial on the SOW was performed by two different jetting tools and in some areas required several passes of the tools in an attempt to achieve that project’s 1.0m target burial depth. In some limited areas of stiff soil conditions, target burial depth was not achieved, with the result of shallow burial depth to 0.3m. However despite this, no remedial external cable protection (e.g. rock placement or similar) was used because 0.3m depth was achieved after several passes of the jetting tool. In this specific case this was considered acceptable as this was in an area of subcropping chalk (with the associated stiff soil conditions increasing the degree of protection to external risks such as anchors). Ongoing geophysical monitoring (e.g. Fugro, 2021) shows that the cable trenches are still visible in a number of discrete locations where burial conditions were challenging and where sea bed sediments are not being rapidly reworked under natural processes.

47. In contrast, export cable burial at DOW was performed by simultaneous laying and burial (SLB) with the vessel Stemat Spirit and the non-displacement plough Sea Stallion. The target burial depth (TOP) for Dudgeon was 1.0m.

48. The DOW export cable corridor and burial performance has been revisited as part of preparing this ICBS, with a particular focus on the area of potential shallow subcropping chalk. Geotechnical conditions found within first 13km from the beach consist of the mixed sediments and anything from clay, sand, clay till, chalk and limestone.

49. Experience from DOW shows that reduction in ploughing speed was influenced by chalk sediments, medium sand, clay till and limestone. In some areas, strength reported within the first 1m reached peaks of 600 kPa. The DOW export cables were successfully installed in 93% of the area where the target depth of 1.0m TOP was reached. Within the first 13km of the route (from the HDD exit, i.e. within the MCZ), 0.5m TOP was reached in nearly 100% of the area (and again no remedial external cable protection was used).

50. Post-construction monitoring of the DOW export cables (e.g. MMT, 2018a-c) confirms that the persistent trenches observed on parts of the Sheringham Shoal route have not been created, noting the difference in installation methodologies as described above.

6 Risk Assessment

51. Based on the information set out above, it is considered likely that the burial level achieved for the Dudgeon cables can also be achieved for the SEP and DEP cables. However, some local variations can be expected since soil data within the areas concerned can vary within short distances. As such, the CBRA will be updated once data from location specific soil (geotechnical) investigation is available for the SEP and DEP export cable corridor. Together with integration with the existing geophysical data, this will be used to confirm the presence of subcropping chalk and other sediments at trenchable depths.

52. A micro-siting exercise will be undertaken at the pre-construction stage to maximise the avoidance of areas challenging to cable burial. A preliminary assessment of the feasibility of micro-siting has been undertaken using the existing geophysical data. This has included interpretations of the subcropping chalk depth and clearly indicates the potential to select a route within the export cable corridor that minimises interaction with the areas considered to be most challenging to cable burial (shown in red on Error! Reference source not found.). A further route update will be performed when the interpretation of the 2021 geotechnical survey data has been completed.

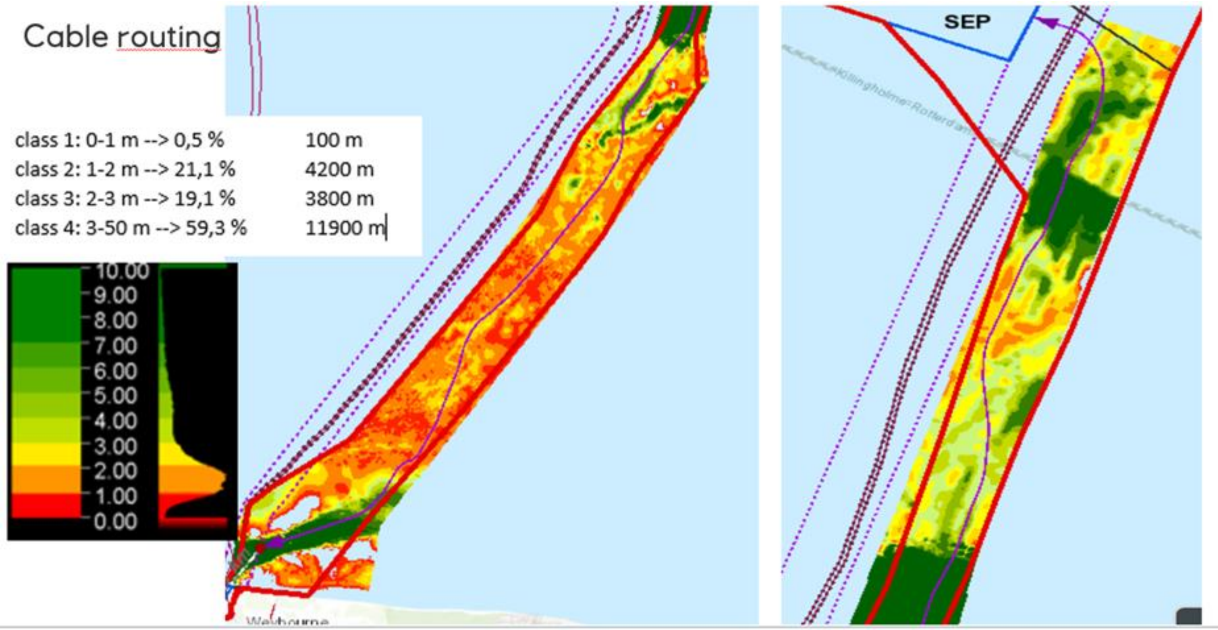

Plate 6-1: Preliminary SEP and DEP Export Cable Routing Showing Micro-Siting Potential based on Chalk Depth Interpretations

53. Where appropriate, a reduced burial depth, taking account of the preliminary CBRA outcomes, may also be considered.

54. The preliminary CBRA takes into account levels and types of marine traffic crossing the export cable corridor (**Plate 6-2**). This shows that the highest density of cargo vessels crosses the sector KP 8.5 – 12, which is inside the MCZ. The spreadsheet at **Annex A Burial Depth** show the probabilities of cable damage from dropped anchors from crossing vessels for segments along the export cable corridor. The preliminary CBRA was based on DNV recommendation, and used an acceptable total risk level within category 2 or better. However, this is considered on a whole route basis to provide an overall acceptable risk level for the export cables, rather than at specific locations.

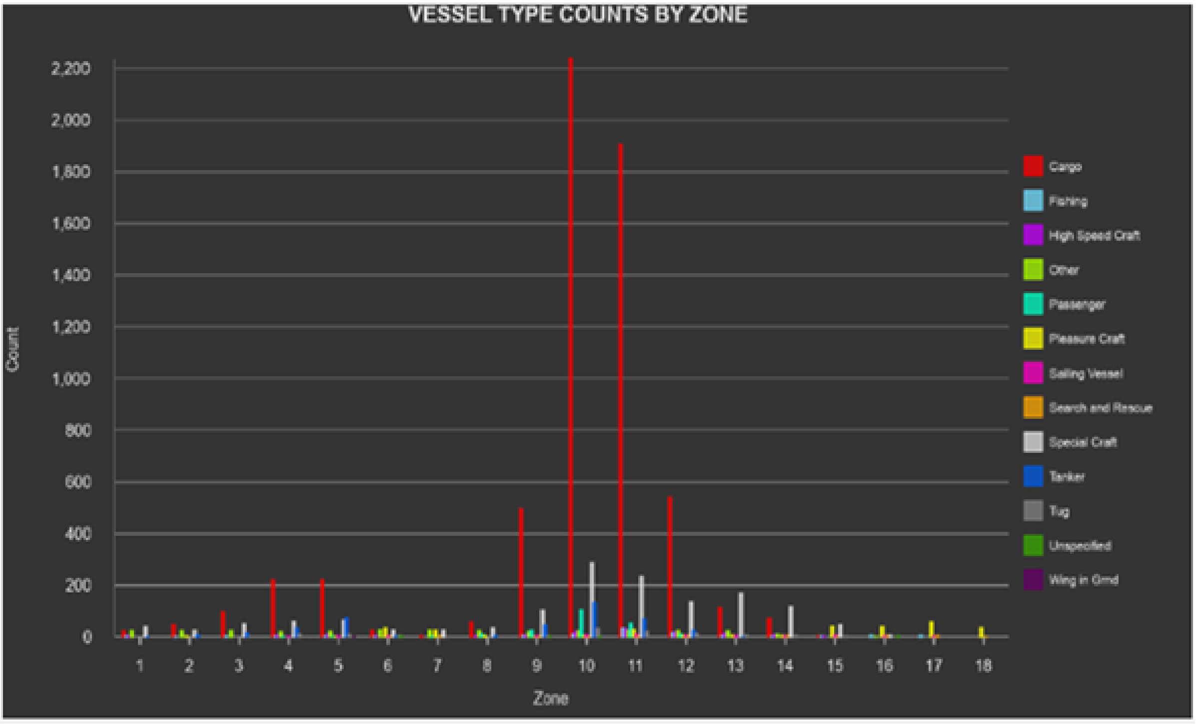

Plate 6-2: Vessel Type Counts by Zone within MCZ (PACE Geotechnics, 2020)

55. Notably, **Annex A Burial Depth** and the preliminary CBRA show that the export cables can be buried to 0.3m TOP inside the MCZ without the need for external cable protection, providing that the cables are buried to minimum 1.0m TOP outside of the MCZ. The final decision for target burial depth along the MCZ and the preferred cable burial tool will be informed by the outcome of the 2021 geotechnical data interpretation, which is ongoing. The use of external cable protection could be required if a target burial depth is not achieved. Experience from DOW shows that this is unlikely and therefore a maximum 100m for each SEP and DEP export cable can be assumed for remedial burial purposes.

7 Remedial External Cable Protection Quantity

56. Based on a geophysical survey of the export cable corridor from the landfall to the SEP wind farm site, sea bed features and sea bed sediments have been interpreted as described above. Together with the lessons learnt from burying the export cables at the SOW and DOW and some geotechnical samples from DOW, it is considered likely that the burial level achieved for the DOW cables can also be achieved for the SEP and DEP export cables along the entire route. Further interpretation of geotechnical data and pre-construction route engineering will be undertaken to verify this assumption, and to reconsider the preferred cable burial tool based on the latest information at the time.

57. At this stage, the available data including the BGS soil interpretations, indicate that a total allowance for remedial external cable protection of up to 100m per cable is appropriate, in the event that challenging burial conditions are experienced. This quantity has been minimised through the commitment to HDD out to a point that allows for complete avoidance of the outcropping chalk feature in the nearshore area between KP 17 – 17.7.

8 References

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Annex A: Burial Depth

Anchor Risk Calculation

	Kp	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0.0	
								end OF MCZ										HDD exit	Landfall	
	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
Adjusted as per interpolation	Dominant Soil Type	SAND	SAND	SAND	SAND	SAND	SAND	SAND	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	SAND	CHALK	
DOL = DOP + a margin	Selected DOL (m)	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,0	
	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	9,29E-08	0,00E+00	3,68E-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	10 767 697	0	272 043
	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

High density of vessel crossing (cargo vessels)

Adjusted as per interpolation	Dominant Soil Type	SAND	SAND	SAND	SAND	SAND	SAND	SAND	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	SAND	CHALK	
DOL = DOP + a margin	Selected DOL (m)	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	0,5	0,0	
	Total Probability (1/yrs)	7,21E-07	1,26E-06	2,37E-06	4,95E-06	5,27E-06	9,31E-07	5,14E-07	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	1,12E-04
	Overall Return Period (yrs)	1 386 688	795 216	421 176	202 211	189 686	1 074 243	1 946 774	596 718	98 133	26 828	34 246	105 258	219 771	378 365	1 679 413	4 463 076	10 767 697	0	8 932
	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

Adjusted as per interpolation	Dominant Soil Type	SAND	SAND	SAND	SAND	SAND	SAND	SAND	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	CHALK	SAND	CHALK	
DOL = DOP + a margin	Selected DOL (m)	1,0	1,0	1,0	1,0	1,0	1,0	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,5	0,0	
	Total Probability (1/yrs)	0,00E+00	1,16E-07	2,63E-07	1,03E-06	4,83E-07	0,00E+00	5,14E-07	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	9,84E-05
	Overall Return Period (yrs)	0	8 640 117	3 805 946	966 616	2 069 287	0	1 946 774	596 718	98 133	26 828	34 246	105 258	219 771	378 365	1 679 413	4 463 076	10 767 697	0	10 167
	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 2

Annex B: Geophysical Interpretation

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

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)
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			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	
							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