

Norfolk Vanguard Offshore Wind Farm

The Applicant's

Response to the

Request for Additional

Information

Appendix 3 Review of Cable Installation, Protection Mitigation and Habitat recoverability

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Appendix 3 Review of Cable Installation, Protection Mitigation and Habitat recoverability. Commissioned by the Crown Estate

4. This appendix is a report that was commissioned by The Crown Estate and written by RPS. It has been submitted as a sperate document.

REVIEW OF CABLE INSTALLATION, PROTECTION, MITIGATION AND HABITAT RECOVERABILITY

The Crown Estate



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Prepared by:

Prepared for:

RPS

Kevin Linnane
Principal Marine Consultant

Unit 10, Beaufort Park, Riverside Court
Chepstow, Monmouthshire NP16 5UH

T +44 (0) 1483 746 500

E

The Crown Estate

Ed Salter
Marine Consents Manager

1, St. James's Market
London, SW1Y 4AH

T +44 (0) 20 7851 5225

E

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Acronyms

Acronym	Definition
AIS	Automatic Identification System
ALARP	As Low As Reasonably Practicable
BAS	Burial Assessment Study
BEIS	Business Energy and Industrial Strategy
BGS	British Geological Survey
CAPEX	Capital Expenditure
CBRA	Cable Burial Risk Assessment
CLV	Cable Lay Vessel
CPT	Cone Penetration Test
CS	Case Study
DOB	Depth of Burial
DOC	Depth of Cover
DoL	Depth of Lowering
DP	Dynamic Positioning
EIA	Environmental Impact Assessment
EPC	Engineering, Procurement and Construction
ESCA	European Subsea Cables Association
FOI	Freedom of Information
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
JNCC	Joint Nature Conservation Committee
KP	Kilometre Point
MDE	Marine Data Exchange
HRA	Habitats Regulations Assessment
MALSF	Marine Aggregates Levy Sustainability Fund
MarESA	Marine Evidence based Sensitivity Assessment
MarLIN	Marine Life Information Network
MBES	Multibeam Echosounder
MFE	Mass Flow Excavator
MMO	Marine Management Organisation
NRW	Natural Resources Wales
OFTO	Offshore Transmission Owners
OPEX	Operating Expense
PLGR	Pre-lay grapnel Run
PLB	Post Lay Burial

REPORT

Acronym	Definition
RBBD	Risk Based Burial Depth
ROV	Remotely Operated Vehicle
SLB	Simultaneous Lay and Bury
SSS	Side Scan Sonar
TCE	The Crown Estate
TSHD	Trailing Suction Hopper Dredging
UXO	Unexploded Ordnance

Units

Unit	Definition
cm	Centimetre
kg	Kilogram
km	Kilometre
kPa	Kilopascal
mm	Millimetre
m	Metre
m ²	Metre Squared
N	Newton
Pa	Pascal
T	Tonne

EXECUTIVE SUMMARY

Background and Introduction

The Crown Estate (TCE) commissioned RPS to undertake a desk study to collate information on offshore electrical cable installation techniques and seabed recovery, in support of the Plan Level Habitats Regulations Assessment (HRA) for Offshore Wind Leasing Round 4. The main driver for this study was a concern that there is a lack of collated information on cable installation techniques used to install power cables in the offshore marine environment. A concern has also been raised by stakeholders about the use of cable protection (e.g. placement of rock and mattresses). Stakeholders had further noted that there is a paucity of information on impacts on seabed habitats from cable installation and the recoverability of these habitats. This study was therefore divided into two broad sections:

- Effectiveness of Cable Installation and Cable Protection; and
- Environmental Impacts and Recovery.

As this study has been undertaken to inform the Plan Level HRA for the next round of offshore wind leasing, many of the conclusions will be relevant to future cabling projects within those Marine Protected Areas (MPAs) with seabed features which may be impacted by subsea cabling (particularly Special Areas of Conservation; SACs). The recommendations made within this report have therefore been developed for projects which involve cabling within SACs, although some could equally be applied to other areas where cabling is a particular concern (e.g. Marine Conservation Zones (MCZs)).

Effectiveness of Cable Installation and Cable Protection

To determine the effectiveness of cable installation techniques, RPS collated and reviewed information on the techniques used to install cables in subtidal environments, using best practice guidelines and recent experience in the offshore wind and interconnector industries. This information was supplemented by information requested (via a questionnaire) from offshore wind and interconnector developers on installed export cables within a defined study area. The aim of this data collation and review exercise was to assess the relative effectiveness of the cable installation methodologies within the different ground conditions present across the study area, with a view to answering three key questions of the study:

- To what degree is success of cable burial driven by ground conditions?
- Are cable protection requirements site specific (i.e. dependant on ground conditions), or do other factors influence whether these are required?
- Can detailed information on ground conditions be used pre consent to accurately establish cable burial and cable protection assumptions within consent applications?

The study was limited by a low level of response to the questionnaire relative to the number of projects where information was requested, and the limited project information provided in those questionnaire responses. However, the questionnaire responses were supplemented by a review of publicly available data sources to ensure that conclusions could be made with respect to the effectiveness of cable installation techniques.

Across the study area, the data indicated successful cable installation across most areas, with non-burial cable protection (largely comprising rock or concrete mattresses) used over very small proportions of the cables installed (i.e. <3% of all export cables considered in the study area). A number of installation tools were used across different ground conditions, with cable plough by far the most frequently used throughout the study area. In most of the case study areas, these installation tools were supported by remedial burial operations following the initial installation phase, with the aim of achieving the target depth of burial to protect the cable. Based on the information reviewed and the assessment completed by RPS, the following conclusions could be made with respect to cable installation techniques (in response to the three questions asked above).

To what degree is success of cable burial driven by ground conditions?

The success of cable installation is driven by ground conditions, as an understanding of the ground conditions is key to the selection of the most appropriate tool for cable burial. However, there are a number of other factors which may influence tool selection and/or the success of a cable installation campaign, including anthropogenic risk in the vicinity of the cable route (e.g. fishing activity and anchoring), seabed mobility, environmental considerations and the contracting mechanism for the cable installation campaign.

Are cable protection requirements site specific (i.e. dependent on ground conditions), or do other factors influence whether these are required?

Cable protection requirements are split into two main cohorts, those that involve burial activities (e.g. jet trenching) and those that are non-burial protection techniques (e.g. rock placement). In cases where installation of the cable has not been fully successful, some form of remedial action may be undertaken to protect the cable. As with cable installation success, the choice of cable protection (i.e. either burial or non-burial) will largely be driven by the ground conditions, e.g. the ability to undertake remedial burial will depend on the presence of sediments which can be mobilised to bury cables which were insufficiently buried during the initial installation campaign. However, other factors may also influence this, including the principal installation method, equipment and scope of the contract with the Engineering, Procurement and Construction (EPC) contractor. For non-burial protection, the type of protection measure used (e.g. mattresses, rock placement or tubular products) will also be highly site specific, and dependent on factors such as local ground conditions (e.g. potential for scour), water depth and hydrodynamic regime, as well as the risk to the cable from anthropogenic activities (e.g. fishing and anchoring).

Can detailed information on ground conditions be used pre consent to accurately establish cable burial and cable protection assumptions within consent applications?

It was concluded that further information on ground conditions may be of value in consent applications, particularly in areas where cabling is of concern to stakeholders. This may be particularly the case in MPAs, where the level of detail required to inform assessments may be higher to fulfil the requirement of the relevant assessment process (e.g. HRA). As such it was recommended that additional engineering input during the consenting process would be useful to help address stakeholder concerns. This may extend to development of a preliminary Cable Burial Risk Assessment (CBRA), or similar process, which develops a preliminary ground model and identifies risks to cables (e.g. fishing and anchoring) across the cable route. However, there are risks associated with undertaking very detailed engineering studies too early in the development process (e.g. Burial Assessment Study; BAS) which may lead to over-specification of installation tools, which would have negative implications for buildability, cost efficiency and potentially environmental receptors (e.g. use of non-burial protection due the most appropriate tools not having been consented).

Further discussion on the recommendations made by this study, including possible information requirements for future consent applications or post consent, are summarised below (and discussed in detail in Section 5).

Environmental Impacts and Recovery

To meet one of the key aims of the study, which was to improve the evidence base on impacts and recoverability of habitats, a detailed review was undertaken of the available evidence on the effects of cabling on subtidal seabed habitats (i.e. physical sediments/substrate and biological communities/habitats). This was undertaken based on publicly available information sources, including monitoring data from offshore wind farms constructed in the UK and focussed on effects of cabling on subtidal seabed habitats. The aim of this part of the study was to:

- Consider the overall evidence base with respect to seabed impacts and recoverability to support future consent applications;
- Identify any data gaps and potential requirements for further study; and
- Identify proposals for good working practices during and after cable installation.

The data reviewed was primarily drawn from geophysical monitoring reports available through the Marine Data Exchange (MDE). One of the main limitations of this study was that the majority of the reports reviewed have not focussed specifically on the recovery of seabed habitats or morphology following cable installation, with only a few exceptions (e.g. Humber Gateway and Race Bank). These geophysical datasets were scoped for a range of reasons, usually related to asset integrity, e.g. monitoring of scour effects around turbines and cable protection, cable integrity monitoring etc., and not for the specific purpose of assessing the recovery of the seabed or seabed sediments. Information was lacking on the sediment composition within cable trenches observed in geophysical datasets with only a small number of monitoring reports including geophysical interpretation of these and no ground truthing (e.g. via seabed imagery) of the sediments within the trenches. Similarly, there was little or no data on benthic communities within cable trenches, with most benthic ecology survey effort focussed on the wider cable corridor (i.e. indirect effects of cabling).

Overall Evidence Base with Respect to Seabed Impacts and Recoverability

Notwithstanding the limitations above, a large number of survey reports were reviewed, and the evidence reviewed as part of this project indicated that Environmental Impact Assessment (EIA) predictions largely align with the monitoring data that is available on seabed impacts and recovery and historic industry evidence reviews (e.g. BERR, 2008; MMO, 2014; RGI, 2015). The monitoring data collated for the current study indicates that cabling results in disturbance to seabed sediments, with the level of initial disturbance dependent on the tool used (e.g. cable ploughs typically result in minimal displacement of sediments beyond the cable trench, while jetting may result in a greater sediment displacement). For most of the projects reviewed, monitoring data has shown that cable installation has resulted in trenches being recorded on the seabed in the geophysical datasets, although the proportions of the cable lengths where these remnant trenches were observed was variable across the projects. The monitoring data also showed that where these trenches were recorded, they infilled over time and that where these are present on the seabed after a number of years, the large majority of trenches are shallow depressions on the seabed (e.g. up to a few 10s of cm). In a small number of cases, more profound changes in seabed sediments/substrates were recorded (e.g. clay exposures in the Humber Gateway export cable), but for soft sediment habitats, there was clear evidence of recovery across a variety of sediment types and installation tools.

Little or no benthic ecology data were available from within the direct disturbance areas (with the exception of seabed imagery data for Humber Gateway), either in the form of seabed sediment sampling or seabed imagery. However, based on information from the analogous industries, it has been reported that benthic communities associated with soft sediments (e.g. muds, sands and gravels) readily recover into areas if the sediment type is reflective of the baseline environment. Therefore, assuming the sediment composition within these shallow trenches is similar to the surrounding sediments, recovery of communities will also occur (as evidenced from other industries, e.g. aggregates).

Data Gaps and Potential Requirements for Future Study

The monitoring data reviewed presented little or no information on the effects of cable protection either on the seabed or on associated benthic ecology communities (e.g. colonisation of installed protection measures). There were a few exceptions, including one example of a cable crossing rock berm where shallow water and a mobile sediment transport regime resulted in a large scour pit adjacent to the cable crossing. This indicates that while minor scouring around cable protection may not have significant implications for seabed habitats and benthic communities, in certain circumstances, scour can be severe, with larger (although in this case highly localised) effects on seabed sediments and habitats.

The main data gap identified in the monitoring review was in relation to the effect of cable protection on benthic communities, e.g. colonisation of artificial substrate, with no monitoring data identified from the UK continental shelf. This is a clear knowledge gap in monitoring data from UK offshore wind farms to date. Placement of cable protection results in a change in the substrate/sediment type, and the direct effects of this change on benthic communities is poorly understood. As such, EIAs take a conservative approach and typically assume that this represents long term habitat loss, with a complete loss of ecological function in the areas affected. While the placement of cable protection (and scour protection) will clearly lead to a change in the substrate type, the effect of this change will depend on the sediment/substrate type of the receiving environment (e.g. in a sediment habitat this may result in a shift from a benthic community dominated by infaunal assemblages to one dominated by epifaunal assemblages). However, in certain circumstances (e.g. areas of rocky substrate or coarse sediments), the use of certain types of cable protection may limit the change of the substrate, therefore allowing some ecological function to continue in the areas affected.

Further discussion on the recommendations made by this study, including recommendations for further study to fill these data gaps, are summarised below (and discussed in detail in Section 5).

Recommendations

The following recommendations have been developed based on the aims of the study and the conclusions summarised above for Effectiveness of Cable Installation Techniques and Environmental Effects of Cabling. Given that the remit of this study is to support the Plan Level HRA for the Round 4 leasing, these recommendations are particularly relevant to cabling within SACs and other MPAs (e.g. MCZs). Further detail of these recommendations, including potential methods for securing these, are discussed in Section 5 of the main report.

Recommendation 1: Cable Protection Reporting

One of the purposes of this study was to collate information on cable installation methodologies and cable protection. Given the efforts made to request information from both developers and public bodies, it is clear that there is no central repository for key pieces of information such as cable locations, and locations and dimensions of installed protection measures. With the ongoing growth of offshore infrastructure as well as historical assets (e.g. from the oil and gas industry), the availability of such information is important to ensure that cumulative effects can be accurately tracked by regulatory bodies and assessed within future consent applications without the need for overly conservative assumptions.

It has therefore been recommended that all data on cable infrastructure (both within and outside MPAs) be submitted to a central repository. This information (e.g. cable protection locations, dimensions, materials used etc.) should be provided in an agreed format to a central database to be agreed with the relevant regulatory bodies and stakeholder groups. This database would ideally not be limited to offshore wind cables, but should be a cross sectoral database, including data from interconnectors and telecommunications cabling and where possible, align with a similar approach being pursued by the Department of Business, Energy and Industrial Strategy (BEIS) for oil and gas infrastructure.

As part of the current project, RPS has compiled some information on cable protection for offshore wind farm export cables, including locations, types of protection etc. This information has been compiled in ArcGIS format and provided to TCE and the mapping outputs presented in this report.

Recommendation 2: Preliminary CBRA

As discussed above, there is the potential for an increase in the level of engineering input prior to a consent application. This may comprise a preliminary ground model and/or initial CBRA (or similar exercise). It is felt that development of a full BAS pre-consent too early in the development process (e.g. pre-consent) would hinder improved burial techniques and tool development in the future. More detailed ground conditions information could be provided during consenting, based on the results of the initial seabed survey, where cabling impacts are of particular concern (e.g. within MPAs), including preliminary assessment of the relative probability of burial, based on ground conditions information and anthropogenic activities in the area. This

information may be useful during pre-application consultation to identify areas of increased risk of insufficient burial and/or risks to cables (e.g. due to fishing or anchoring) and therefore potential requirement for non-burial cable protection measures. However, it should be noted, that this may not necessarily result in a reduction in the project design envelope, or restrictions to non-burial cable protection within specific parts of cable routes as developers may feel the need to account for unforeseen ground conditions or other factors which may lead to the requirement for non-burial cable protection.

The requirement to provide this additional information pre-consent would depend on the relative risk that cabling posed to the environment. Such information would be particularly useful to inform applications for cabling within MPAs, where a greater level of evidence is typically required to inform assessments.

Recommendation 3: Developer Engagement with Stakeholders

Alongside the provision of preliminary information on ground conditions during the pre-consent phase discussed above, it is also recommended that the level of involvement statutory consultees and other stakeholders (if deemed appropriate by the regulator) post consent could be increased for cabling projects within MPAs. The purpose of this would be to ensure that all parties have a full understanding of the approach to cable installation and the conditions in which non-burial cable protection may be deployed. This may include discussion of mitigation strategies with incentives for reducing the likelihood of the use of non-burial protection along cable routes, as agreed between the developer and the relevant authorities. The key aim of this process would be to ensure that the use of non-burial protection is agreed to be a last resort, with agreed mitigation to avoid use of these measures, but an acknowledgement from relevant authorities that this may need to be used in some circumstances.

This consultation process could be progressed alongside the normal consent compliance discussions and agreement of discharge of consents, with more in-depth discussions for those projects where cabling is a particular concern (e.g. within marine protected areas).

Recommendation 4: Future Monitoring of Seabed Recovery

As outlined above, the monitoring data reviewed largely reflects the assessments presented in offshore wind consent applications, with an initial period of disturbance to seabed habitats followed by a recovery period, the length of which is dependent on the sediments/habitats affected. Future monitoring of effects of cabling in most soft sediment areas (particularly sandy sediments) would not be expected to add further to the evidence base.

However, where cabling effects and associated recovery rates are of particular concern (e.g. in MPAs) it may be considered necessary to undertake post construction monitoring to assess the effects of cable installation in certain habitats (e.g. coarse and mixed sediments, reef habitats). Where this is agreed to be undertaken, it is recommended that geophysical surveys should be scoped to ensure the data collected and the subsequent interpretation focusses on recovery of the seabed, with ground truthing within the trenches also likely to be useful to fill any data gaps.

Recommendation 5: Cable Protection Monitoring

The main data gap identified in the review of environmental impacts was on the effect of cable protection on benthic communities. As such, it is recommended that studies on colonisation of cable protection are undertaken to understand effects on benthic communities. While most environmental assessments (e.g. EIA and HRA) assume total habitat loss beneath cable protection, there is some uncertainty as to whether some ecological function (e.g. infilling or colonisation of rock protection) may continue while protection measures are in place and the degree to which different cable protection measures have different levels of effect.

The proposed studies should comprise seabed imagery surveys to identify the level of colonisation of the protection measures, with appropriate comparison with adjacent areas of seabed to determine to degree to which these have been colonised by local fauna. Comparisons between different types of cable protection and/or in different environments (e.g. sediment types) would also be useful to determine the influence of environmental conditions and protection design on colonisation.

1 INTRODUCTION

1.1 Background

- 1.1.1.1 In November 2017, The Crown Estate (hereafter referred to as TCE) announced plans to work with the offshore wind sector and stakeholders, to consider making new seabed rights available to offshore wind developers. In order to identify the regions that will be released as part of the new leasing round, TCE has undertaken engagement with stakeholders and updates on their approach throughout 2018 and 2019. In November 2018, TCE published an Interim Regions Refinement Report which identified five regions for inclusion in the fourth round of leasing (TCE, 2018), with a further four regions to be considered further as evidence becomes available. The nine regions proposed or that were under further consideration for the Round 4 offshore wind leasing are presented in Figure 1.1. As these were the areas under consideration at the time that this study was completed, these areas comprised the study area for this project. On 19 September 2019, TCE launched the Offshore Wind Leasing Round 4 ¹, which further refined the areas shown in Figure 1.1, identifying four Bidding Areas.
- 1.1.1.2 As part of the new round of leasing TCE has identified that these activities could be classed as a 'plan' within the meaning of the Habitats Regulations, and that a Habitats Regulations Assessment (HRA) for the new leasing round is therefore likely to be required as part of the leasing process. TCE has been undertaking a number of workstreams in advance of the HRA, to support and build the evidence base for the plan-level HRA for Round 4.
- 1.1.1.3 TCE has therefore commissioned RPS to undertake this desk study to collate information on offshore electrical cable installation techniques used in the UK, consider the effectiveness of these installation methods and tools in different seabed types and collate information on the impacts of cabling on seabed habitats and communities. The main driver for this study was a concern that there is a lack of collated information on cable installation techniques used to install power cables in the offshore marine environment and how these have been used in different sediment/substrate types. There had also been a concern raised by stakeholders about the use of cable protection (i.e. placement of rock and mattresses). Stakeholders had further noted that there is a paucity of information on impacts on seabed habitats from cable installation and the recoverability of these habitats.
- 1.1.1.4 The project scope and the aims below have therefore been designed to address these concerns.

¹ <https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2019-the-crown-estate-launches-the-uk-s-first-major-offshore-wind-leasing-round-in-a-decade-opening-up-the-opportunity-for-at-least-7gw-of-new-clean-energy/>

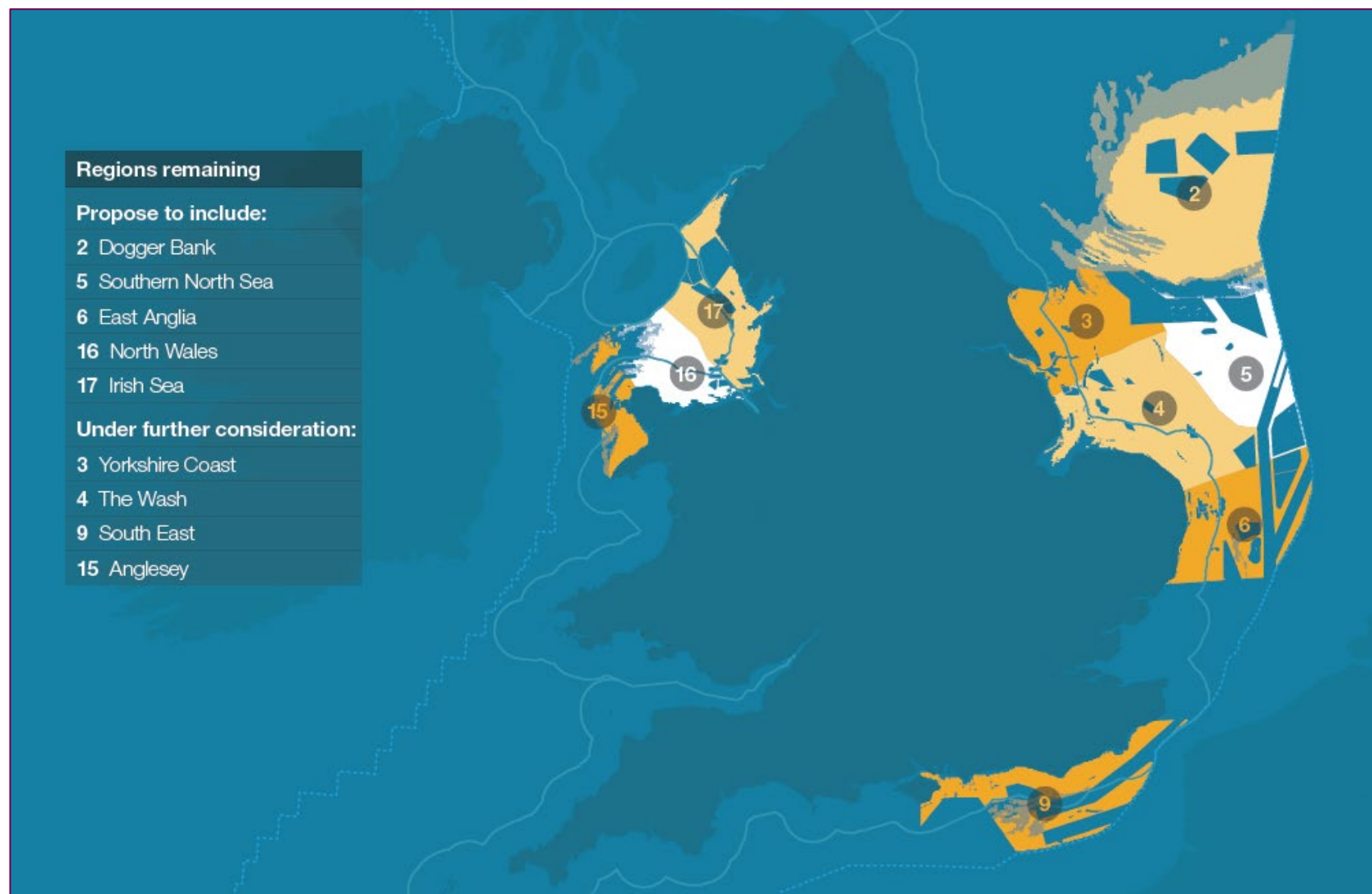


Figure 1.1: Project Study area - TCE proposed regions to be included in Round 4 and those under further consideration (November 2018).

1.2 Aims of the Project

- 1.2.1.1 As outlined above, this project has been subdivided into two broad sections, i.e. (i) Effectiveness of cable installation techniques and (ii) Environmental effects of cabling, with the aims set out below according to these subdivisions.

1.2.2 Effectiveness of Cable Installation Techniques and Cable Protection Requirement

- 1.2.2.1 To determine the effectiveness of cable installation techniques, RPS has collated and reviewed information on the techniques used to install cables in subtidal environments, using best practice guidelines and recent experience in the offshore wind and interconnector industries. This information was supplemented by information requested (via a questionnaire) from offshore wind and interconnector developers on installed export cables in the regions discussed in Section 1.1, including project specific information on cable installation techniques used, seabed types, requirement for cable protection and details of protection measures deployed. For offshore wind cables, the scope was largely restricted to export cables only.
- 1.2.2.2 The aim of this data collation and review exercise was to assess the relative effectiveness of the cable installation methodologies within the different ground conditions present in the nine study regions, with a view to answering three key questions of the study:
- To what degree is success of cable burial driven by ground conditions?
 - Are cable protection requirements site specific (i.e. dependant on ground conditions), or do other factors influence whether these are required?
 - Can detailed information on ground conditions be used pre consent to accurately establish cable burial and cable protection assumptions within consent applications?

1.2.3 Environmental Impacts and Recovery

- 1.2.3.1 One of the overall aims of the project was to help to improve the evidence base on impacts and recoverability of habitats. As such, a detailed review was undertaken of the available evidence on the effects of cabling on subtidal seabed habitats (i.e. physical sediments/substrate and biological communities/habitats), based on publicly available information sources, including monitoring data from offshore wind farms constructed in the UK. This study focussed on effects of cabling on subtidal seabed habitats and therefore effects on intertidal and coastal habitats (e.g. saltmarsh and sand dunes) were not part of the scope for this project. The aim of this part of the study was to:
- Consider the overall evidence base with respect to seabed impacts and recoverability to support future consent applications;
 - Identify any data gaps and potential requirements for further study; and
 - Identify proposals for good working practices during and after cable installation.

1.3 Steering Group

- 1.3.1.1 Consultation with stakeholders has been identified by TCE as being fundamental to progressing the plan-level HRA for Round 4 and finalising TCE's plans for a further offshore wind leasing round within UK waters. The primary way in which stakeholders have been engaged has been through participation in an Expert Working Group for the HRA process.
- 1.3.1.2 At inception of the current project, a Steering Group was established involving some of the relevant organisations within the Expert Working Group, specifically representatives from Natural England, Natural Resources Wales (NRW), the Joint Nature Conservation Committee (JNCC) and The

Wildlife Trusts. The Steering Group met in May 2019 to discuss and agree the scope and aims of the project, the development of the questionnaire and data sources to be used to inform the study.

- 1.3.1.3 Following compilation of the draft report (Rev02), this was circulated to the Steering Group for comment and discussion (September 2019). A meeting was held with the Steering Group in October 2019 to discuss their comments, particularly on the conclusions and recommendations made within the draft report (Rev02). The report was subsequently updated to address comments made by the Steering Group on the draft report (Rev03; i.e. this report). This report also incorporates comments received from offshore wind farm developers on the draft report (Rev02), which was provided to developers via the Renewable UK Offshore Consents and Licensing Group (OCLG).

1.4 Structure of the Report

- 1.4.1.1 The report is structured as follows:

- Section 2: Cable Installation Techniques Review – Provides a brief summary of the installation techniques used for cable installation in the offshore environment to provide background information for Section 3.
- Section 3: Effectiveness of Cable Installation Techniques and Cable Protection Requirements – Presents a description of the factors influencing successful cable installation and an assessment of project specific cable installation information (with Case Studies).
- Section 4: Environmental Impacts and Recovery – Provides a summary of all evidence related to effects of cabling on the seabed, including summaries of project specific information (e.g. monitoring) which were reviewed as part of this project.
- Section 5: Recommendations are provided based on the conclusions presented for Sections 3 and 4, with consideration of the aims set out in Section 1.2 above.

1.5 Plan Level HRA and Marine Protected Areas

- 1.5.1.1 As outlined above, the aims of the study and the reviews undertaken within Sections 2, 3 and 4 was developed to support the Plan Level HRA process for the Round 4 offshore wind leasing. The reviews undertaken were based on information collected from within the study area shown in Figure 1.1. This has included some information from within Marine Protected Areas (MPAs), including Special Areas of Conservation (SACs) where available, although the majority of cabling has been undertaken outside these areas. As such, the reviews and assessments undertaken as part of this project do not specifically focus on the effect of cabling on qualifying features of MPAs or the relevant conservation objectives for these sites and features. However, the information provided within this study on cable installation methods and environmental impacts could be applied to MPAs, where relevant.
- 1.5.1.2 Within Natura 2000 sites, the precautionary principle must be adopted where there is reasonable scientific doubt as to whether there are likely significant effects or adverse effects on integrity of the relevant features. As such, reports to inform appropriate assessment undertaken for activities (e.g. cabling) within SACs projects will require detailed information (e.g. information on the proposed activities, seabed types, qualifying features present etc.) to be provided to support an accurate assessment of the effects of that activity on the relevant features.
- 1.5.1.3 Many of the recommendations made within Section 5 have therefore been developed for projects which involve cabling within MPAs, although some of these recommendations are also relevant to cabling activities more generally.

2 CABLE INSTALLATION TECHNIQUES REVIEW

2.1 Introduction

- 2.1.1.1 This section provides a brief summary of the installation techniques used for cable installation in the offshore environment, based on best practice guidelines (e.g. DNV, 2016), typical installation methodologies presented in the most recent offshore wind and interconnector consent applications, and the experience of our RPS personnel from working on offshore cabling projects. The purpose of this section is to provide some general information on the techniques used, as background to Section 3 on the effectiveness of cable installation techniques.

2.2 Route Selection

- 2.2.1.1 As part of route development for sub-sea linear assets, developers typically undertake a number of steps and associated activities to establish a route, in consultation with stakeholders, which best reflects the developer's particular attitude towards risk. Here, risk can be related to the risk to a successful consent, delays to consent, construction risk being too costly to support a business case, or perhaps operational risks associated with increased likelihood of damage or delays to repairs.
- 2.2.1.2 The first step in this process is often to undertake a desktop routing exercise to determine possible connection routes to the connection points offered by National Grid, typically using publicly available information, providing a base map of constraints within the area of search. The constraints are categorised in line with the potential risk, usually risk to consenting and technical risk. Desktop routing then aims to establish the shortest route whilst maintaining levels of acceptable risk to the developer. Typically, each route option would have a width of 500 m (although at early stages of route selection, these may be wider), with appropriate buffers applied to constraints identified in the desktop study. In some cases, wider corridors (e.g. up to 2 km) may be applied to allow for mitigation/avoidance through more detailed routing at a later stage of the development process.
- 2.2.1.3 Once the preferred route option is chosen, the developer would seek to gain a detailed characterisation of the seabed, in particular regarding the sediment and bedrock geology. The purpose of this is to provide sufficient information to support the consenting process and also inform the ongoing improvement and refinement of the technical installation and information for the installation contractors. Geophysical and geotechnical seabed surveys would be scoped for the preferred route in order to characterise the seabed sediments and subsurface geology across the route. These surveys typically comprise multibeam echo sounders (MBES), side scan sonar (SSS), sub-bottom profilers, magnetometers, cone-penetration tests (CPTs), core sampling, grab sampling and seabed imagery data (i.e. video and stills). The survey swath, which is normally determined by the Developer and may be variable due to type of cable configuration, cable system, ground conditions and number of cables, is typically 500 m. This allows for some possible subsequent micro-routing around obstacles and obstructions, such as wrecks, possible unexploded ordnance (UXO) or previously unidentified protect habitat. However, wider corridors may be used where a large number of cables are to be installed or in areas of known constraints, e.g. sensitive habitats.
- 2.2.1.4 Should the survey highlight features which would represent a constraint which would present an unacceptable risk to development, e.g. unexpectedly challenging ground conditions within the surveyed corridor, then the likely course of action would be to conduct additional surveys of alternative routes to avoid significant constraint. As set out above, the site survey information is also used to inform the consent application, allowing for the project design parameters to be defined, including expected burial depths, extent of pre-clearance activities (see Section 2.3.1 below). Data collected during site surveys are also used to inform a characterisation of the baseline environment for a number of receptor topics assessed within the Environmental Impact Assessment (EIA) accompanying the consent application (e.g. seabed habitats and ecology, marine archaeology,

marine processes). As with the technical risks, where site surveys identify unacceptable consenting risks associated within the preferred route which cannot be resolved through micro-siting, this may also lead to consideration of alternative routes, with associated additional site surveys, to avoid such constraints.

2.3 Installation Phases

2.3.1 Pre-Installation Phase

- 2.3.1.1 Once the cable route has been selected and the cable is being manufactured, the Project will initiate Pre-Installation Activities. As outlined above, the pre-installation survey is the initial step in this process with the aim of reviewing the current situation along the route, its continued viability and to confirm the extent of the remaining pre-installation activities, including assessment of anticipated engineering volumes for sandwave or mega-ripple pre-sweeping, boulder clearance, unexploded ordnance inspection and clearance, possibly remotely operated vehicle (ROV) survey of third party asset crossings and preparation and finally the pre-lay grapnel run.

Sandwave Pre-sweeping

- 2.3.1.2 Following interrogation of the pre-installation survey data, sandwaves and similar bedforms may be identified and require reduction before cables are installed. This is done for two reasons: firstly, many of the cable installation tools require a relatively flat seabed surface to operate in a safe manner without risk of damaging the equipment or the cable. It may not be possible to install the cable up or down a slope over a certain angle, nor where the installation tool is working on a camber. Secondly, the cable should ideally be buried to a depth where it may be expected to stay buried for the duration of the project lifetime. Sandwaves are generally mobile in nature, therefore the cable can be buried beneath the level where natural sandwave movement may uncover it; the non-mobile seabed level. This can be done by removing the mobile layer of sediment before installation takes place. Sandwave reduction is typically undertaken via Trailing Suction Hopper Dredging (TSHD, described below) or Mass Flow Excavation (MFE; see Section 2.4.7).
- 2.3.1.3 TSHD operate by lowering a dredging arm to the seabed, where the trailing drag head is in contact with the seabed, as the vessel is in motion. High pressure water pumps flush water into the seabed loosening the sediment which is suctioned up and into the hopper onboard the vessel. Sediment is then disposed, where required (e.g. by direct release from the hopper to the seabed or fluidising the sediment and pumping it to the disposal location). TSHD are used in aggregate extraction, navigational dredging and marine construction to remove sediment and allow access to more stable seabed sediment.

Boulder Clearance

- 2.3.1.4 The presence of boulders on the seabed can affect the ability of certain cable installation tools to effectively install cables beneath surface sediments. In areas where boulders have been identified during pre-installation surveys, it may be considered necessary to clear these, with two methods typically used to clear boulders to areas adjacent to the cable trench: the displacement plough and the subsea grab. The displacement plough effectively displaces boulders from the route using a Y-shaped design configured with a boulder board and generating an open cable trench. However, this tool is limited in that it may not be effective in highly sloped areas or where the tool encounters a considerable force (e.g. very large boulders). As a result of these limitations, this technique is often used in-combination with a subsea grab, which uses a mechanical arm to relocate the boulder outside the cable route, with Remotely Operated Vehicle (ROV) support. The subsea grab may also be used in instances where boulders are present in small numbers and scattered over a relatively wide area.

Unexploded Ordnance Clearance

- 2.3.1.5 UXO, often from World War I, World War II, military training or disposal sites, are commonly encountered during offshore projects. This emphasises the importance of pre-installation surveys, inspection and removal for mitigating UXO risk to as low as reasonably practicable (ALARP). Once a survey determines the location of UXO, decisions are made to either avoid, remove or detonate *in-situ*. Removal or detonation requires careful excavation of suspected UXO and visual identification using ROVs, whereby an immediate risk assessment and management decision will be made. Once a decision has been made, the target is either confirmed as non-UXO (i.e. inert) and removed from the environment or a controlled explosive detonation is required to make the target safe for removal.

Pre-Lay Grapnel Runs

- 2.3.1.6 Following the pre-installation surveys and clearance works, it is likely that a pre-lay grapnel run (PLGR) of the final route will be undertaken. The PLGR involves the dragging of a grapnel over the seabed prior to cable installation in order to clear debris which is lying on the seabed or buried in the very top layer of the sediment. The results of the PLGR will determine if any further clearance works are required. Once the route has been cleared, the cable can then be installed following the cable installation techniques described below.

Asset Crossing Preparation

- 2.3.1.7 The majority of linear offshore projects will cross other existing assets. During route development of the new asset, the crossing location and angle of approach (typically between 65 and 90 degrees) will be identified. This angle facilitates the crossing being as small as possible and limits interactive forces being induced between assets depending on their type. Crossing preparation will usually include a separation layer, typically rock, concrete mattresses or polyurethane collars, across the existing asset to provide an agreed minimum vertical separation distance. The new asset will then be installed across the top of the existing asset, laid on top of the separation layer, with post installation rock protection to follow. As an alternative to rock, concrete mattresses may be used.

2.3.2 Cable Installation Phase

- 2.3.2.1 The aim of the cable installation phase is to deliver and bury the cable as per project or consenting requirements below the seabed. This can be completed by two principal methods (see further discussion of these in Section 2.4 below):
- Post Lay Burial (PLB) is the process by which the cable lay and cable burial are two discrete operations, separated physically and sometimes occurring a number of days apart; or
 - Simultaneous Lay and Bury (SLB) is where the cable is deployed and buried as a single activity behind a vessel.

Post Installation Phase

- 2.3.2.2 Once the cable installation has been completed there are a number of follow-on activities as part of the post installation phase. In the same way the pre-installation phase was initiated through a survey, an as-built survey will establish the current situation of the installed cable, leading to a clear understanding of the post installation phase activities. Principally this phase is made up of remedial burial operations and/or installation of cable protection over asset crossings and where cable burial is deemed not to be sufficient.
- 2.3.2.3 Dependant on the local situation rock or other protection materials can be used to further protect the cables. Protection stability calculations are completed to ensure stability on the seabed and attain

the required depth of cover of the cables, whether that is as part of an asset crossing or as mitigation protection (cable protection is further discussed in Section 2.5).

2.4 Cable Installation Techniques

- 2.4.1.1 There are two principal activities to complete a cable installation: the cable has to be lowered under control to the seabed and the cable has to be buried. As outlined above, PLB or SLB establishes the decision to complete the activities sequentially or together respectively. SLB and PLB are completed utilising different methodologies and sub-sea equipment; explored further later in this section. The option of SLB or PLB is usually determined by site specific considerations and the choice of installation tool itself (e.g. where there are multiple crossings, SLB may not be appropriate), though developer preference and attitude to risk is also a key factor.
- 2.4.1.2 Cables are installed via Cable Lay Vessels (CLV; which may include cable lay barges), using a cable tracking system to monitor and maintain cable lay route, cable tension, configuration and load. Figure 2.1 provides a schematic of the cable installation process.

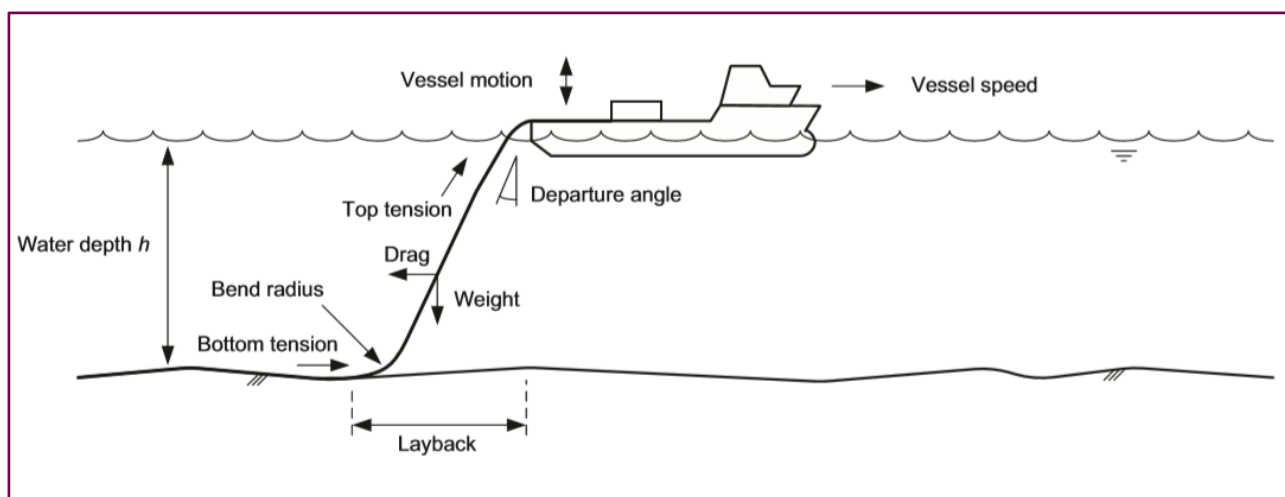


Figure 2.1: Cable laying process (DNV, 2016).

- 2.4.1.3 The CLV has one or two cable carousels on board and under controlled conditions allows the cable to be released off the back of the vessel. These vessels typically have dynamic positioning systems supporting these cable lay activities, although other vessel types (e.g. barges) may also be used in some areas. The vessel will have touch down monitoring ensuring the cable is laid where it is intended and within the margin of error.
- 2.4.1.4 Installation equipment is either operated directly from the CLV and is installing the cable at the same time as it is being laid (Simultaneous Lay and Bury; SLB), or a separate installation vessel follows the CLV and operates the installation tool as a Post Lay and Bury (PLB) activity.
- 2.4.1.5 A diverse range of cable laying and burial equipment with differing capabilities can be used in the cable installation process. The selection of equipment is an iterative process to determine the best suited method, following development of a detailed ground model based on geophysical and geotechnical datasets and a Cable Burial Risk Assessment (CBRA). This is followed by a review of the following criteria to determine the type of equipment that can be used;
- Seabed conditions: Consideration of general feasibility of cable burial, achievable burial depth and suitable burial method;

- Cable properties: Consideration of lengths, mechanical properties, vessel size, marine conditions and limitations of handling of the cable;
- Laying and burial combinations: Consideration of the project requirements and seabed sediment conditions;
- Mode of movement/ burial tool carrier system: Consideration of tool movement i.e. towed, bottom crawling or free-swimming (negatively to neutrally buoyant);
- Anticipated performance: Consideration of predicted versus actual achievable burial depth, sediment stability, tool stability, speed of lay, power requirements, wear and maintenance; and
- Water Depth and operational constraints.

2.4.1.6 Figure 2.2, provides a high-level model and a basis to define which tool should be considered for installation in a range of sediment conditions. It should be noted that this is a simplified model and there are additional considerations to account for, such as gravel content, peat and boulders. Further discussion on which tool is suitable for which type of sediment can be found below, with specific discussion of the following installation methods:

- Seabed preparation, including sandwave and boulder clearance;
- Jet trenchers;
- Mechanical trenchers;
- Cable ploughs;
- Jet sleds;
- Vertical injectors; and
- Mass flow excavators.

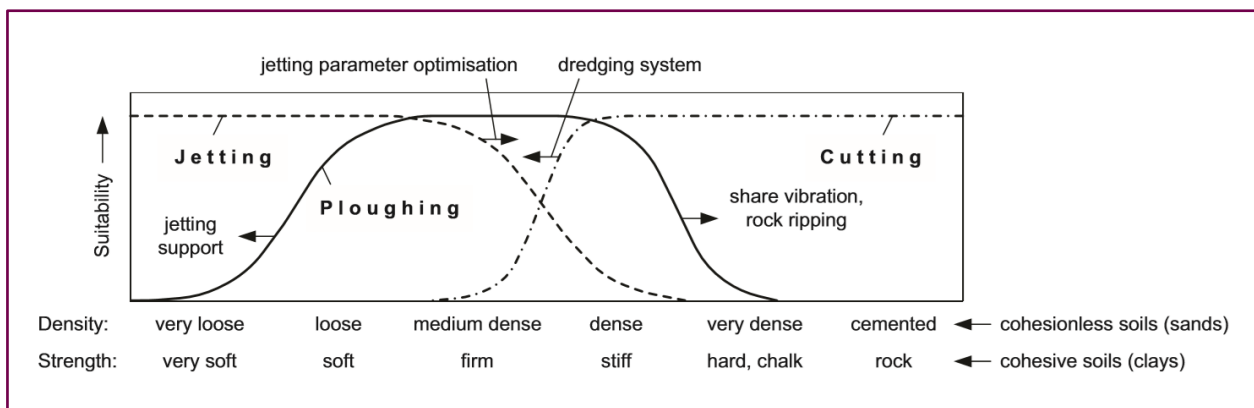


Figure 2.2: Indicative burial tool suitability in different ground conditions (DNV, 2016).

2.4.2 Jet Trenchers

2.4.2.1 Jet trenchers fluidise the soils by pumping seawater at high pressure through a series of small diameter nozzles arranged on opposing jet legs which locate either side of the cable. The legs are slowly lowered into the seabed until near vertical and the trencher, which is usually driven on tracks as opposed to free flying, moves forwards forming a trench. The cable lies between the jetting swords on the seabed and lowers into the trench, either under gravity or supported with a depressor, as the trencher progresses. Backwash nozzles are often located at the base of the legs to mobilise sediment along the trench and prevent it from settling out of suspension before the cable touches down (Figure 2.3).

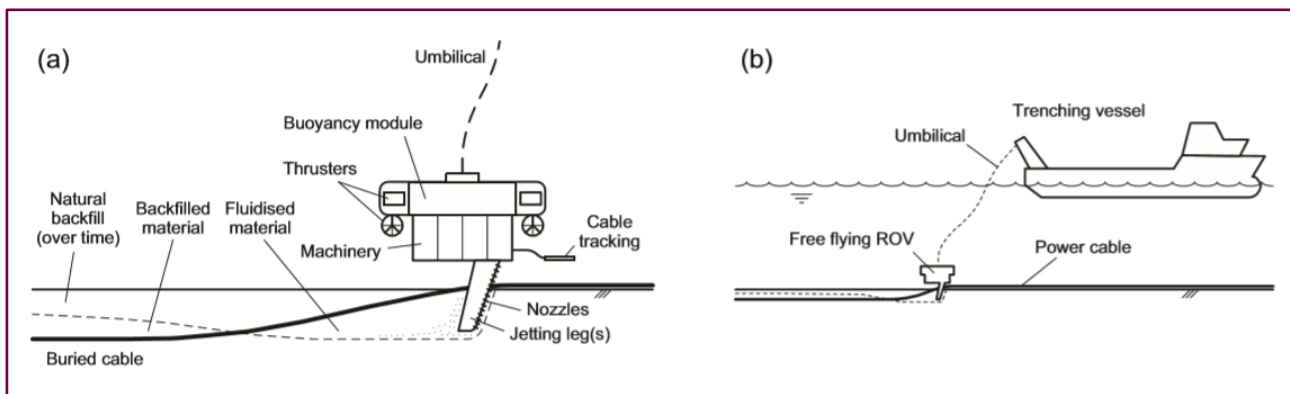


Figure 2.3: ROV jet trencher. (a) Principal components, (b) Cable lay operation (DNV, 2016).

- 2.4.2.2 Jet trenchers are best suited to fine to medium grained sands and soft clays, with the more powerful jet trenchers able to jet firm clays as well. They are less well suited to very stiff clays or areas of coarse sand and gravel although it is possible to achieve some lowering in the latter case by carrying out multiple passes or through adaptations of these tools.
- 2.4.2.3 Jet trenchers are a very popular tool particularly for cables as most do not actually engage with the cable meaning that the risk of damage to cables is low and they can carry out multiple passes. They are normally used in a post lay and burial application.

2.4.3 Mechanical Trenchers

2.4.3.1 Mechanical trenchers physically cut a trench, usually with a series of conical picks mounted on either a wheel or as a chain on a mechanical digging boom (Figure 2.4). The typical process is for the trencher to engage with and raise the cable whilst deploying the wheel or chain below and then for it to progress forward digging a trench.

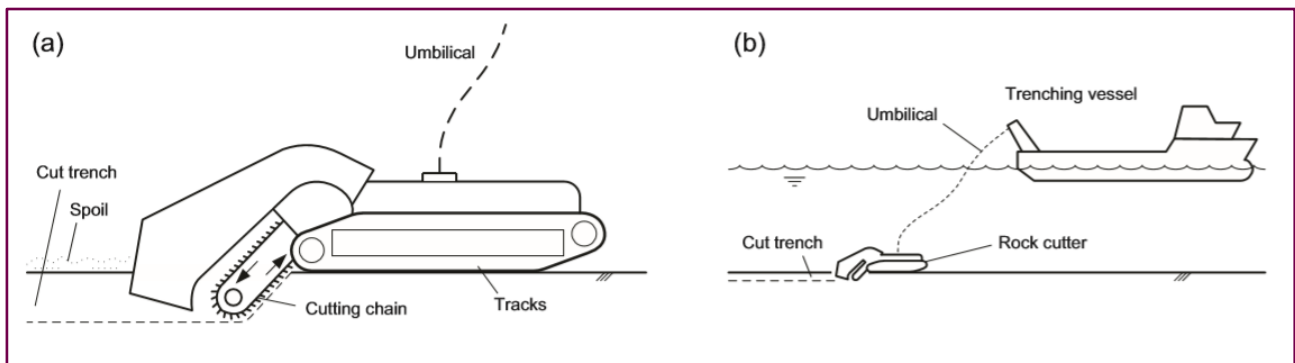


Figure 2.4: Chain cutter. (a) Principal components, (b) Pre-lay rock cutting operations (DNV, 2016).

- 2.4.3.2 Mechanical trenchers are best suited for hard ground conditions i.e. stiff clay. They do not perform well in granular soils as the silica causes high wear on the picks and the trench tends to collapse before the cable touches down, although there are trenchers on the market which include jetting systems and cable depressors which keep the trench open until the cable touches down.
- 2.4.3.3 Most if not all mechanical trenchers engage with the cable so there is a greater risk of damage to the cable and it is essential that cable slack is closely monitored during lay and trenching operations. Mechanical trenchers are not able to carry out more than one pass, and like a jet trencher they are typically used for post lay burial, with the exception of very hard soil conditions and minimal seabed mobility where rock cutters can be used to create a pre-lay trench.

2.4.4 Cable Ploughs

- 2.4.4.1 Cable ploughs come in a variety of shapes and sizes and are designed specifically for different soil types and burial depths. All ploughs are towed from a vessel or barge which must be able to provide adequate tow force, or in the case of landfall approaches pulled in from a fixed anchor point. Some ploughs are designed to allow for simultaneous lay and burial as shown in Figure 2.5, where the cable is lowered and fed through the plough and into the trench. Other ploughs are used as a pre-lay activity to plough a large furrow for the cable to be lowered into.

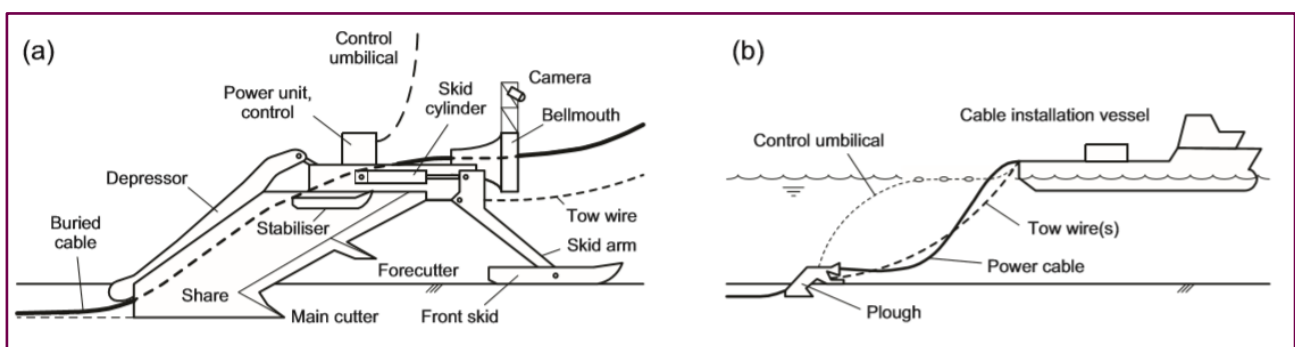


Figure 2.5: Subsea cable plough. (a) Principal components, (a) Cable lay operations (DNV, 2016).

- 2.4.4.2 Ploughs can be either non-displacement or displacement. Non-displacement ploughs trench and bury the cable in a single pass leaving less disturbance on the seabed and are typically used for simultaneous lay and burial. They are often fitted with additional features to improve performance in certain soils, for example water jets for burying in sand.

- 2.4.4.3 Displacement ploughs are typically large heavy-duty ploughs used to pre-cut a trench; typically in hard ground conditions where the trench remains open. The cable is then laid into the trench and a secondary backfill pass carried out to bury it.

2.4.5 Jet Sleds

- 2.4.5.1 Jet sleds are a hybrid of a jet trencher and a cable plough. They are not usually self-propelling and therefore need to be towed or pulled, but they often include a pumping system and jet legs.

2.4.6 Vertical Injectors

- 2.4.6.1 Vertical injectors can be mounted on sleds or tracks or suspended vertically over the side of a vessel. They are used mainly for very deep burial.

2.4.7 Mass Flow Excavators

- 2.4.7.1 Mass flow excavators, though generally used for sandwave or mega-ripple pre-sweeping, have also been successfully used as a post lay burial tool, where it is lowered towards the seabed from a vessel. These can be used in a combination of modes – to either fluidise the seabed beneath the cable and allow it to sink further into the trench beneath, or used to jet the seabed soils at an angle, pushing sediment across and into the cable trench to increase the depth of cover in loose sandy conditions.

2.5 Cable Protection

2.5.1 Cable Armour

- 2.5.1.1 Subsea cables are designed and manufactured to include a certain amount of inherent protection, through the inclusion of cable armouring. Cable armour is the layer of stranded steel wiring along the length of the cable which is included to enable the cable to be robust enough to withstand mechanical stresses due to handling, storage, transportation, installations and repair works. Most cables installed only require single armour, however double armour could be useful for cables that are required to be pulled across landfall areas or for installation in deep waters and heavy large core cabling. However, cable armouring is not sufficient to protect from external interference, for example dragged anchors or fishing gear, and hence the significant efforts made to provide protection via burial and additional cable protection.

2.5.2 Purpose of Cable Protection

- 2.5.2.1 Adequate cable protection is paramount, be it through depth of cover or through additional cable protection laid on an installed cable and, in some cases, alternative methods such as marking cable exposures with navigation markers/buoys are used in place of direct protection. Damage to marine cables can result in partial, or even complete, failure of the cable system leading to potential significant loss of revenue and critical energy supply. Repairs are often costly and time consuming and may result in a complete halt in operations (depending on the cable). The export cables should be covered by adequate sediment or appropriate protection materials to protect them from natural (e.g. seabed mobility) and anthropogenic threats (e.g. strikes from shipping anchors or entanglement with fishing gear).

2.5.3 Burial

- 2.5.3.1 Cable burial is typically the preferred method of protection for electrical cables. Cable burial protection is also dependent on the substrate type as discussed in Section 2.1. The degree of protection offered by seabed substrates is dependent on the strength of the substrate and the depth

of lowering beneath the surface of the substrate. This is usually considered within a Cable Burial Risk Assessment (CBRA), which also considers the risks to the cable given the prevailing conditions (e.g. shipping activity, fishing intensity and type of gear used, seabed mobility). Figure 2.6 indicates how the different sediment types can offer protection to cables installed using the installation methods summarised in Section 2.1. Note: no single burial technique will work in all ground conditions.

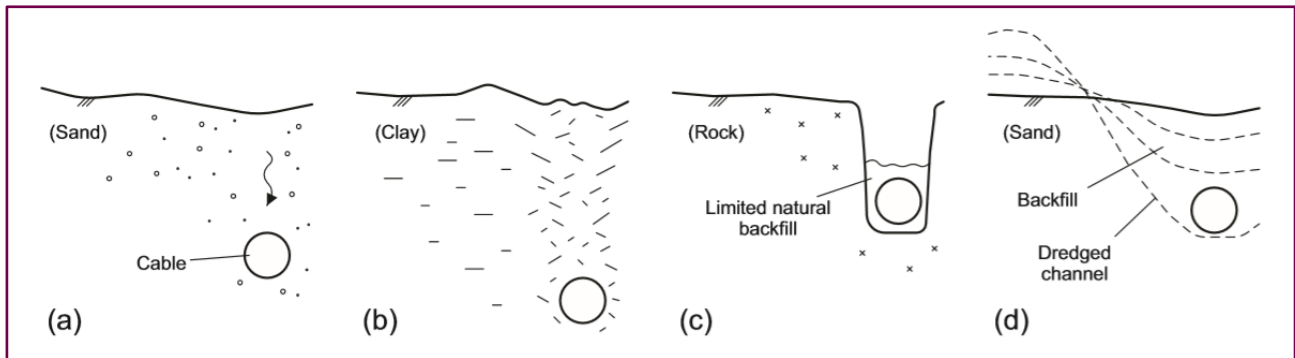


Figure 2.6: Protection of cable through burial. (a) Jetting/fluidisation, (b) Ploughing, (c) Mechanical cutting, (d) Open trench dredging (DNV, 2016).

2.5.4 Non-Burial Protection

2.5.4.1 Non-burial protection may be used where cable burial is not advisable/practicable or where additional/corrective measures may be required. This may be where subsea cables cross existing infrastructure (e.g. installed cables and pipelines), or perhaps subsea cables have not been sufficiently protected by burial beneath natural sediments (e.g. due to hard substrates / mobile sediments expose previously buried sections of cable), or where cable repairs have taken place and an omega joint cannot be reburied. Options for non-burial include the use of tubular products, concrete mattresses and rock placement, or a combination of these as per DNV guidelines ((DNV, 2016; Figure 2.7), though alternatives are also available including, but not limited to rock bags, grout bags, frond mattresses as well as surface protection measures such as marker buoys for exposed cables. Protection measures are site specific and will depend on the risk to electrical cables (e.g. fishing activity).

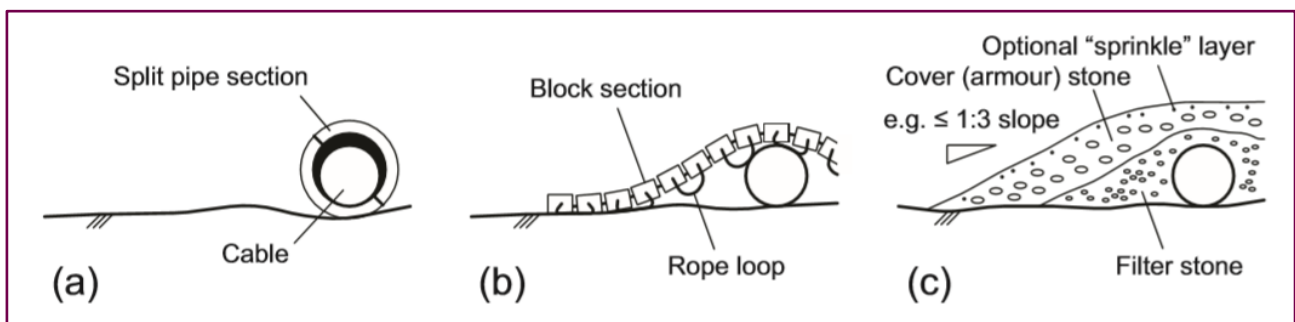


Figure 2.7: Cable protection. (a) Tubular product, (b) Mattress, (c) Rock placement (DNV, 2016).

2.5.4.2 Cable protection also needs to be designed correctly to facilitate local fishing activities, where berms can be designed and constructed to be over-trawlable, i.e. minimising risk of snagging.

Tubular Products

- 2.5.4.3 Tubular protection includes protective sleeves that consist of sections made from polyurethane or ductile iron. The tube is generally a cylindrical half-shell that fits around the cable, overlaps and interlocks. They are flexible and articulated structures. These products are often used in combination with mattresses or rock placement to support stability of the cable and protect fishing activities from entanglement.

Mattress

- 2.5.4.4 Concrete mattresses are lattice structures, consisting of segmented, mould-produced blocks of concrete or bitumen connected by polypropylene ropes. The structure can then be laid over a cable to stabilise and protect it. Additionally, any gaps between sections can be filled with pre-filled grout bags or gabion bags to support reduction in winnowing and possible sagging of the cable through scour.

Rock Placement

- 2.5.4.5 Rock placement involves the installation of crushed stone of varying size to form a protective barrier over the cable. This method is generally used as scour protection at infrastructure crossings, or where minimum burial depth has not been achieved.
- 2.5.4.6 The local conditions have a significant effect on the type, size and design of rock protection. The water column depth helps determine the significance of wave action at the seabed. Shallow waters mean the movement of water is greater and therefore the level of energy to potentially move rocks is higher, leading to a choice of larger grades of rock to support greater stability.
- 2.5.4.7 Softer and finer seabed sediment in more dynamic areas can lead to winnowing beneath assets and sagging or eventually free spans. Where this is a possibility, a combination of smaller grade rocks act as a filter layer, with larger graded rocks as stabilisers.

3 EFFECTIVENESS OF CABLE INSTALLATION TECHNIQUES AND CABLE PROTECTION REQUIREMENTS

3.1 Factors Affecting Cable Installation

3.1.1 Phases and Sequencing

3.1.1.1 Section 2.2 outlines the construction phases for a typical cable project programme. These are split across three distinct phases of pre-installation, installation and post installation and broadly describe the different activities available to support the completion of cable installation into the seabed:

- Pre-Installation Phase;
- Cable Installation Phase; and
- Post Installation Phase.

3.1.2 A Successful Installation

3.1.2.1 Across the project installation phases, within each activity there are a number of methods and tools available to complete that particular activity. Developers have the task of discussing with and contracting various construction companies to complete the detailed planning and execution of the activity to achieve an ultimate end goal of a protected cable ready for operational use.

3.1.2.2 A protected cable is less likely to be damaged (discussed further in paragraph 3.1.3.8) and thus avoiding:

- Repair operations and significant associated financial costs;
- Repair operations which may also take some time, which can significantly affect the business return;
- Additional environmental impact due to repeat disturbance of sediments/communities, delaying recovery periods (discussed further in Section 4); and
- Exposed cables posing a risk to other users, principally fishing.

3.1.2.3 To constitute a successful cable installation there are a number of factors to be considered including:

- Minimising the risk and impact on the environment, the installation and future operational teams;
- Minimising the risk and impact on socio-economic stakeholders (e.g. commercial fisheries);
- Meet installation project targets of burial and protection; and
- Meet installation project targets on cost and schedule.

3.1.2.4 Each of these factors can have varying influences on the choice of installation method and tooling. Some of these factors are similar or can be managed during the preparation and execution of the installation works, for example the risk and impact on socio-economic stakeholders.

3.1.2.5 The weight of each influencing factor on the choice of method and tooling is driven through various channels, including the consenting process, stakeholder engagement, contracting methodology and risk strategy, seabed conditions etc.

- 3.1.2.6 This part of the report focuses on the execution of the project success with respect to the target burial and protection.

3.1.3 Options Within Activities

- 3.1.3.1 The list of activities to complete a particular project are unique. Developers often face a balance when generating specifications for cable installation, between freedom for installation contractors to offer innovative, cost reduction and schedule improvements, whilst meeting a minimum set of requirements. This can include construction methodologies or installation tools considered within EIAs, particular license conditions and even concerns and mitigations for particular stakeholders. It is therefore often challenging when trying to ensure the proposals are comparable. Inevitably the activities proposed for the same project by multiple installation contractors will vary.

Establishing Project Requirements

- 3.1.3.2 When considering the protection requirements for the cable, burial into the seabed provides effective protection, with the principal requirement being what depth of burial into the seabed is deep enough to be considered successful (as defined in Section 3.1.2).
- 3.1.3.3 To achieve the installation targets and protect the cable below seabed, the methods and equipment vary. The current market has a number of installation methods; each of which have limitations on their suitability in certain soil types.
- 3.1.3.4 To align understanding between developers and installation contractors and ultimately to achieve an agreed approach to the installation methods, tools and activities, the basis of the project needs to be clear. Principally the developer's installation required outcomes and the seabed conditions need to be understood, and to facilitate the understanding of seabed conditions and soil types the developer will likely have completed a pre-construction seabed survey.
- 3.1.3.5 The seabed survey incorporates geophysical survey and seabed sampling, along with geotechnical ground truthing activities at specified locations. The total survey data generated is reviewed and the data cross referenced across the different survey outputs to produce an integrated analysis along the route.
- 3.1.3.6 The survey outputs are a number of survey charts, reports and supporting digital deliverables providing an interpreted understanding of the seabed sediment, geology, anthropogenic and natural hazards and seabed habitats along the route.
- 3.1.3.7 This data is not enough to establish a set of installation requirements and an engineering review needs to be completed to ascertain the local situational risks of the route in the form of a CBRA. These are usually prepared in accordance to the requirements of CTC835 (Guidance for the Preparation of Cable Burial Depth of Lowering (DoL) Specification; Carbon Trust, 2015).

Cable Burial Risk Assessment

- 3.1.3.8 The CBRA is a risk assessment that reviews the situational soil data against the situation risk. Utilising additional, principally desktop data for example vessel Automatic Identification System (AIS) information, the analysis will tackle each risk against the local soil conditions, in regards;
- Fishing;
 - Anchoring;
 - Foundering vessels;
 - Dropped objects; and
 - Soil instability, mechanics and particle size.

- 3.1.3.9 The complete assessment leads to the identification of a recommended Depth of Lowering (DoL). It is worth noting that by following the Carbon Trust guidance, the CBRA generates a recommended DoL. The developer may go on to determine a required Depth of Cover (DOC), which is the depth of material above the top of cable product. The reason for doing this would be to establish this requirement with installation contractors.
- 3.1.3.10 A cable is physically protected when there is a physical barrier between the cable and the potential threat. Cables that have not reached an agreed DoL beneath the seabed may not have enough, if any, sediment on top of the cable, as this is dependent on the installation equipment and methodology for the given seabed conditions.
- 3.1.3.11 For some projects, developers also complete additional assessments beyond the CBRA, for example a Risk Based Burial Depth (RBBB) assessment, where a value is assigned to the depth of seabed above the buried cable that is required to protect against a certain risk level.
- 3.1.3.12 Target burial depths are indicated in consent applications for offshore wind farms and interconnectors (i.e. usually specified within the project description for both array and export cables). As these are revised post consent (i.e. through the CBRA process outlined above), these revised burial depths may be communicated to regulators and other stakeholders, through post consent plans (e.g. cable burial plan, cable specification and installation plan). It should be noted, however, that Development Consent Order (DCO) or marine licence consents in the UK do not typically specify burial depths which need to be achieved. This is primarily an asset integrity issue and therefore the responsibility of the developer to ensure that the cable is adequately buried and protection for operational use (see Section 3.1.2).

Installation Methods for the Soil Conditions

- 3.1.3.13 As described in Section 2, there is correlation between the installation method (jetting or dredging or ploughing) and soil conditions.
- 3.1.3.14 DNV (2016) provides a high-level overview that gives a basis to understand the methods of installation that could be considered for installation in a range of sediment conditions. Methods include, the following (as described in Section 2.4; see also Figure 2.2);
- Jet trenchers;
 - Mechanical trenchers;
 - Cable ploughs;
 - Jet sleds;
 - Vertical injectors; and
 - Mass flow excavators.
- 3.1.3.15 Soil density and soil strength are affected by the principal soil mechanics of particle size, leading to cohesion and therefore shear strength. Particle sizes visible to the eye and larger are categorised as sands or coarser sediments (e.g. gravel, cobbles etc.). These particle sizes have less cohesion, except temporary cohesion through quick deformation. The particle size affects settlement (sedimentation) velocity, where particle sizes of approximately 0.2 mm or larger start to hamper jet trenching.
- 3.1.3.16 Particle size not visible to the eye are categorised as Silts and Clays, i.e. particle sizes of approximately 0.06 mm and smaller. These much smaller grain sizes infer much more friction and increase the shear strength of the soil.
- 3.1.3.17 The shear strength unit of measure is Pascal, Pa. where:
- $1 \text{ Pa} = 1 \text{ N} / \text{m}^2 = 0.1 \text{ kg} / \text{m}^2$

- $1 \text{ kg} / \text{cm}^2 = 100,000 \text{ Pa} = 100 \text{ kilopascal (kPa)}$
- 100 kPa is approximately equal to the shear strength of London Clay.

3.1.3.18 In relation to the terms used by DNV (2016) and to facilitate an understanding of the shear strength values, Table 3.1 below describes how the shear strength of a soil affects how it can be manipulated by hand.

Table 3.1: Indicative shear strength values and description (DNV, 2016).

Term	Strength	Shear strength
Very soft	Exudes between fingers when squeezed	<12.5 kPa
Soft	Moulded by light finger pressure	12.5-25 kPa
Firm	Moulded by strong finger pressure	25-50 kPa
Stiff	Can be indented by thumb	50-100 kPa
Very stiff	Can be indented by thumb nail	100-200 kPa
Hard	Difficult to indent by thumb nail	200-400 kPa

3.1.3.19 Installation tool specifications show the anticipated effectiveness of the trencher in particular soil conditions with upper, and sometimes lower, limits of shear strength.

Classification of Cable Installation Tools

3.1.3.20 The variety of soils found at the seabed, in combination with requirements for varying cable installation depths (i.e. based on the CBRA and subsequent assessment of RBBD) have led to a number of cable installation tool types and designs. The effectiveness of a tool is measured by the outcome from installation in a particular set of soil conditions.

3.1.3.21 To install a cable below the seabed all trenchers need to:

- Penetrate the seabed;
- Allow / guide the cable below the seabed; and
- Migrate and move along the installation route.

3.1.3.22 By reviewing the following questions and overlaying the installation types, as proposed by DNV, it is possible to draw high level conclusions on the tooling that could be appropriate for the given seabed conditions (see Figure 3.1 below). However, note that Figure 3.1 is a simplification which provides indicative examples and should not be used for tool selection. Individual tools can sometimes be modified to support burial in alternative soil conditions.

3.1.3.23 How does the trencher penetrate / open the soil?

- Suction / blowing;
- Erosion / fluidisation by jetting;
- Cutting soil as a knife, pushing it to the sides;
- Loosening soil by vibration;
- Cutting soil as a chainsaw or circular saw; or
- Cutting soil as a plough, pushing it up and to the side.

3.1.3.24 How is the cable lowered to the required depth?

- On its own weight;

- By pushing it down; or
- By guiding it down sloped / vertically.

3.1.3.25 How does the trencher move (horizontally / vertically)?

- Pulled forward by a vessel / pontoon;
- On its own power – on thrusters or tracked; or
- Free swimming / on skids / on tracks / on wheels.

Cable Installation Types		Fine sands	Medium Sands	Course Sands	Soft Clays	Stiff Clay	Peat	Glacial Till	Sand stone	Rock
Mechanical Wheel cutter	With depressor									
Mechanical Chain cutter	Without depressor									
Mechanical Chain cutter	With depressor									
Jet Vertical Injector	Stinger, cable guidance									
Plough V-shape	Route preparation plough									
Plough Jet assisted	With depressor									
Jet Sledge	With depressor, multiple swords									
Jet Sledge	With backwash sword, depressor									
Jet ROV	With backwash sword, depressor									
Jet ROV	No backwash sword, depressor									
Suction Dredging	Loose soils only									
Mass Flow Excavators	Loose soils only									

Figure 3.1: Indicative tool penetration method, cable guidance and appropriate soil conditions matrix.

Installation Tool Considerations

3.1.3.26 In addition to the soil conditions and the required cable installation depth, there are a number of other considerations when selecting the optimum equipment for cable installation/burial. These include;

- Rate of installation;
- Mitigation / remedial actions available, should depth not be sufficient;
 - For the particular soil conditions; and
 - Alternative tools on board.
- Number of crossings;
 - Possible number of 'return to deck' and re-launch activities;
 - Possible installation direction away from crossed asset only. Should this form part of crossing agreements this could mean multiple vessel manoeuvres if there are many existing assets along the cable corridor; and
 - Crossing approach limit may be affected by tool choice, where some tool choices that have less control on the seabed or higher implications should an impact occur may be subject to greater stand-off / approach limits. This then requires additional installation tools or larger volumes of remedial rock or mattress protection.
- Suitability for bundled or unbundled cabling;
- Consent conditions of Licence, including, but not limited to, environmental considerations;
- Vessel of operation;

- DP class; and
- Crew experience with selected installation tool.
- Number of required vessels;
 - Pre-construction activities, including dredging / pre-sweeping;
 - Support vessels, including anchoring tugs and crew vessels; and
 - Post installation activities, including cable crossing protection and possible remedial cable protection.
- Soil strength, stability for installation tool;
 - Approx. < 5-10 kPa: a non-free flying installation tool likely to become stuck in the sediment; or
 - Approx. > 10 kPa: cable installation tool would be expected to be able to crawl on it, depending on the contact area of the tracks and weight of the particular tool.

3.1.3.27 These considerations can feature in the overall Capital Expenditure (CAPEX) costs for the installation of the project. The Operating Expense (OPEX) of the project is much more reliant on the successful execution of the installation, delivering the best possible results for cable protection below the seabed. As such, the installation methodology and tool selection are crucial.

3.2 Methodology – As-built Cable Burial Technique and Protection Review

3.2.1.1 As outlined in Section 1, in order to assess the effectiveness of installation techniques, information on existing offshore wind and interconnector projects and cable installation methodologies was sought from offshore wind and interconnector developers. It should be noted that the scope of this part of the study, and the information requests from developers, was focussed on export cables in the subtidal environment. Cabling within intertidal areas was not part of the scope for this project, as were inter-array cables.

3.2.1.2 A questionnaire was circulated to these developers requesting information on the methods and tools used to install cables in subtidal environments, and the effectiveness of these techniques in different sediment/seabed types. Individual questionnaires were issued to developers requesting such information for specific projects identified across the nine regions identified by TCE for inclusion in (five regions), or under further consideration for (four regions), the Round 4 leasing activities. In addition, questionnaires were also circulated to developers with projects within the Thames region (i.e. TCE Regions 7 and 8, which were not taken forward as part of Round 4; TCE, 2018). These projects were included as the environmental conditions in these areas were considered to have some similarities to parts of the other nine Round 4 leasing regions and therefore would be applicable to the conclusions of the current assessment. An example of the questionnaire as provided to offshore wind farm developers is presented in Appendix A.

3.2.2 Developer Questionnaire

3.2.2.1 General project information was requested regarding:

- Cable system design (i.e. High Voltage Alternating Current (HVAC)/High Voltage Direct Current (HVDC)); and
- Bundled / Unbundled.

3.2.2.2 Site specific information was requested regarding:

- Sediment type(s), KP (kilometre point) to KP;

- Location(s);
- Water depth(s);
- Soils Shear Strength (kPa);
- Metocean conditions (seabed mobility / current); and
- Soil depth to reach non-mobile seabed reference level.

3.2.2.3 Project requirements were requested regarding:

- Cable Depth of Lowering – Target;
- Cable Depth of Lowering – Achieved;
- Cable Depth of Burial – Target; and
- Cable Depth of Burial - Achieved cable protection.

3.2.2.4 Project installation methods and tools were requested regarding:

- Burial Strategy (Pre-plough / Simultaneous Lay and Bury (SLB) / Post Lay Burial (PLB) / Natural backfill /None;
- Burial method(s) (Jetting / Mechanical Trenching / Plough / MFE); and
- Installation tool(s) used (Capjets A/B / T3200 / T1100 / Excalibur etc).

3.2.2.5 Cable protection information was requested regarding:

- Protection material (mattress / rock / sand / other);
- Cable protection volume total;
- Cable protection volume / depth above seabed;
- Consented cable protection – total volume (offshore activity);
- Consented cable protection – total volume (nearshore activity); and
- Any additional protection required as part of operations/maintenance and repair.

3.2.3 Questionnaire Participants

3.2.3.1 To elicit as much of a response as possible, the number of recipients of the questionnaire and list of relevant projects identified was considerable, as was the follow-up with each developer and asset owner. The following interconnector, offshore wind farm companies and offshore transmission owners (OFTOs) were contacted and issued with questionnaires:

- Interconnectors:
 - BritNed;
 - National Grid;
 - RTE;
 - Nemo Link; and
 - Western Link.
- Offshore Wind Farms/OFTOs (number of projects where information was requested):
 - E.On (4 projects);
 - Equinor (2 projects);

- Siemens/ XceCo (1 project);
- Ørsted (12 projects);
- Innogy Renewables UK (4 projects);
- Vattenfall (3 projects);
- SSE Renewables UK (1 project);
- Transmission Investment (5 projects; includes some Ørsted projects); and
- Diamond Transmission (2 projects; includes some Ørsted projects).

Cable and Pipeline Protection Information

3.2.3.2 As outlined above, the study aimed to gather information, via the questionnaire, on cable protection (e.g. locations, materials, areas and volumes) for the defined offshore wind farm and interconnector projects. Other than the main aims of the current study, information on cable protection measures was also collected in order to develop a database and associated spatial mapping of cable protection within the Round 4 leasing regions. It was also intended to collect information on cable and pipeline protection measures deployed for oil and gas pipelines and telecommunications cables, in order to produce a cross sectoral map across the Round 4 leasing regions. This was progressed via consultation with and information requests from the Department for Business Energy and Industrial Strategy (BEIS) on oil and gas developments and the European Subsea Cables Association (ESCA) for telecommunications. The outcomes of this exercise are further discussed in Section 5.

3.2.4 The Questionnaire Responses

3.2.4.1 The response to the questionnaires was lower than anticipated. Throughout the project, RPS made significant efforts to discuss the opportunity for developers to provide information in order to support the output of the report. There may have been a number of factors that may have contributed towards the relatively low level of response to the questionnaire.

3.2.4.2 As outlined in Section 3.2.3, information was sought via the questionnaire on 27 offshore wind farm projects and 5 interconnector projects. Of those questionnaires issued, only 7 were received, with varying degrees of completeness/detail provided. Table 3.2 presents an overview of the completeness of the responses received. While there were a number of factors affecting developers' ability to provide questionnaire responses, one limitation was associated with the availability of information from those projects/cables which had been installed during the earlier rounds of offshore wind farm leasing, i.e. up to 10 years ago. In some cases, it is likely that information on the installation strategies and methodologies, perceived success of cable installation and lessons learned, were not readily available due to internal staff changes, or in some cases changes in asset ownership, in the intervening period.

3.2.4.3 Given the level of response to the questionnaire, it was agreed with TCE that further data would be sought from publicly available sources. RPS therefore undertook a data mining exercise across a number of publicly available resources including;

- Marine Data Exchange;
- Information within the 4coffshore website;
- Marine Management Organisation (MMO) Public Register; and
- Freedom of Information (FOI) request from the MMO.

3.2.4.4 This data mining exercise has provided some additional information for current offshore wind farm projects, as summarised in Table 3.2 below. It should be noted that extracting this information from publicly available sources has limited the quality of the information, as these publicly available

sources do not capture the developer/engineering knowledge and experience which was requested via the questionnaires. As such, many of the RPS generated questionnaires were only part completed, as indicated in the completeness of the responses in Table 3.2 below.

Table 3.2: Indicative number of projects and completeness of information in total.

Completeness of Response	Number of Project Responses	RPS Generated	Total Projects Information Available
Very High	0	0	0
High	1	0	1
Medium	2	2	4
Low	5	2	7
Very Low	3	6	9
Total	11	10	21

3.3 Assessment of Installation Effectiveness

3.3.1 Use of Project Data

3.3.1.1 Table 3.3 below provides a summary of the project information available for each of the TCE Regions, based on questionnaire responses and data mining of publicly available sources. Regions 2 (Dogger Bank) and 15 (Anglesey) currently have no projects established within them, while in Region 5 (Southern North Sea) there are limited constructed projects and no information has been made available at this time.

Table 3.3: Project information for each TCE Region (see Figure 1.1 for map of TCE Regions).

TCE Areas		No. of Projects Considered**	No. of Projects Requested**
Proposed to Include			
2	Dogger Bank	0	0
5	Southern North Sea	0	0
6	East Anglia	2	3
16	North Wales	2*	4
17	Irish Sea	7*	8
Under Further Consideration			
3	Yorkshire Coast	1	3
4	The Wash	5	6
9	South East	1	1
15	Anglesey	0	0
Not in Consideration			
7	Kent Coast	4	7
8	Thames Approaches		

*Note that Burbo Bank Extension export cable route carries across both Region 16, and Region 17.

** These indicate number of projects where questionnaire information was available to inform the study (i.e. Projects Considered) and the total number of offshore wind and interconnector projects where information was requested via the questionnaire (i.e. Projects Requested).

Approach

- 3.3.1.2 To represent and review the available project information, a number of case studies have been established, with each case study combining the available data to provide a representation of the projects and methods within each case study area.
- 3.3.1.3 The case study areas have been established by grouping projects within adjacent TCE Regions (see Table 3.4) allowing the available information to be harmonised across these areas.
- 3.3.1.4 Based on the project specific information (as set out in Table 3.3) and the similarities in geology and sediment types (discussed further in Section 3.3.2 below), the TCE Regions were grouped into the case study areas presented in Table 3.4.

Table 3.4: Case Study groupings and TCE Regions (see Figure 3.2).

Case Study (CS)		TCE Areas	
01	North East	2	Dogger Bank
		3	Yorkshire Coast
		4	The Wash
		5	Southern North Sea
02	East Anglia	6	East Anglia
03	The East	7	Kent Coast
		8	Thames Approaches
04	South East	9	South East
05	North West	15	Anglesey
		16	North Wales
		17	Irish Sea

3.3.2 Ground Conditions

- 3.3.2.1 This section provides an overview of the available datasets on ground conditions used to inform the assessments within each of the case studies. These datasets are broadly divided into Marine Bedrock (i.e. surface and subsurface geology) and Marine Seabed Sediments. The following paragraphs discuss these datasets in the context of the TCE Regions, including the rationale for case study groupings. Further discussion of these datasets are presented within the Case Studies, alongside information on project specific ground conditions as provided by questionnaire responses and/or data mining of publicly available data sources. The Case Studies consider this information in order to assess the effectiveness of the cable installation methodologies and tools for the relevant projects.

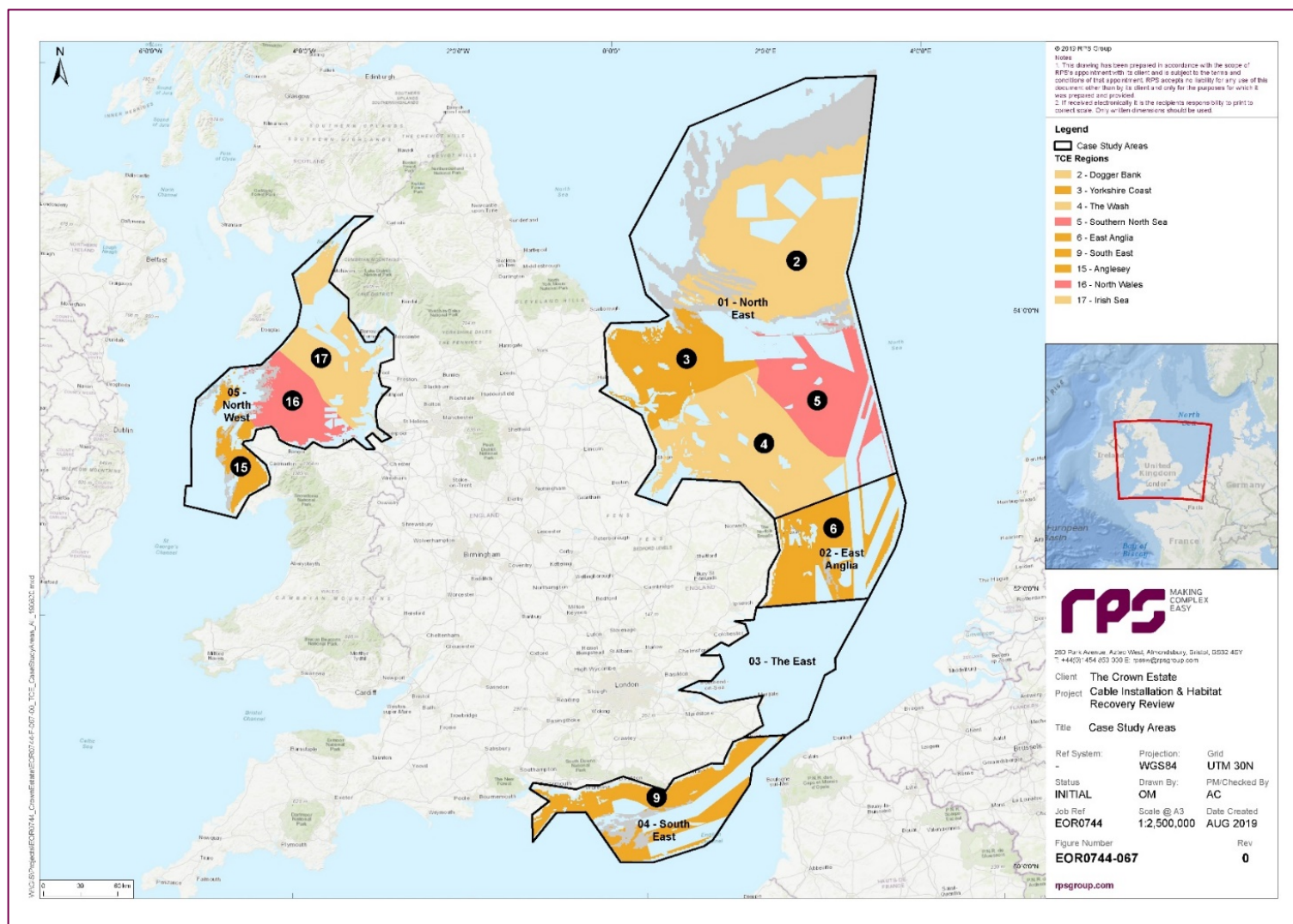


Figure 3.2: Case Study Areas.

Marine Bedrock

- 3.3.2.2 Understanding the bedrock and the subsurface geology is key to understanding the risks that are avoidable when establishing a feasible cable route, as well as the challenges that the installation and operational teams will face during the execution of the project. This is particularly important where bedrock is shallow to the seabed surface or even exposed.
- 3.3.2.3 To gain a clearer understanding of the bedrock and subsurface geology across the TCE Regions, publicly available data from the British Geological Survey (BGS; BGS Geology: marine bedrock 250k) were used to provide a broad description for each of the TCE Regions. Figure 3.3 provides an overview of this data for the UK, with the same data provided for each of the TCE Regions in the charts in Appendix B. This provides the basis of information on marine bedrock and is assumed to be correct where no additional data is provided for a particular project in that region. The principal bedrock delineations across the regions are summarised in Table 3.5.

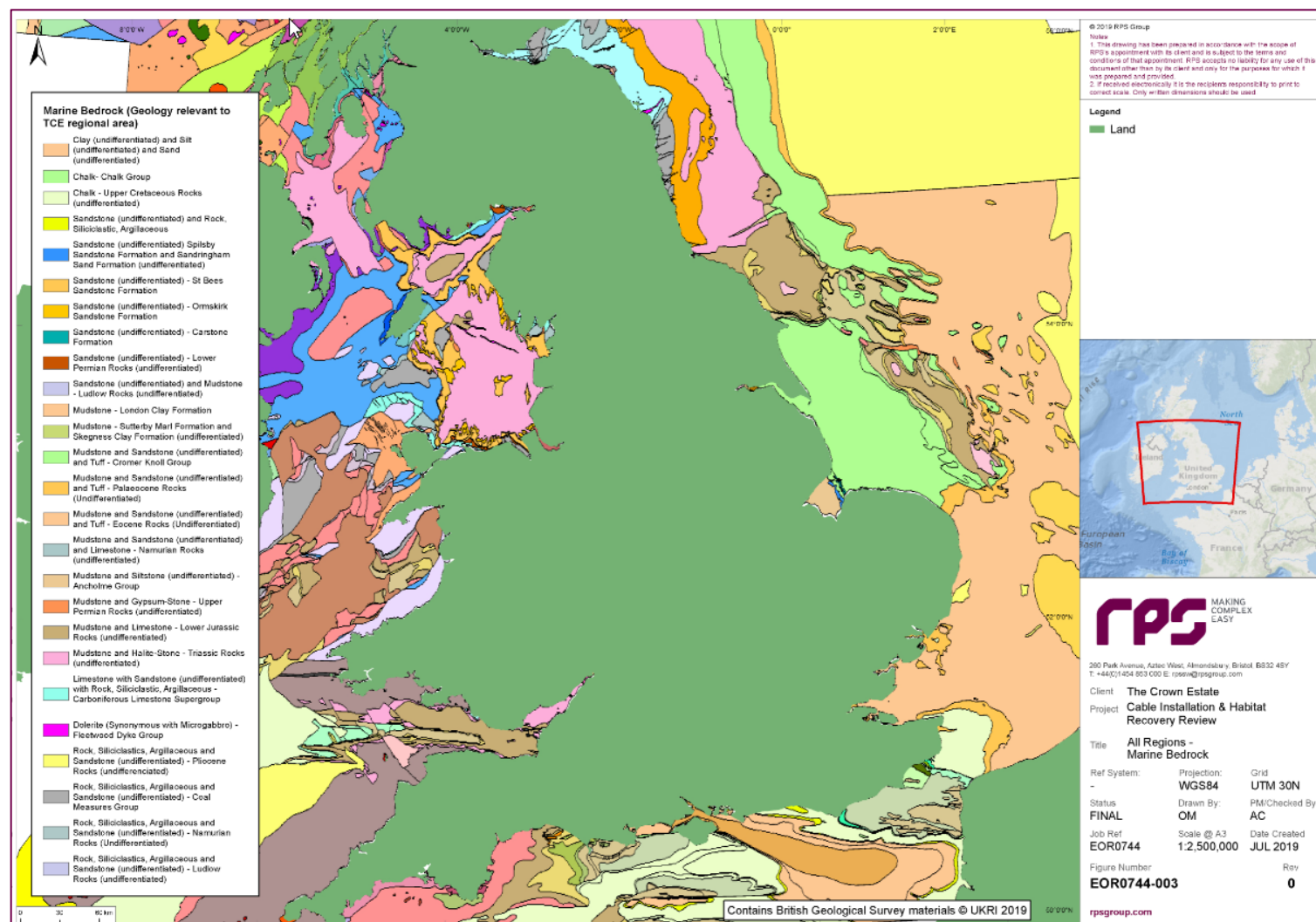


Figure 3.3: Marine Bedrock Around the UK.

Table 3.5: Marine Bedrock Types for each of the TCE Region considered in this report.

Case Study	TCE Region		Bedrock Types
01 – North East	2	Dogger Bank	Rock, Siliciclastic, Argillaceous and Sandstone.
	3	Yorkshire Coast	Chalk, Mudstone and Limestone.
	4	The Wash	Chalk, Mudstone and Siltstone, Mudstone and Sandstone and Rock, Siliciclastic, Argillaceous and Sandstone
	5	Southern North Sea	Mudstone and Sandstone and Rock, Siliciclastic, Argillaceous and Sandstone.
02 – East Anglia	6	East Anglia	Mudstone and Sandstone and Rock, Siliciclastic, Argillaceous and Sandstone.
03 – The East	7	Kent Coast	Mudstone and Sandstone, Rock, Siliciclastic, Argillaceous and Sandstone.
	8	Thames Approaches	Chalk, Mudstone and Sandstone, Rock, Siliciclastic, Argillaceous and Sandstone.
04 – South East	9	South East	Rock, Siliciclastic, Argillaceous, Chalk and Mudstone.
05 – North West	15	Anglesey	Rock, Siliciclastic, Argillaceous and Sandstone, Mudstone and Halite-Stone, Mudstone and Sandstone and Limestone.
	16	North Wales	Mudstone and Halite-Stone, Sandstone and Limestone.
	17	Irish Sea	Mudstone and Halite-Stone, Sandstone, Mudstone and Limestone.

Marine Seabed Sediment

- 3.3.2.4 The seabed sediment forms a mobile blanket across the seabed bedrock, in some locations this sediment blanket is thick, mobile and homogeneous. In other locations the sediment type varies considerably over short distances. By understanding the sediment, projects are better equipped to engineer the route and design cable systems efficiently and effectively.
- 3.3.2.5 The BGS seabed sediment dataset (BGS Geology: marine sediments 250k) has been used to inform the Case Studies and is assumed to be correct for the respective region where further project data has not been available.
- 3.3.2.6 The marine sediment around the UK varies between the different TCE Regions, with Figure 3.4 providing an overview of this data for the UK, with the same data provided for each of the TCE Regions in the charts in Appendix B.
- 3.3.2.7 The principal sediment delineations across the TCE Regions are presented in Table 3.6, however it should be noted that only the top surface layer of sediment is available within the dataset and should there be variations in the layers through the sediment, this information is not available, unless this has been provided at a project specific level. The seabed sediment identified as Rock and Sediment is likely highlighting that there may only be a thin veneer of sediment, and that bedrock is located close to the seabed surface.

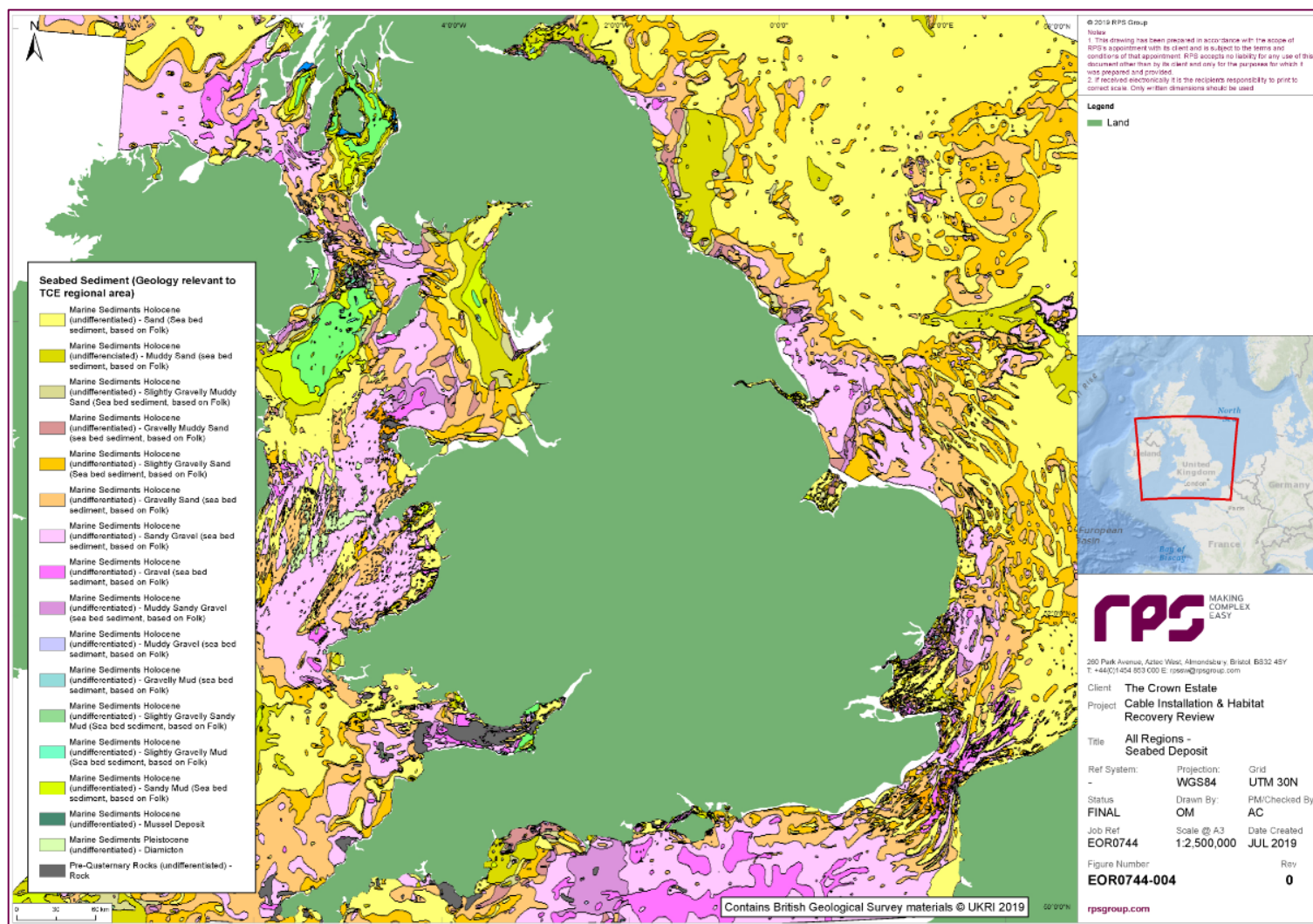


Figure 3.4: Marine Seabed Sediment around the UK.

Table 3.6: Surface Sediment Types for each of the TCE Region considered in this report.

Case Study	TCE Region		Sediment Types
01 – North East	2	Dogger Bank	Sand and Muddy Sand.
	3	Yorkshire Coast	Sandy Gravel, Gravelly Sand and Sand.
	4	The Wash	Sandy Gravel, Gravelly Sand, Sand and Gravelly Muddy Sand.
	5	Southern North Sea	Sand, Slightly Gravelly Sand and Gravelly Sand.
02 – East Anglia	6	East Anglia	Sand, Slightly Gravelly Sand, Gravelly Sand, Sandy Gravel and Gravel.
03 – The East	7	Kent Coast	Sand, Slightly Gravelly Sand, Gravelly Sand, Sandy Gravel and Gravel.
	8	Thames Approaches	Sand, Slightly Gravelly Sand, Gravelly Sand, Sandy Gravel and Gravel.
04 – South East	9	South East	Rock and Sediment, Sandy Gravel, Gravelly Sand and Gravel.
05 – North West	15	Anglesey	Rock and Sediment, Gravelly Sand, Sandy Gravel, Gravel and Muddy Sand.
	16	North Wales	Rock and Sediment, Gravelly Sand, Sandy Gravel, Gravel and Muddy Sand.
	17	Irish Sea	Sandy Gravel and Gravel.

3.3.3 Case Study Overview

3.3.3.1 The case studies provide a summation of the available information across the region, to understand the synergies in developer understanding of soil conditions and installation tool choices, whilst identifying strengths and weaknesses in construction methodology when trying to reach cable depth of burial requirements. For the purposes of the case studies, installation success was defined by whether the target depth of burial had been achieved.

3.3.3.2 Each case study focuses on the following items for the given area:

- Export cable route length;
- Export cable ground conditions (i.e. surface sediments and subsurface geology);
- Export cable installation tool;
- Export cable depth of burial; and
- Export cable remedial protection (i.e. remedial burial and/or placement of rock protection/mattresses).

3.3.3.3 The individual case studies are presented in Appendix B, with a summary provided below.

3.3.4 Case Study Summary

3.3.4.1 Each individual case study (Appendix B) provides a more detailed assessment of the installation methods and respective outcomes of the cable burial campaigns. The level of remedial works to ensure the protection of installed cables is also included in the case study where known. Such works

not only include cable protection measures (e.g. rock protection and mattresses) but also remedial burial operations (e.g. reburial using a MFE or jetting tool).

- 3.3.4.2 Taking all the available project information and combining it, Table 3.7 below provides a summary of the total installation distances performed by the various typical installation tools, based on the project information available at the time of the study. This is visually represented for all Case Studies combined in Figure 3.5.

Table 3.7: Summary of Total Cable Installation Lengths per Installation Tool.

Installation Tool	Installed Cable Length (km)					Total
	CS01	CS02	CS03	CS04	CS05	
Cable Plough	137.31	137.31	285.3	19.2	264.7	843.82
Mechanical Trenching	78.35	0	0	20	136.6	234.95
Jet Trenching	35.5	0	0	5.8	0	41.3
Trailing Suction Hopper Dredger	0	0	0	0	24	24
Vertical Injection	0	0	0	0	25.2	25.2
Total	251.16	137.31	285.3	45	450.5	1169.27

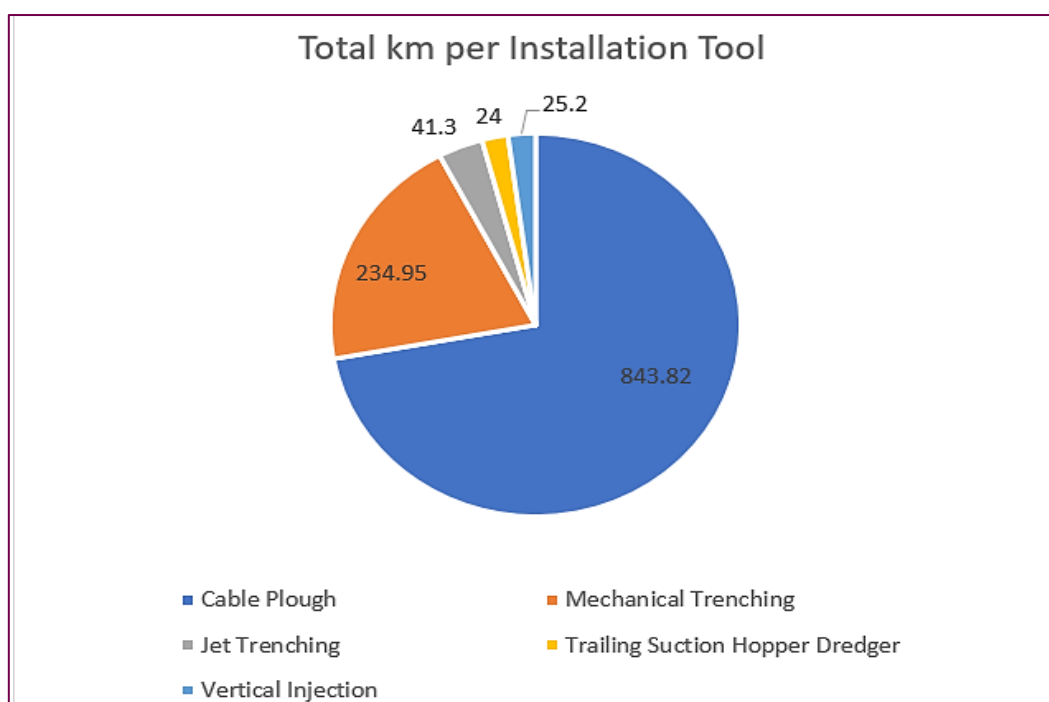


Figure 3.5: Total Installation Lengths per Tool for all Case Studies.

Taking each case study area and reflecting the tool type used for cable installation (

- 3.3.4.3 Figure 3.6), allows a clear visualisation of the most common installation tools used for the offshore wind farm cables in the UK. This indicates that cable plough is the most commonly used tool across all regions with the exception of Case Study 04 (South East), where the shortest length of cables were installed. The sediment types across the Case Study areas (and individual TCE Regions) can be quite variable, though when considering a varying target depth of burial, in combination with the

ground conditions, it is foreseeable that the right selection of tool from each group supports successful cable installation in the appropriate conditions.

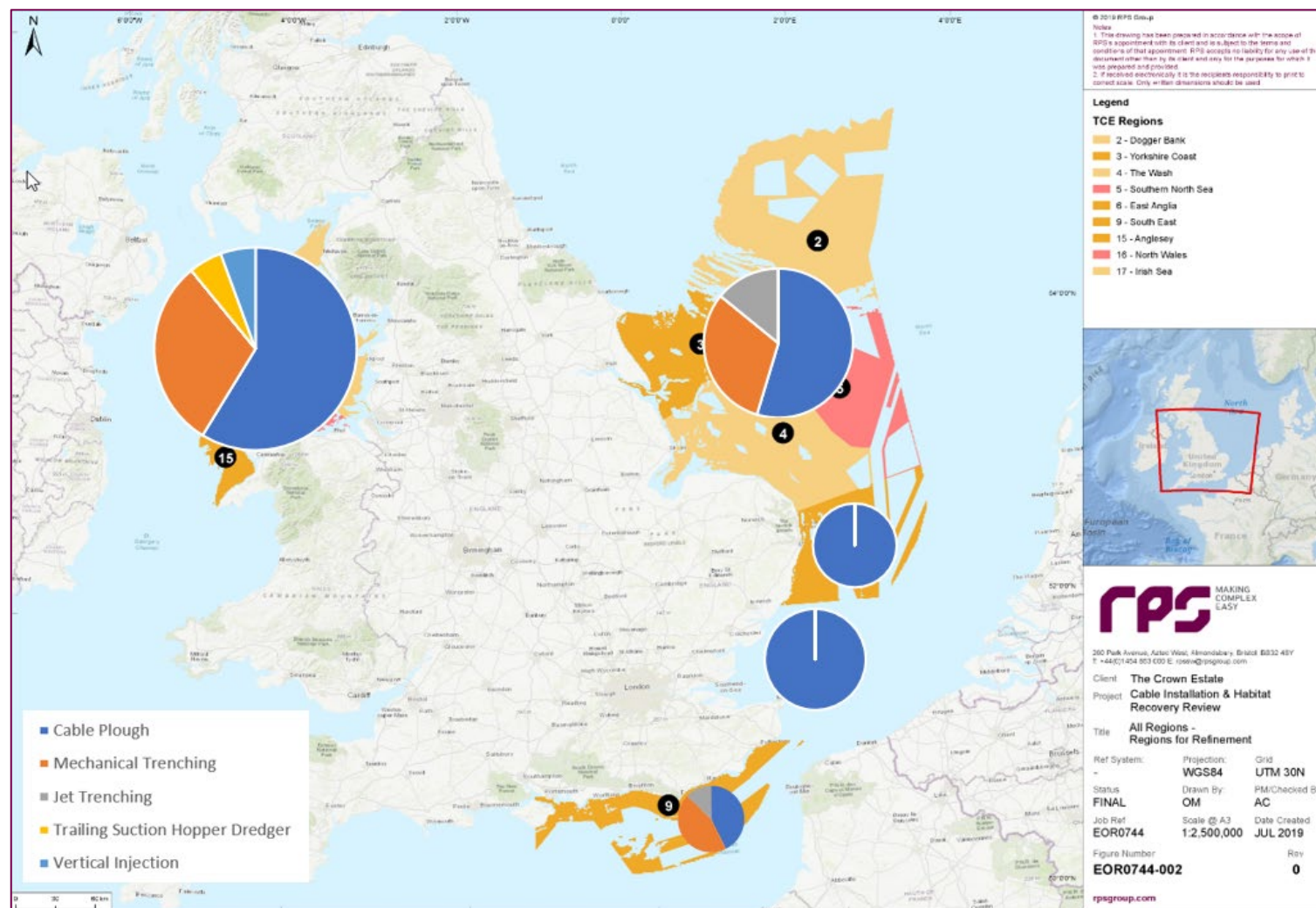


Figure 3.6: Summary Total Installation Lengths per Tool for each case study.

3.3.4.4 Taking all the available project information for the Case Studies (see for further discussion per Case Study), the protection lengths of installed export cables across each Case Study are presented in Table 3.8. These include remedial burial operations (e.g. using MFE and jet trenching) as well as placement of remedial cable protection measures. This includes the proportion (as a %) of the total length of installed cable which has required additional protection measures for each Case Study. As can be seen in Figure 3.7, the majority of these are comprised of remedial burial operations, with placement of cable protection (primarily rock and concrete mattress placement) accounting for approximately 1/3 of the post installation cable protection measures.

Table 3.8: Summary Cable Protection Measures within each Case Study.

Protection Measure	Installed Cable Length Protection Measure (km)					Total
	CS01	CS02	CS03	CS04	CS05	
Mass Flow Excavation (MFE)	19.3	0	0	0	0	19.3
Jet Trenching	0	0	0	4.54	41	45.54
Rock Placement	1.7	0	0.2	3.01	21.54	26.45
Concrete Mattresses	0.2	1.971	1.045	0	0.52	3.736
Concrete Bags	0.05	0	0	0	0	0.05
Total	21.25	1.971	1.245	3.01	63.06	95.076
Total Route length (km)	251.16	137.31	285.3	45	450.5	1169.27
Total Route length %	8.46%	1.44%	0.44%	16.78%	14.00%	8.13%
Total Non-burial Protection (km)	1.95	1.971	1.245	3.01	22.06	30.24
Total Non-burial Protection %	0.78%	1.44%	0.44%	6.7%	4.92%	2.59%

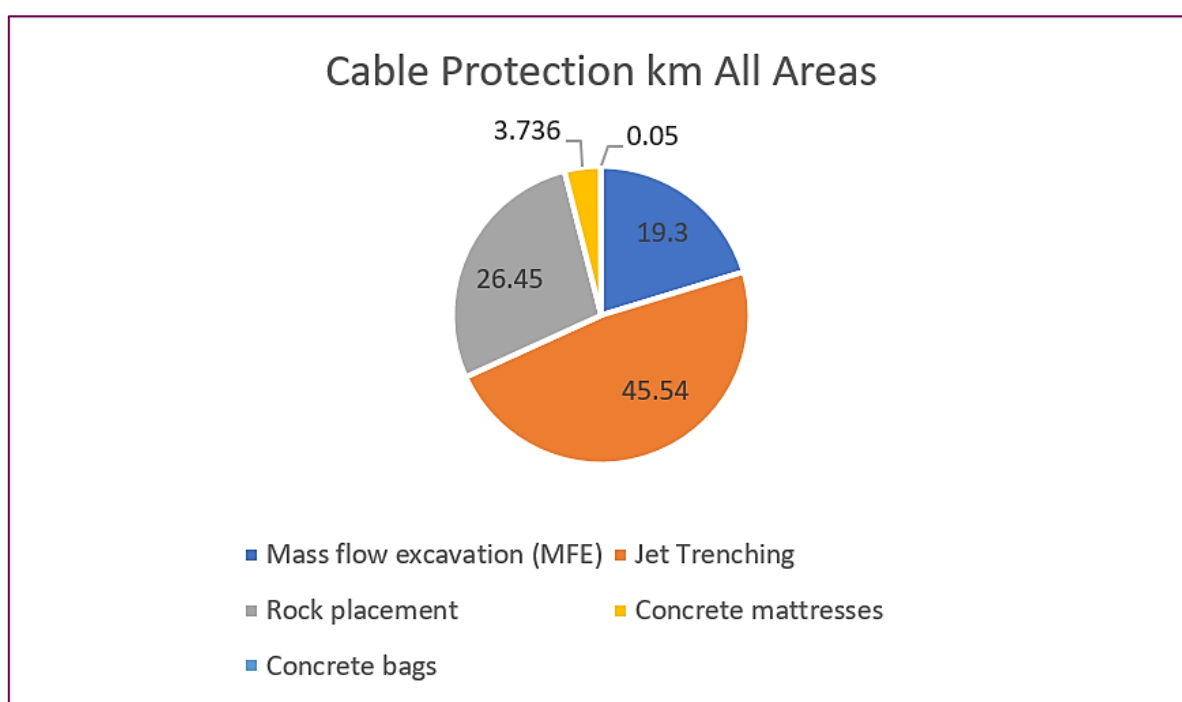


Figure 3.7: Total Protection Lengths per Method for all Case Studies.

- 3.3.4.5 Taking each Case Study and reflecting on the protection type used for the cable installation protection mitigation allows a clear visualisation of the trends used in these areas around the UK (Table 3.8). The sediment types, thickness and mobility can be subject to considerable variation and these factors can influence the choice of protection method. Figure 3.8 below provides a visualisation of the consistent use of rock and concrete mattress placement across all the Case Study areas, as well as the use of alternative non-permanent methods of increasing depth of cover, including MFE and mitigation jet trenching in the appropriate conditions.
- 3.3.4.6 Combining the data of installed cable lengths and protection lengths across each Case Study area (see Table 3.8), the percentage of installed cables requiring some form of mitigation reaches a maximum of 16.78% (Case Study 04 – South East). The average across all Case Studies is just over 8% of the route lengths requiring some form of remedial protection activities. However, placement of non-burial cable protection measures (i.e. rock or mattressing) accounted for <3% for all Case Study areas. This compares to recent consent applications where the non-burial cable protection parameters (e.g. rock or mattressing) are based on proportions of the overall export cables lengths of approximately 10% (e.g. Viking Link, Hornsea Three), but can be as high as 25% (e.g. Hornsea Projects One and Two).

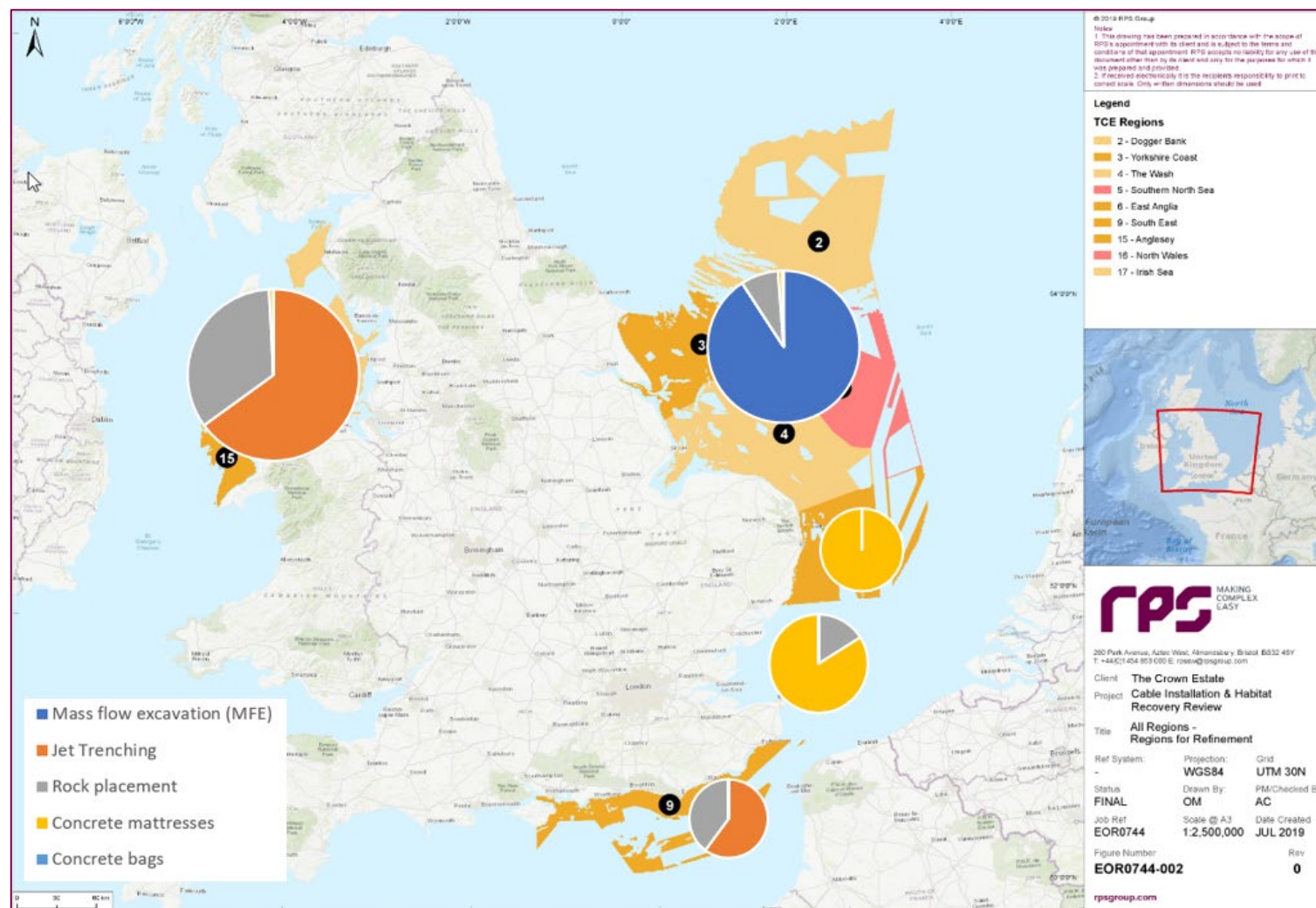


Figure 3.8: Summary Installation Protection Length per Method for each Case Study area.

3.3.5 Variance of Installation Tool Success Between Areas

3.3.5.1 Figure 3.9 below shows the percentage success for each installation tool type used in each of the case study areas. The installation tools/methods were used to different degrees across the five Case Studies, though three installation methods (i.e. plough, mechanical trenching and jet trenching) were used most commonly across the Case Studies, allowing for some comparison of the tools across regions.

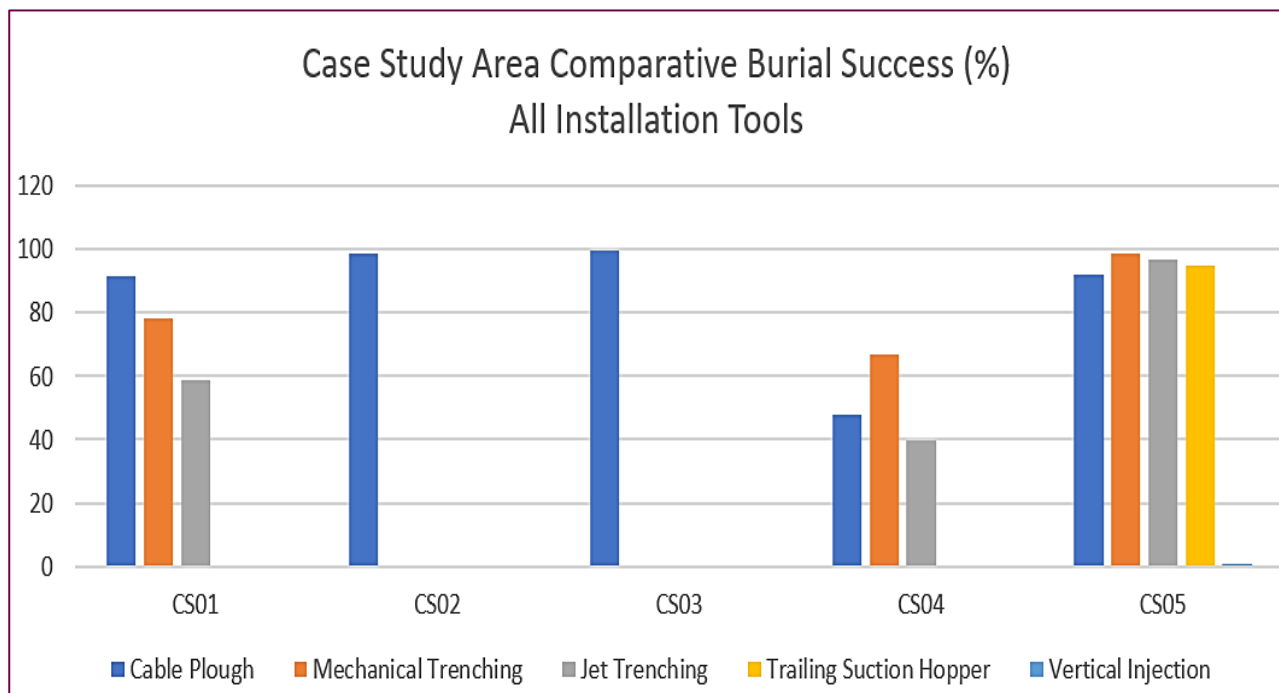


Figure 3.9: Comparative Burial Success for all Installation Tools.

3.3.5.2 When trying to establish a baseline for comparison between the Case Studies, information on ground conditions (i.e. sediment type, thickness, layering and subsurface geology) was limited across the Case Studies, particularly at a project level. The single directly comparable piece of information which was available from the case studies was the maximum shear strength (kPa) reported across the Case Study Areas; these are reported in Table 3.9.

Table 3.9: Maximum Shear Strength values for each Case Study Area.

Shear Strength	Case Study Area				
	CS01	CS02	CS03	CS04	CS05
kPa	175	150	175	266	150

3.3.5.3 The shear strength maximum value for each Case Study area can only be used as an indicative benchmark for the local conditions that were seen during cable installation. The direct comparison of burial success against shear strength kPa values are not intended to indicate that these typical tools are capable of these level of success for these shear strength values. This comparison can only be used as a single datum to indicate whether the installation campaigns were generally more or less likely to have seen high shear strength values compared to another Case Study area.

3.3.5.4 Figure 3.10 to Figure 3.12 present the relative success of cable plough, mechanical trencher and jet trencher against the maximum kPa for each of the Case Studies. Where Case Study 02 and Case

Study 03 show no data for mechanical trenching and for jet trenching, this indicates that there is no project data for those Case Studies and these installation tools (rather than 0% success).

- 3.3.5.5 Using the respective maximum kPa value as a bench mark for each Case Study, there is a correlation between each of the installation equipment types and the shear strength value. The higher the shear strength, the lower the percentage successful installation. The resultant decrease in burial success where higher shear strength values are expected to be present, directly correlates with the guidance in DNV (2016).
- 3.3.5.6 A secondary finding is in relation to the scale of impact on burial success between different installation tool types. Where the assumed same changes in substrate shear strength between different Case Studies is seen, there are different levels of success between the tools. The jet trencher and the cable plough are more affected by the increase in substrate shear strength and burial success reduces by over 50% across the Case Studies. In comparison, the mechanical trenching equipment cable burial success is reduced by a smaller degree, with greater burial success in harder soil types (e.g. CS04; see Figure 3.11). This finding is again in line with the DNV (2016) guidance (see Figure 2.2).

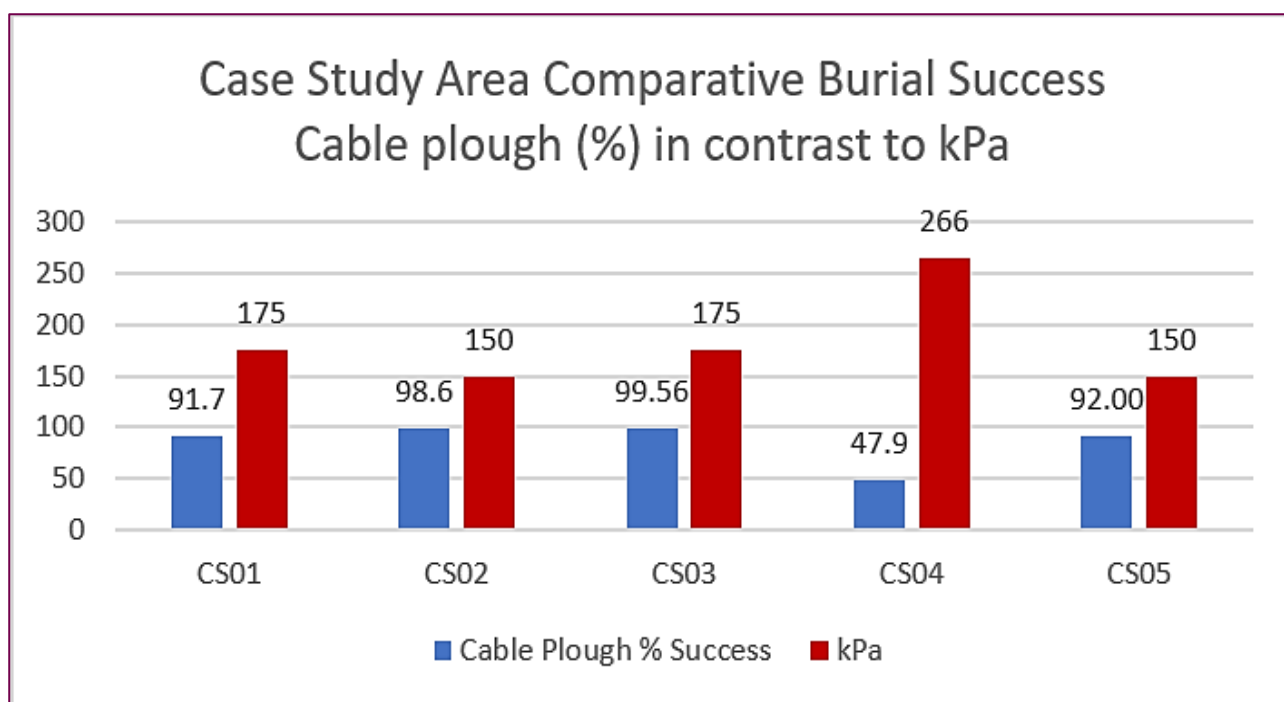


Figure 3.10: Comparative success of cable ploughs (%) relative to maximum shear strength values (kPa) for each Case Study area.

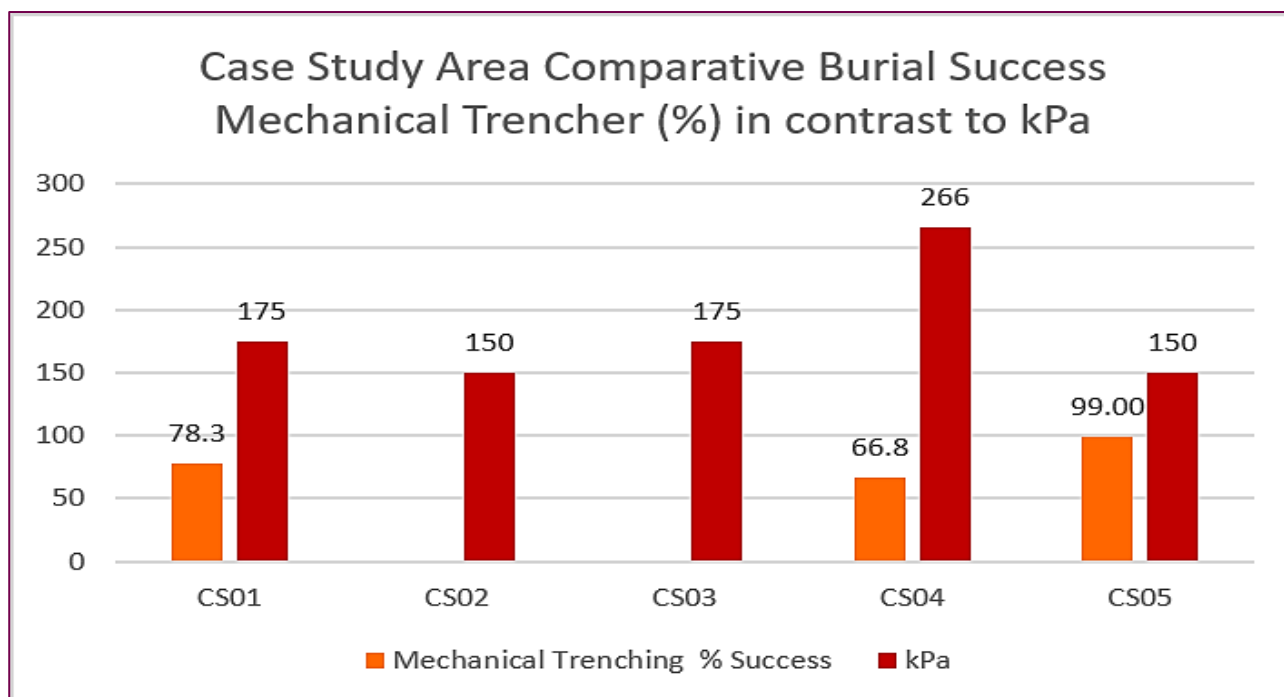


Figure 3.11: Comparative success of mechanical trencher (%) relative to maximum shear strength values (kPa) for each Case Study area.

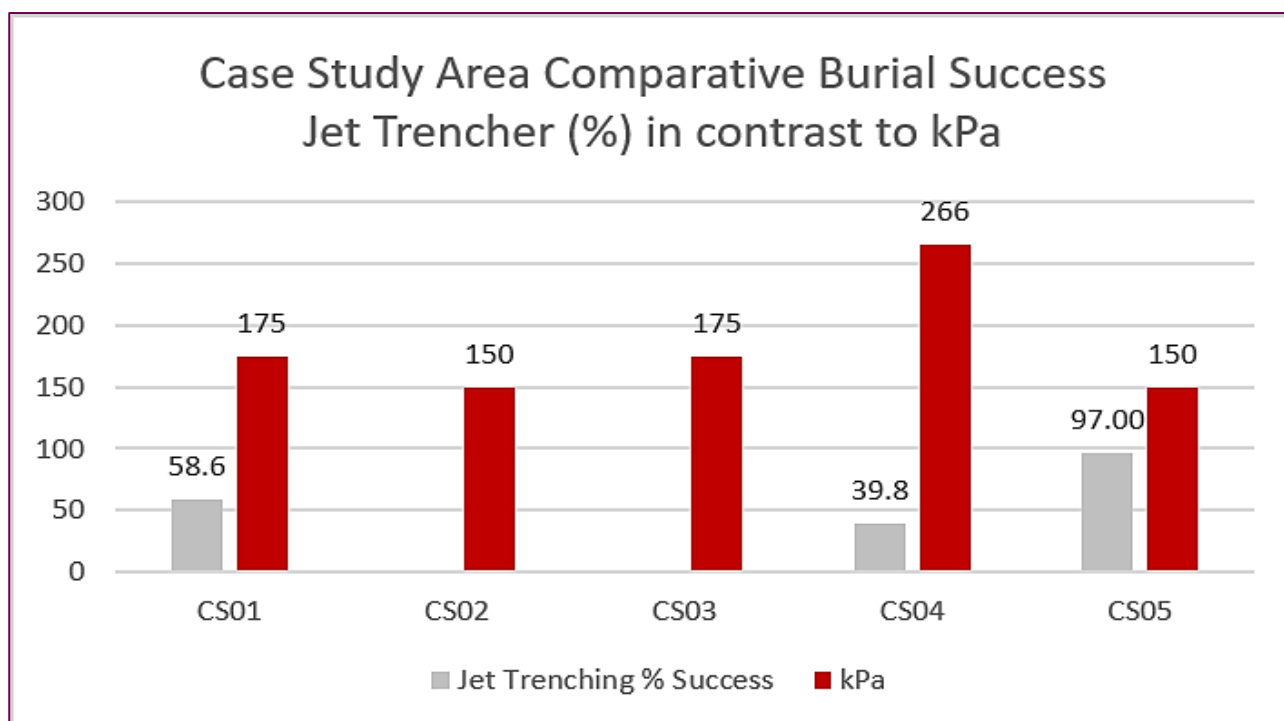


Figure 3.12: Comparative success of jet trenching relative to maximum shear strength values (kPa) for each Case Study area.

3.4 Conclusions – Effectiveness of Cable Installation

3.4.1.1 The original intent for this section of the report (see Section 1.2) was to capture an understanding of installed export cable assets, the burial equipment used, seabed conditions and remedial protection locations across the UK, in order to answer the following questions:

- To what degree is success of cable burial driven by ground conditions?
- Are cable protection requirements site specific (i.e. dependant on ground conditions), or do other factors influence whether these are required?
- Can detailed information on ground conditions be used pre consent to accurately establish cable burial and cable protection assumptions within consent applications?

3.4.2 Limitations

3.4.2.1 The conclusions of this part of the study are discussed below in the context of the data which was made available over the course of the study, however these should be considered with the following limitations in mind, principally related to the limited response to the questionnaire:

- There was a need to utilise publicly available sources of information in the absence of project specific data (see paragraph 3.2.4.2) and such information may not be completely accurate, in particular, data on:
 - cable protection locations;
 - cable installation lengths; and
 - installation tools along given route lengths.
- Remedial burial may have been undertaken on greater lengths of cable than assumed based on public information;
- BGS data on bedrock and sediment is assumed to be correct, but has limitations, including that this only shows information on the top sediment layer, without any direct data on thickness of the substrate above bedrock. Some information on thickness of sediment can be inferred based on any local exposed bedrock or lack of exposed bedrock, though this is fairly binary or not conducive to allow conclusive statements to be made;
- Where project data is not complete, in particular depth of burial requirements, the working assumption has been that for projects in the same case study area, these are likely to have similar sediment conditions and perceived anthropogenic risk to the cables, and have therefore been aligned with a similar depth of burial;
- Where the quantity of remedial rock protection is identified as a volume, this has been calculated to an assumed rock density of 2.7 t/m³;
- Where the quantity of remedial rock protection is identified as a weight, this has been calculated to an assumed rock berm height of 0.5 m and 3.1 t/m of protection length. Please note that this does not apply to crossings and assumed only as remedial rock placement to complete the depth of burial activity above a cable.

3.4.3 To what degree is success of cable burial entirely driven by ground conditions?

3.4.3.1 The success of cable burial is driven by ground conditions. The ground conditions dictate the physical effort it will require to install the cable below the seabed.

- 3.4.3.2 Across the Case Study areas, the predominant installation tool type was the cable plough. The sediment layers across the clays, peats and bedrock formations are varying and when looking for a tool that is robust enough to handle varying conditions, it is the cable plough that is often offered and opted for by developers. This is not irrespective of the soil conditions, but a reflection on the wish to complete the burial as best as possible to minimise the risk to long term cable integrity.
- 3.4.3.3 There are a large number of factors that directly affect the outcome of the installation campaign:
- Are the ground conditions well understood?
 - The fundamental understanding of the anticipated ground conditions is key in the selection of the appropriate tool. There are some types of tool better suited to certain types of soil conditions. Section 2 provides an overview of the different installation equipment types and utilisation in various sediment densities, as acknowledged by DNV (2016), where fluidising the seabed with jet trenchers is appropriate for less dense soil conditions, ploughs offer solutions in denser soil conditions, but it is only mechanical trenchers that can tackle very stiff and hard sediments.
 - Cable protection requirements are site specific. The burial of the cable into the seabed with the sediment resting directly above the cable is the protective layer. The sediment characteristics of that particular area are therefore going to dictate the vulnerability of the cable and the level of exposure to risk of damage.
 - Where the sediment is loose and of low shear strength there is highly likely to be a requirement for a deeper depth of burial when compared to chalk bedrock, where the external risk factors are the same.
 - It is not always the most appropriate installation tool that is selected for a particular part of a cable burial campaign. The overall understanding of the soil conditions is usually considered and a perspective on the dominating route conditions and likelihood of achieving burial success is weighed up against a range of factors. These include failure to meet the depth of burial and the obligations in terms of cost and effort to mitigate. For example, for a long cable route, where short sections appear to have significantly harder substrate but are spaced far enough apart to not consider using a mechanical trencher for the whole route, it may be more economically advantageous to either, use rock as burial mitigation instead of continuously swapping between installation tools, or to choose a tool that avoids standing bites (i.e. short sections of shallow buried cables) by swapping tools and is therefore also likely to create a need for rock placement to protect the cable.
 - There may be environmental considerations, in areas where cabling is of particular concern (e.g. within MPAs there may be implications for the conservation objectives for certain features for example reef habitats), and these may have an influence on the cable burial strategy, depending on the specific sensitivities and environmental objectives (e.g. avoidance of sensitive habitats).
 - Anthropogenic risk in the vicinity of the cable route is often the driving force for determining the depth of burial. The location of the cable route in relation to other activities allows for appropriate determination of burial requirements, in conjunction with the sediment conditions.
 - Seabed mobility is felt to be harder to discern as accurately as the ground conditions themselves but has a major role to play in understanding the non-mobile reference level for long term cable protection. Where it is not possible to identify the non-mobile reference level, the effective datum for measuring the depth of burial is non-existent. This can lead to issues including cables becoming exposed and at risk of damage or conflict with other marine users or a lack of understanding of the potential for over-burial

and the cable design not being robust enough for increased temperatures at greater depths, with the possibility of generating a hot spot and de-rating the cable capacity or risking the cable integrity.

- The contract mechanism for completing the cable installation campaign could have an influence. For example, how the “best endeavours” of the Engineering, Procurement and Construction (EPC) contractor are formulated, or if the absolute burial of the cable is the key requirement, with all mitigating burial actions included under the contract. Such differences in the contracting mechanism is likely to have an influence on behavioural performance during installation.
- In addition, there may be other factors related to breakdown of equipment or vessels, which may affect successful cable installation.

3.4.4 Are cable protection requirements site specific (i.e. dependant on ground conditions), or do other factors influence whether these are required?

- 3.4.4.1 As outlined in Section 3.3, remedial cable protection activities are split into two main cohorts, those that involve burial activities (e.g. jet trenching), and those that are non-burial protection techniques (e.g. rock placement). In cases where installation of the cable has not been fully successful, remedial action can be taken in order to further protect the cable. The proposed activities will depend on the principal installation method, equipment, ground conditions and scope of the contract with the EPC contractor.
- 3.4.4.2 Where a greater amount of cover is required for the protection of the cable, the environmental conditions and the installation methodology must be taken into account. For example, in cases where the principal installation tool is a typical mechanical trencher and the burial is not sufficient, the option to attempt burial via a second pass with the same tool is not usually viable. The remaining options depend on the availability of a suitable tool for remedial burial (e.g. jetting trencher) or placement of non-burial protection. Similarly, if a cable has been installed by a cable plough, there may be tension on the cable, meaning that remedial burial may not result in a greater depth of burial beyond that achieved during the initial installation phase.
- 3.4.4.3 When considering the viability of a jetting trencher for remedial burial, the ground conditions must be considered carefully. At this point in the installation process, the cable is already partially buried and as the sediment deepens, it is more likely that the stiffness value will increase, with implications for the viability of tools such as jetting trenchers. In addition, the sediment grain size in the cable corridor need to be considered, due to the need to fluidise the sediment for long enough to allow the cable to be lowered further below the seabed. This is likely to be more successful in finer sediments (e.g. sands) than gravel, as gravels are extremely difficult to fluidise for a duration long enough to provide further lowering of the cable.
- 3.4.4.4 For example, in Case Study area 05, it is understood that a number of principal installation tools were used during the installation phase, i.e. plough, mechanical trenching, jet trenching and TSHD. Where it was determined that cable burial depths were not sufficient in some areas and mitigation required, jet trenching was the primary method used, followed by rock placement (see Table 3.8). The rationale for choosing a burial method, rather than non-burial protection (i.e. rock placement) was supported by the understanding of the sediment conditions, with limited amounts of gravel in the northern part of the cable corridors portion. Where conditions (including sediment type) were not deemed to be conducive or cost effective to attempt remedial burial, rock placement was undertaken.
- 3.4.4.5 Remedial cable burial activities that are non-burial techniques come in a fairly limited number of generally accepted forms. These have been described above in Figure 2.7 as:

- Tubular product;
- Mattresses; and
- Rock placement.

3.4.4.6 The results of this part of the study provide an overview of the non-burial cable protection techniques used in UK waters, with inclusive techniques of rock protection, mattresses and concrete/rock bags. Project data available does not show the use of tubular products, with the exception of a Horizontal Directional Drill (HDD) and J-Tube type construction (Note: non-burial protection measures related to HDD and J-Tubes were not included within the case study review). As per Figure 3.8, non-burial cable protection methods are used in a variety of sediment conditions, in a variety of water depths, seabed mobility level and wave and current action conditions.

3.4.4.7 The use of a particular non-burial remedial protection is almost always at the discretion of the developer, unless otherwise stated as a licence condition. There are considerations to be taken when deciding on which technique is most suitable, these include:

- Water depth: where there is a reduced water column, often any licence will limit the reduction on the water column. This may steer a decision towards mattresses over rock as no specific rock berm is required and mattresses are often lower in profile.
- Sediment types: where there is very loose sand, this may lead to rock protection sinking into the seabed and reducing the cable cover. It is worth noting that designing the protection appropriately for loose sediment is very important, even by choosing mattresses there is a risk that poor design leads to the cable supporting the weight of a mattress, with consequent risks to the cable integrity.
- Wave and current data should be considered as part of protection stability analysis, in combination with developing the rock grading if required. The wave and current information allow decisions to be made on the size of rocks required for the rock berm to be stable. The grade of the rock has implications on the ease and cost of installation. Too large and a typical fall pipe vessel may not be able to support the installation and single grab installation needs to be completed instead. Whilst individual rocks may initially be at some risk of moving during significant weather, once the berm has been in place for some time, it would tend to settle and become even more robust and stable in position. Mattresses are, on their own, not typically more stable than rock.

3.4.5 Can detailed information on ground conditions be used pre consent to accurately establish cable burial and cable protection assumptions within consent applications?

3.4.5.1 The level of engineering input in support of the consenting process in the UK is appropriate to inform the environmental assessment required to achieve consent, noting that for developments within SACs, a higher level of detail may be required to fulfil the requirements of the HRA process (see Section 1.5). Development expenditure above the minimum is all at risk capital from an investor and developer perspective. The typical process of project development will seek to de-risk the programme of works such that consent is achieved prior to committing to large scale EPC contracts which are costly to renege on, or open the door to, significant variation orders should delays occur or unexpected licence conditions form part of the project development.

3.4.5.2 Each EPC contractor for cable design, manufacture and installation has their own specific benefits and draw backs, their own cable design preferences, their own options of installation equipment, and their own support from subcontractors to complete the execution, etc. As such, the variations in the possible combinations of methods of cable burial and cable protection to provide specific input into the environmental assessments and consent applications would be vast.

- 3.4.5.3 It is usually expected that some engineering input is undertaken pre-consent, for example determining approximate depth of burial, identifying areas where pre-clearance activities may be required etc., in order to inform the environmental assessments to support consent applications. As set out above, where these occur in SACs (and other MPAs), a greater level of input may be required. These engineering inputs are usually based on the findings of an initial seabed survey of the offshore wind farm and export cable routes. However, these do not typically extend to the production of detailed CBRAs and possible RBBB reports as part of consent applications, although some of the preliminary work to inform these, e.g. derive the precise Depth of Burial requirement along the cable routes, is undertaken pre-consent to inform the project design envelope.
- 3.4.5.4 For offshore wind farm projects, these engineering assessments/reports are usually produced post consent and often need to be submitted to the relevant regulatory authority as a condition of the consent granted. In many cases, these use information from the original seabed survey (undertaken pre-consent), although for many offshore wind farms, these may also be informed by a post consent seabed survey, which may provide more detail on the seabed conditions (e.g. degree of seabed mobility) to inform the CBRA and the Depth of Burial across the route. Following production of the CBRA, the next step is to develop the Burial Assessment Study (BAS), which requires a significant effort and detailed information on specific installation tools.
- 3.4.5.5 Upon completion of the BAS, it is understood where along the cable route there is a lower likelihood of successful cable burial for a particular tool. The likelihood then provides an indication of possible areas along the route where mitigation activities may be needed. The BAS lower burial probability areas are estimates based on the available data, against an expected installation tool performance, using assumed and interpreted ground conditions.
- 3.4.5.6 While this type of assessment might be useful to inform a consent application (e.g. to inform where cable protection may be required), completion of the BAS prior to consent would be costly given the number of possible contractors, tools and the different ways to mitigate the unsuccessful cable burial.
- 3.4.5.7 Without knowing the specific contractor, installation tools and intended mitigation strategy, there are a multitude of different options, as represented in typical offshore wind farm consent applications, which include wide project design envelopes to cover these options. As such, undertaking the BAS too early (e.g. during consenting) would likely result in a BAS that is too restrictive (e.g. restricting the project to a single or small number of tools) and could be found to be inadequate and inappropriate at a later date (e.g. due to unforeseen ground conditions). The flexibility in the approach to cable installation is a necessity to ensure that costs are minimised as much as possible and to take into account the variability in the market with respect to the tools for cable installation. An overly prescriptive BAS would likely result in increased costs, through the need for remedial activities where unforeseen ground conditions or inappropriate tool selection leads to more time and effort to complete the installation. This may also increase the need to deploy greater amounts of non-burial protection (e.g. rock or mattresses), due to unsuccessful burial during the initial installation.
- 3.4.5.8 For the data presented in this report, the projects have had varying levels of successful burial. The burial campaigns were intended to reach Depth of Burial and while this has been reached in most of the cable routes, for a number of reasons this has not been completed for some parts of the cable routes.
- 3.4.5.9 The projects in most cases had the ability to remedy the Depth of Burial through post installation activities such as jet trenching, to increase their burial success. However, in all Case Studies, non-burial techniques have been required at points along some of the cable routes, regardless of the location along the cable route (Note: not all projects within the individual case studies required remedial burial or cable protection).

- 3.4.5.10 There are a lot of ground conditions in the UK including, boulders, clay pockets, peat pockets, and inconsistent substrate shear strength, that are more difficult to identify and predict with complete accuracy. As such, developers include a range of cable installation tools and methodologies (including non-burial techniques) to ensure that the most appropriate tools are consented to deal with unforeseen eventualities and ensure a successful cable installation. If an onus on absolutely clear understanding of non-burial mitigation activities were to be specified prior to consent application, then there is a high likelihood of developers pushing EPC contractors into utilising over specified tools for the given conditions. Whilst this may support cable burial, the level of environmental impact (e.g. use of non-burial techniques) could be affected.
- 3.4.5.11 Further discussion of recommendations, including possible information requirements for future consent applications or post consent, are presented in Section 5. This includes recommendations on requiring more detailed information on ground conditions which could be provided during consenting, where cabling is proposed within MPAs.

4 ENVIRONMENTAL IMPACTS AND RECOVERY

4.1 Background

- 4.1.1.1 As part of the scope of works for this project, TCE identified a paucity of information on impacts to benthic communities and seabed habitats from cable installation and cable protection. There is a perception that predicted impacts made in Environmental Statements are often referred to which may not have been subsequently validated or are based on outdated sources of evidence.
- 4.1.1.2 As such, the purpose of this section of the report is to present a comprehensive desktop review of the findings of all publicly available monitoring reports for existing and consented power cables, to improve the evidence base on impacts and recoverability of seabed habitats and benthic habitats/communities specifically relating to the extent of direct impacts on the seabed (e.g. from cabling or cable protection, including scour) and recovery timescales for seabed sediments and associated benthic communities.

4.2 Methodology – Data Review

4.2.1 Data Sources

- 4.2.1.1 This task has been informed by a comprehensive review of data held by the following sources:
- TCE's Marine Data Exchange (MDE);
 - National Infrastructure Planning Project Register;
 - The MMO's Marine Case Management System (MCMS) Public Register; and
 - RPS knowledge and experience.
- 4.2.1.2 The first step in this process was to identify all the available seabed monitoring reports for UK offshore wind farms from the sources outlined above. These were not limited to benthic monitoring reports, but also included post construction geophysical survey reports, which were usually undertaken for the purposes of assessing the integrity of the assets (i.e. foundations and cables), including effects of scour. In order to ensure the most appropriate information sources were used to inform the assessment, a rapid review of the publicly available information was undertaken and an Excel spreadsheet database of these was created. This was circulated to the Steering Group for their feedback in order to highlight which information sources were being used to inform the assessment and to allow stakeholders to identify further reports or information sources which may be relevant to the study. This was followed up by a more detailed review of the available reports, as described in Section 4.2.2.
- 4.2.1.3 As part of the Steering Group consultation in May 2019, it was requested that the members of the group review this database and highlight any omissions. Following the Steering Group meeting, Natural England and Natural Resources Wales highlighted a number of relevant monitoring reports for a number of wind farms, including Gunfleet Sands, Scroby Sands, London Array, North Hoyle, Burbo Bank Extension and Thanet offshore wind farms. While some information on these projects has been made available, the specific reports highlighted by the Steering Group (specifically for Thanet and Burbo Bank Extension) were not available (either on the MDE or other public sources) to RPS to inform this assessment.

4.2.1.4 No monitoring reports which were relevant to this study (i.e. studies which could be used to infer seabed impacts and recoverability following cable installation) were found in the public domain (including the sources outlined above) for the following offshore wind farms:

- Gwynt y Môr;
- Galloper;
- Rampion;
- Rhyl Flats; and
- West of Duddon Sands.

4.2.2 Review of Data Sources

4.2.2.1 Once the monitoring reports were downloaded, each was reviewed to consider whether the reports and data presented within them would be useful for the purposes of informing the review of effects on seabed habitats and benthic ecology from cabling (i.e. array or export cables). As outlined above, the majority of the reports reviewed were not specifically designed to monitor the effects of cabling on the seabed, although these did provide useful data on the condition of the seabed following cable installation and in the subsequent years after cable installation had occurred. In some cases, these monitoring reports provided time series data, allowing for some commentary on the recovery of the seabed over time.

4.2.2.2 The monitoring reports were summarised for each of the offshore wind farm projects individually (see Appendix C) and the broad patterns in the monitoring data available identified (Section 4.3.2). This evidence is considered in the context of other evidence on the effects of cabling on seabed habitats and benthic communities, typically considered in offshore wind farm EIAs, which are discussed further in Section 4.3.1 below.

4.3 Assessment of Environmental Effects of Cable Installation

4.3.1 Background Information

Predictions from Historic Environmental Statements

4.3.1.1 Typically, EIAs for offshore wind farms assess the effect of cable installation on seabed habitats as part of a broad impact assessment which considers a range of activities and impacts from offshore wind farm construction and operation. This approach has been adopted due to the relatively wide project design envelopes considered for offshore wind farm projects, which for cable installation, include a range of installation tools. Cable installation tools interact with the seabed in different ways, as outlined in Section 2; for example cable ploughs typically result in minimal displacement of sediments as the cable is simultaneously buried and laid, while jetting may result in a greater sediment displacement as surface sediments are brought into suspension in order to bury the pre laid cable. However, from the perspective of the impact assessment, the *type* of effect on seabed receptors (e.g. benthic ecology communities, seabed sediments) is similar for the cable installation tools, with all installation methodologies resulting in some level of disturbance or displacement of surface sediments and recovery of sediments and associated fauna following cable installation. However, the level and consequences of this effect, i.e. the *magnitude* and *significance* of the impact, will vary depending on details of the installation tool (e.g. footprint of tool, volume of sediments disturbed etc.) as well as site specific details, including the seabed type, seabed/sediment mobility and the sensitivities of the benthic ecological receptors present.

- 4.3.1.2 In certain circumstances, there is a need to undertake more detailed, receptor specific assessments. For recent EIAs, this has included consideration of effects of cable installation on sensitive habitats such as reef habitats (e.g. biogenic and rocky reefs), although direct effects on these are usually avoided through micrositing, noting that in some cases avoidance has not been possible (discussed further in paragraph 4.3.2.13). Recent EIAs have also given specific consideration to certain activities including sandwave clearance and boulder clearance.
- 4.3.1.3 Impact assessments based on a maximum/worst case design scenario usually assess a maximum disturbance corridor within which cable installation activities occur. The width of disturbance associated with cable burial is typically 10-15 m. This corridor is the entire footprint of the installation tool, not solely the width of the cable trench, which is usually up to a few metres wide depending on the installation tool used. Wider corridors have often been included in the project design envelope, where pre-clearance activities such as sandwave clearance and boulder clearance are required (e.g. between 20 and 30 m wide). Sandwave clearance activities may also include disposal of cleared material, although this is not relevant for all clearance tools (e.g. MFE).
- 4.3.1.4 It is noted that while Round 1 and Round 2 offshore wind farms considered effects of cabling from relatively short export cable routes (i.e. 10s of km lengths), more recent offshore wind applications including some of the Round 3 offshore wind farms currently in construction have much longer export cable routes (sometimes >100 km), with consequently greater footprints.
- 4.3.1.5 Benthic ecology assessments often draw upon the physical processes assessments and supporting modelling conducted for the EIA, where relevant. Assessments of effects on physical processes consider the differing effects of the cable installation tools on the volumes of sediment disturbed or actively displaced from the seabed during cable installation. Jetting is generally considered to result in the greatest volume of sediment disturbance (i.e. the maximum design scenario), although other factors including the hydrodynamic regime, baseline sediment types, volumes and types of sediments displaced, are also considered. As outlined above, recent EIAs have also given consideration to pre-clearance activities such as sandwave clearance, which involves the removal or reprofiling of sandwaves to maximise the potential for cable burial (e.g. by dredging or MFE; see paragraph 2.3.1.2); sandwave clearance monitoring data are discussed further in Section 4.3.2 below. In general, these impact assessments have predicted that for soft sediment environments (i.e. sand and gravel habitats which dominate the southern North Sea and Irish Sea), cable trenches infill over time (e.g. Ørsted, 2018a and 2018b; Vattenfall, 2018a and 2018b), with benthic communities recovering into the affected areas as the sediments re-establish. As such, previous reviews of the effects of cable installation on seabed habitats (e.g. BERR (Department for Business, Enterprise and Regulatory Reform), 2008; MMO, 2014; Renewables Grid Initiative, 2015) have concluded that cable installation effects result in temporary and localised effects, particularly in the context of the impacts of offshore wind turbine installation.
- 4.3.1.6 In contrast, placement and presence of cable protection (i.e. remedial protection and protection at asset crossings) over the operational lifetime of the project is considered to represent a change in the habitat type and is therefore usually considered as long-term habitat loss. The degree of change of habitat type, and consequent effect on benthic ecology communities, will depend on the material used for cable protection (e.g. rock protection, concrete mattresses, rock bags etc.) and the receiving environment. For example, introduction of rock protection within a muddy or sandy sediment environment would be expected to be a more profound change of habitat compared to introduction of rock into a naturally rocky or coarse sediment (e.g. cobbles and boulders) dominated environment. However, due to the uncertainties associated with the effect of cable protection on benthic communities (discussed further in Section 4.4.4), for the purposes of the EIA, cable protection is usually considered long term habitat loss.

Evidence Used to Support Impact Assessments

- 4.3.1.7 Evidence used to support impact assessments come from a range of sources, although one of the key sources of information on the sensitivity and recoverability of different seabed sediment types and associated benthic ecology communities is the Marine Evidence based Sensitivity Assessment (MarESA). The MarESA methodology provides a systematic process to compile and assess the best available scientific evidence to determine the sensitivity (considering factors such as resistance, resilience and recoverability) of marine and coastal habitats in the northeast Atlantic (Tyler-Walters *et al.*, 2018). This methodology was developed by the Marine Life Information Network (MarLIN) team at the Marine Biological Association of the UK and built on (and superseded) the previous sensitivity assessments developed through the MarLIN approach. The resultant 'evidence-base' has become a useful source of information for the application of the sensitivity assessments in management and planning decisions and is advocated by regulators and statutory nature conservation advisors for use in EIAs.
- 4.3.1.8 In addition to the MarESA evidence base, evidence from other industries has also been used to inform offshore wind EIAs, including oil and gas and telecommunications cabling. Historic monitoring and research undertaken for the aggregates industry is one information source which is highly relevant to assessing the effects of cable installation (and other offshore wind farm construction activities), particularly due to both aggregates and offshore wind farm developments occurring in similar parts of the UK continental shelf (e.g. the southern North Sea, the Irish Sea and English Channel) and therefore affecting similar seabed habitat and sediment types.
- 4.3.1.9 The Marine Aggregates Levy Sustainability Fund (MALSF) was a programme of marine research undertaken from 2004 to 2011, funded by a UK Government levy on primary marine aggregate production. The main aim of the MALSF programme was to promote environmentally friendly aggregate extraction in the marine environment in English waters. A large number of research and monitoring programmes were funded by the MALSF, including those that investigated the effect of aggregate extraction (i.e. dredging) on seabed sediments and associated benthic ecology communities. These studies, alongside other monitoring and research undertaken at other aggregate extraction sites and prior to the MALSF, provide a robust evidence base for the effects of sediment removal/disturbance on subtidal seabed habitats/sediments and these have been used to inform the MarLIN sensitivity assessment and subsequently the MarESA evidence base.
- 4.3.1.10 In general, these studies indicated that benthic communities recover into areas affected by aggregate extraction, following cessation of dredging, if the sediment type is reflective of the baseline environment (e.g. see Tillin *et al.*, 2011; Robinson *et al.*, 2005; Marine Ecology Surveys Ltd., 2008; Newell *et al.*, 1998; Desprez, 2000; Newell *et al.*, 2004; Pearce *et al.*, 2007). These studies demonstrated that the timescales for recovery of seabed habitats depend primarily on the sediment composition, with sandy sediments recovering over relatively short timescales (e.g. months to 1-2 years; Newell *et al.*, 2004) and coarse, gravelly and mixed sediments showing longer recovery timescales, usually within 5 years (see Desprez, 2000; Newell *et al.*, 1998; Pearce *et al.*, 2007), but in some cases, recovery has been reported as taking up to nine years following cessation of dredging (see Foden *et al.*, 2009).
- 4.3.1.11 It should be noted when considering evidence from aggregate extraction sites that the degree to which seabed habitats are affected from cable installation are considerably smaller in magnitude than aggregate extraction. For example, aggregate extraction typically extracts sediment (i.e. removal of habitat) to several metres deep within licensed extraction sites, while cable installation displaces tens of centimetres of sediment in a relatively narrow corridor. Sand and gravelly sediments (e.g. sandy gravel) have been reported as recovering from cable burial activities within approximately one year following cable installation (Andrulewicz *et al.*, 2003, as reported in Foden *et al.*, 2011). However, as outlined in paragraph 4.3.1.3, with the greater export cable lengths (and inter array cables) for larger offshore wind farms currently being constructed/consented, the overall

footprints of export cables have considerably increased compared to the Round 1 and Round 2 offshore wind farms reviewed for this study.

- 4.3.1.12 Offshore wind farm EIAs have also referred to the evidence collated from pre and post construction monitoring programmes for the offshore wind industry in order to inform EIAs. While these monitoring reports largely focus on effects of offshore wind farm array construction and operation (e.g. foundation installation, scour around foundations), some monitoring has also been undertaken on the effects of cable installation and operation on seabed features habitats, such as rocky reef habitats and subtidal sandwaves (further discussed in Section 4.3.2 below and Appendix C).

Industry Reviews of Evidence

- 4.3.1.13 A number of reviews of the effects of cable installation have been undertaken since the first rounds of offshore wind development in UK and European waters, including two reviews specific to the UK offshore wind industry, i.e. BERR (2008) and the Marine Management Organisation (MMO, 2014) and a wider review of the effect of electrical cabling, including from offshore renewables and interconnectors, i.e. Renewables Grid Initiative (RGI, 2015).
- 4.3.1.14 The BERR (2008) review presented an overview of cable installation techniques and reviewed environmental effects of cabling on a wide range of receptors. For effects on benthic ecology, this review drew upon evidence from the aggregates industry and other sources, as outlined in paragraphs 4.3.1.7 *et seq.* above. This concluded that recovery following cable installation was dependent on a number of characteristics including the nature of the seabed/sediment type, communities present, the duration and footprint of the proposed activity and the degree of disturbance already experienced (e.g. from demersal fishing activity). This review provided a summary of potential effects from disturbance on seabed habitats as follows:
- Rock – some scarring may occur dependent on the rock type e.g. effects on soft rock such as sandstone habitats will be more significant. Encrusting and attached fauna and flora can be dislodged/disturbed. Species inhabiting rock habitats are often sessile species and are therefore more susceptible to disturbance.
 - Chalk – a permanent scar is likely. Cable burial techniques will disturb epifauna/ flora inhabiting chalk habitat. Disturbance of chalk will cause a high visibility plume which will remain in suspension for long periods of time, but which is unlikely to cause more than an aesthetic effect.
 - Clay – A permanent scar will be left in stiff clay habitats following cabling activity. In soft clay, infilling is expected to occur rapidly. In harder or stiffer clays, a cutting wheel disc is often used which allows a wedge of soil to be cut by the action of the plough. This process leaves minimum disturbance to the seabed with no spoil mounds. Spoil mounds are only found with 'V' shape plough shares more commonly associated with pipeline burial. Clay supports a species poor community due to the cohesive nature of the substrate. Cabling through soft clay is likely to put more sediment into suspension than in stiff clay where the habitat is more cohesive.
 - Sand – Sand will infill rapidly following disturbance by ploughing or trenching. Burrowing species may be affected but are generally adapted to change through natural disturbance due to the mobility of the substrate.
 - Gravel – Certain types of gravel habitat will infill immediately following cable laying activity, others may leave a shallow trough following initial infill. Generally, species inhabiting mobile gravel are adapted to harsh living conditions and would be expected to recover quickly.

- 4.3.1.15 The BERR (2008) review also noted that there had been a deficit in the monitoring of offshore wind farm cable burial activities, as the impacts have been regarded as secondary in terms of scale when compared with those from the installation and operation of the wind turbines.
- 4.3.1.16 In 2014, the MMO published a report which provided a review of environmental data from post consenting monitoring for offshore wind farms in the UK. This review found that seabed monitoring for the early rounds of offshore wind farms was primarily focussed on effects of scour around turbines and cables to assess the integrity of these assets and the need for protection measures (e.g. scour and cable protection). These monitoring reports did not therefore specifically look at the degree or rate of recovery of the seabed based on the data collected during post construction monitoring.
- 4.3.1.17 With regard to effects on benthic ecology, the MMO review found that the focus of benthic ecology monitoring was on survey designs that allowed for any major changes in the infaunal community to be monitored. Based on the offshore wind farm monitoring evidence considered, the MMO (2014) review reported that no large-scale impacts were identified. The MMO review reported that the data indicated a lack of ecological impact due to cable laying and that where cables are laid, an initial disturbance to the seabed would be followed by a period of recovery, unlike conditions created by the installation of the turbine or scour/cable protection, where longer lasting effects would occur (paragraph 4.3.1.16). However, one of the main limitations of these monitoring datasets was that benthic infaunal data were collected within the cable corridors, and therefore were likely to be in areas of seabed close to, although not directly within those impacted by cable installation (i.e. cable trenches; discussed further in Section 4.3.2 below).
- 4.3.1.18 The review undertaken by the RGI (2015) provided an overview of electrical cable installation techniques and a review of the current evidence of environmental effects on a range of receptors. The study was also based on stakeholder data collection, including an online survey and interviews with a range of stakeholders, industry representatives and marine environmental specialists, to understand stakeholder concerns and perceived evidence gaps in relation to offshore electrical cables. In line with previous studies, the RGI (2015) review reported that compared to other offshore activities such as bottom trawling, ship anchoring or large scale dredging, seabed disturbance resulting from subsea cable activities is considered to be temporary and have a relatively limited extent (Carter *et al.*, 2009; OSPAR, 2012), with the seabed usually returning to its original state (BERR, 2008).
- 4.3.1.19 The general conclusion from the RGI (2015) study was that although the effects of cable installation on seabed habitats are considered to be relatively well understood, there is a perception amongst stakeholders that there is a need for further study, particularly on the effects of cabling on discrete habitats, such as seagrass and reefs. Concerns have also been raised by stakeholders about uncertainty relating to the effect of different tools in different sediment types (further discussed in the next section and Appendix C).

4.3.2 Review of Offshore Wind Farm Monitoring Data

- 4.3.2.1 As outlined in Section 4.2 above, as part of this study, a comprehensive review has been undertaken of offshore wind farm monitoring reports for the UK continental shelf. A summary of the findings of the monitoring undertaken for each project individually is presented in Appendix C below with a discussion of the overall patterns presented here. As outlined in Section 4.2.1, these were sought from the public domain, with the majority of data sourced from the MDE.
- 4.3.2.2 The majority of the reports reviewed have not focussed specifically on the recovery of seabed habitats or morphology following cable installation, with only a few exceptions (e.g. Humber Gateway and Race Bank) which are discussed further in Appendix C. Most of the monitoring data summarised below was drawn from geophysical datasets which were scoped for a range of reasons, usually related to asset integrity, e.g. monitoring of scour effects around turbines and cable protection, cable

integrity monitoring etc., and not for the specific purpose of assessing the recovery of the seabed or seabed sediments. Typically, benthic ecology monitoring surveys have focussed on broadscale changes in benthic communities (see MMO (2014) review), rather than recovery of the seabed following cabling, except in those circumstances where cabling has been of particular concern (e.g. see Humber Gateway and Race Bank examples discussed below). This is due to cabling being identified as being of relatively low concern with respect to seabed impacts (in comparison to the offshore windfarm itself), with most EIAs predicting non-significant effects due to the ability of many soft seabed sediment types and their associated communities being able to recover following cable installation (as discussed in Section 4.3.1 above).

Physical Impact on Seabed

- 4.3.2.3 With respect to the physical impact of cable installation on seabed sediments/substrates, the general patterns observed in the geophysical datasets summarised in Appendix C broadly aligned with the conclusions of the BERR (2008) evidence review discussed in paragraph 4.3.1.13 *et seq.* above. For sandy sediments, these were generally shown to recover well following cable installation, as evidenced by a lack of cable trenches observed at a number of offshore wind farms (e.g. Barrow, Burbo Bank, sandy areas of Sheringham Shoal and Robin Rigg). Trenches were observed in some sandy sediments, particularly in areas with relatively low levels of sediment transport and areas with higher fine sediment content (e.g. muddy sands and sandy muds). Examples include Ormonde and Gunfleet Sands 1, 2 and 3, where remnant trenches (and anchor drag marks for Gunfleet Sands) were observed years following cable installation within areas of muddy sand sediments, although these were relatively shallow features (i.e. a few 10s of centimetres). Similarly, Kentish Flats and London Array cables showed some evidence of relic trenches in stable sediments and muddy sands (e.g. in inshore areas), although these were relatively low relief, showing as slight scars on the seabed.
- 4.3.2.4 At Walney 1 and 2, most of the array cable trenches were considered to be remnant, with the majority of these recorded as being infilled during the first post construction survey and having little relief showing in the geophysical datasets, while others were shown to infill over time (i.e. in further post construction monitoring). Along the export cable route, remnant trenches were also recorded, with one such area interpreted as a jetting scar following post lay cable burial and subsequent natural infilling of this scar. One stretch of array cable installed immediately prior to the year 2 monitoring survey was indicated by a 1 m depth trench immediately following cable installation. During the subsequent year 3 monitoring survey (i.e. approximately 1 year after installation of this cable), this trench was not shown to have infilled. This may be related to sediment mobility at this site being limited during this time period, particularly since recovery of the seabed (i.e. infilling of cable trenches) occurred over a relatively short time period following the initial construction phase. However, this may also be related to differences in installation techniques used in the initial cable installation, compared to remedial burial operations (e.g. post lay jetting) undertaken prior to the year 2 monitoring survey.
- 4.3.2.5 Most remnant trenches recorded during post construction monitoring at offshore wind farms (as summarised in Appendix C) were associated with coarse and mixed sediments (i.e. sandy gravels and gravelly sands). In most cases, evidence of trenches were observed at most offshore wind farm sites and/or export cable routes in the years following cable installation. In many cases, these trenches are shown to be of limited depth (i.e. 10s of centimetres) relative to the surrounding seabed, over a horizontal distance of several metres (e.g. usually up to 10 m wide) and are therefore shallow depressions in the seabed with gently sloping sides.
- 4.3.2.6 As reported by BERR (2008), in some cases this infilling occurs quickly, either through the edges of the trenches collapsing (e.g. Sheringham Shoal) or through the natural sediment mobility in the local area (e.g. Barrow). The Humber Gateway monitoring also indicated that away from the exposed areas of clay and cobble reefs (discussed further in paragraph 4.3.2.13 below), the coarse and

mixed sediments showed less evidence of cable installation effects, with sediments and communities reflective of the pre-construction baseline and adjacent unimpacted areas. However, in many cases, trenches can take many years to infill completely. Where trenches have been recorded over multiple post construction surveys, there is evidence of consistent infilling year on year, e.g. at Westermest Rough, where infilling of approximately 0.1 m per annum was reported across multiple post construction surveys.

- 4.3.2.7 The degree to which these trenches infill over time and the rate of infilling, is likely to be site specific and dependant on the direction of sediment transport processes in the vicinity of the project and these factors are shown to be variable over a relatively small area. This is evident from Robin Rigg and Sheringham Shoal monitoring, where areas of mobile sands and gravels (e.g. in shallow inshore areas) showed fast recovery, while in areas characterised by a mixed sands and gravels, or veneers of sand over till (Robin Rigg only), trenches were more evident. Similarly, at Lynn and Inner Dowsing, relic plough features over array cables were less likely to have completely infilled even three years post construction, for those cables orientated east-west, compared to those orientated north-south.
- 4.3.2.8 Infilling was also observed for HDD exit pits in geophysical datasets (specifically Westermest Rough). The depth of these HDD exit pits is typically greater than for other parts of the cable corridor (e.g. the Westermest Rough HDD exit pit was >2 m deep immediately post construction) and therefore the rate of infill would be expected to take longer than for infilling following cable installation (although this depends on the sediment type and local hydrodynamic regime). This was reflected in the Westermest Rough data, with infilling of up to 1 m during the first post construction survey (approximately one-year post construction) and infilling of up to 2 m during the second post construction survey (approximately 3 years post construction).
- 4.3.2.9 While most of the projects monitored showed some evidence of persistent trenches or relic trenches, where these have infilled over time, these were generally associated with relatively small proportions of the total length of cables, with the majority of areas recovering with no evidence of persistent trenches reported. Where these were present, they were generally short sections (i.e. 10s to 100s of metres) of the array and export cables, with a few exceptions where some trenches/relic trenches extended over a kilometre or more (e.g. Robin Rigg and Gunfleet Sands). As outlined above, in most cases, where these trenches persist, these occurred as shallow trenches with gently sloping sides and are therefore likely to be reflective of the naturally occurring bedforms in the surrounding area. The potential implications for benthic community composition within the areas of disturbance from cable installation is therefore likely to be more closely linked with the sediment composition within the cable trenches, compared to adjacent areas, rather than the seabed morphology of these cable trenches. This is based on evidence from the aggregates industry, which indicates that benthic communities recover into disturbed areas, if the sediment is reflective of the baseline environment (see paragraph 4.3.1.10). There is little definitive data on the sediment types within cable trenches as there has been limited ground truthing within areas directly impact by cable installation.
- 4.3.2.10 In a small number of cases, seabed imagery data has indicated that the sediments within these areas are similar to surrounding areas, for example Humber Gateway, where seabed imagery data indicated coarse and mixed sediments within areas affected by cable installation were similar to those in adjacent areas. In other cases, side scan sonar data indicated that sediments within remnant trenches had lower reflectivity than surrounding sediments (which aided in the interpretation of these areas), which suggested that sediments within trenches were finer than surrounding areas (see Barrow, Walney 1 and 2 and Westermest Rough). However, side scan sonar data from relic trenches for the Sheringham Shoal export cables (see Ørsted, 2018c) indicated that sediments within these areas were similar to surrounding areas.
- 4.3.2.11 The effects of pre-clearance activities, including sandwave and boulder clearance, has also been recorded in geophysical datasets. For boulder clearance, this pre-clearance activity was undertaken at the Westermest Rough offshore wind farm for array and export cables and although monitoring

was not specifically designed to monitor the effects of this activity, observations were made during review of the geophysical datasets. The Westernmost Rough geophysical data recorded the boulders cleared from the cable corridors as being displaced to adjacent areas of seabed, with infilling of the trenches observed by soft sediments, as outlined above. Recovery of the seabed following sandwave clearance operations was also monitored at a number of sites within the Race Bank array area and the export cable route and occurred within one and two years following clearance operations. The monitoring undertaken within one-year post clearance showed that recovery was occurring, although complete recovery had not yet occurred. Monitoring undertaken two years after clearance showed a greater degree of recovery, with some large features (i.e. approximately 5 m in height) recovering close to the pre-construction height (i.e. 3 to 4 m height) within two years of the clearance activity.

Effects on Benthic Ecology

- 4.3.2.12 In general, benthic ecology monitoring programmes which have included consideration of impacts of cabling have targeted relatively broad cable route corridors, with limited sampling expected to have occurred within the direct area of disturbance (i.e. the cable trench). This is due to practical, safety related reasons for avoidance of cable trenches (e.g. risk of cable strike with sampling equipment such as grab samplers). This is a clear limitation of these datasets, and as such, benthic ecology monitoring (and particularly sediment sampling) should be considered to be investigating the indirect impacts of cabling (e.g. effects of dispersion and deposition of sediments during cabling), rather than direct impacts. Examples outlined in Appendix C included Burbo Bank, Greater Gabbard, Gunfleet Sands 1, 2 and 3, Kentish Flats, North Hoyle, Ormonde, Robin Rigg, Scroby Sands, Thanet and Westernmost Rough. These datasets have not recorded any significant effects on benthic communities in a range of sediment types, with any changes recorded considered to be within the natural variability of the relevant parts of the UK continental shelf surveyed. However, it is important to recognise that this observation of a lack of significant effects is limited to indirect impacts rather than direct impacts, which were not monitored (as noted above).
- 4.3.2.13 Where information on recovery of benthic communities are available within or in the vicinity of installed offshore wind cables, these are usually in the form of a combination of geophysical datasets (i.e. multibeam and sidescan sonar) and seabed imagery data (e.g. drop-down video) investigating the impact of cabling on reef features. The clearest example of such a dataset is Humber Gateway, where cabling was undertaken close to and within areas of cobble reef and post construction monitoring was designed to monitor the direct effects on these habitats. Where cables were installed through areas of cobble reef and exposed clay, these were clearly delineated by geophysical and seabed imagery datasets, with such areas characterised by relatively flat areas of seabed compared to the more elevated and heterogenous cobble reef habitats not affected by cabling. However, effects on these habitats was spatially limited to the cable corridor (i.e. 10 to 20 m wide), with no effects detected in adjacent reef habitats (i.e. <50 m from the installed cable).
- 4.3.2.14 The summaries in Appendix C also provide some evidence from post construction monitoring of biogenic reef habitats within offshore wind farms following cable installation. This includes the Lynn and Inner Dowsing offshore wind farms, where reef forming species were recorded in areas where cables were installed between one and three years post construction. These species included the reef building amphipod species *Ampelisca* (note: not an Annex I reef building species), *Sabellaria spinulosa* and *Mytilus*, all of which were recorded during post construction surveys. During the first post construction survey, an area of low-lying *S. spinulosa* reef was recorded in areas where array cables were installed, indicating this species had colonised areas of seabed affected by cable installation in the preceding year. Similar observations were made for the Thanet offshore wind farm, although geophysical datasets were not available or reviewed as part of this project, with the evidence available limited to benthic ecology monitoring across the offshore wind farm site. However, mapping of *S. spinulosa* habitats across the offshore wind farm area indicated high

abundances of this species (i.e. possible reef habitats) within parts of the offshore wind farm site where array cables had been installed, approximately 2 years earlier. These observations are not direct evidence of recovery of reef habitats following cable installation through reefs, rather they provide evidence that reef building species have been recorded colonising areas which had recently (i.e. within 1-2 years) been disturbed from cable installation.

- 4.3.2.15 As outlined in paragraph 4.3.2.12, there is little or no benthic infauna data from within the remnant cable trenches discussed in paragraphs 4.3.1.1 to 4.3.1.10, and only limited seabed imagery data from these. While this is a deficiency in the monitoring evidence base, it is a reasonable assumption (based on evidence from other industries) that where sediments have recovered in areas where cables have been installed, the benthic communities would be expected to have also recovered into these areas. However, notwithstanding this conclusion, recommendations have been made in Section 5 with regard to the priorities for future evidence and monitoring for offshore wind farm cables.

Effects of Cable Protection

- 4.3.2.16 Monitoring of cable protection has historically been limited for UK offshore wind farms and where this has been undertaken, these have focussed on cable integrity and effects of scour around cable protection measures. For Burbo Bank Extension and West of Duddon Sands, scour in the vicinity of cable protection is usually limited to a few 10s of centimetres in close proximity to the rock berms, where scour occurs at all (see Appendix C). However, the London Array monitoring showed significant (i.e. up to 9 m depth) scouring associated with rock protection in the nearshore environment. This scouring was observed between export cable circuits, where rock berms (approx. 2 m high) had been installed at a crossing with the BridNed interconnector. This scouring may have been related to the shallow water in which the crossing berms were installed (i.e. <5 m) and the mobile nature of the sediments in this part of the outer Thames Estuary, although it is worth noting that similar levels of scour were not observed at the Kentish Flats crossing (also in <5 m water depth). This indicates that in some circumstances and environmental conditions, scour effects may be significant.
- 4.3.2.17 The monitoring data reviewed and presented in full in Appendix C also presented little or no information on the effects of cable protection either on associated benthic ecology communities (e.g. colonisation of installed protection measures). This is a clear knowledge gap in monitoring data from UK offshore wind farms to date. As noted in paragraph 4.3.1.6, placement of cable protection results in a change in the substrate/sediment type, and the direct effects of this change on benthic communities is poorly understood. As such, EIAs take a conservative approach and typically assume that this represents long term habitat loss, with complete loss of ecological function in the areas affected. There is, however, some evidence from other countries (e.g. Denmark and the Netherlands) on the species expected to colonise rock protection. These were largely associated with scour protection associated with turbine foundations, however, these provide some information on the types of species expected to colonise artificial rock substrates, in the southern North Sea. Many of these studies were undertaken to identify ways to implement the Netherlands government policy of 'Building with North Sea Nature' in offshore infrastructures in the North Sea (e.g. van Duren et al, 2017; Lengkeek et al., 2017; Vanagt and Faasse, 2014).
- 4.3.2.18 One study, (Coolen, 2017) collected samples from scour protection at oil and gas platforms which have been in place for 22 to 40 years and compared these with communities at a more recently (2006/2007) constructed wind farm (Princess Amalia Wind Farm; Vanagt and Faasse, 2014) and a natural rocky reef (Borkum Reef) in the Dutch continental shelf. This found that scour protection was colonised largely by species known to occur throughout the North Sea, including natural and artificial reefs (e.g. the anemone *Metridium dianthus* and the colonial bryozoan *Electra pilosa* dominated both rock protection material and natural rocky reef). Analysis of the associated benthic communities demonstrated an overlap between the rock protection and scour protection around offshore

installations and the communities at the natural Borkum reef, indicating that rock protection is colonised by local North Sea fauna.

- 4.3.2.19 Lengkeek et al. (2017) summarises the monitoring of the development of benthic communities on scour protection at two Dutch offshore wind farms (Egmond aan Zee and Princess Amalia) and one Danish wind farm (Horns Rev). These found that colonisation by native North Sea species was variable and dependent on the types of rock protection used and the local environmental conditions (e.g. at Princess Amalia wind farm, some infilling of rock protection was observed in the lower energy environment). The conclusion of the Lengkeek et al. (2017) report is that the number of species on the conventional scour protection material currently deployed in the North Sea is relatively low compared to other artificial hard substrates (i.e. wrecks) and natural rocky reef habitats, although ecological improvements in scour protection (e.g. altering the size of rock protection) could stimulate overall native biodiversity, species richness and abundance of policy relevant focal species in the North Sea.
- 4.3.2.20 While the placement of cable protection (and scour protection) will clearly lead to a change in the substrate type, the effect of this change will depend on the sediment/substrate type of the receiving environment e.g. in a sediment habitat this may result in a shift from a benthic community dominated by infaunal assemblages to one dominated by epifaunal assemblages. However, in certain circumstances (e.g. areas of rocky substrate or coarse sediments), the use of certain types of cable protection may limit the change of the substrate, therefore allowing some ecological function to continue in the areas affected, as suggested by the studies outlined above.

4.4 Conclusions – Environmental Impacts and Recovery

- 4.4.1.1 As set out in Section 1.2, the aims of this section of the report were to review the overall evidence base with respect to seabed impacts and recoverability and identify data gaps and potential requirements for further study. These are discussed in the following sections, based on the evidence base reviewed, including offshore wind monitoring data, with the following limitations to be considered when reviewing this evidence base.

4.4.2 Limitations

- 4.4.2.1 Many of the monitoring reports reviewed have been for purposes other than to investigate the recovery of the seabed (i.e. asset integrity survey) and the geophysical interpretation has not specifically focussed on the recovery of the trenches. As such, where these trenches are reported in the geophysical reports, these have not always been quantified in terms of the width of remnant trenches or depth of these depressions relative to the surrounding seabed.
- 4.4.2.2 Similarly, information was lacking on the sediment composition within the trenches with only a small number of monitoring reports including geophysical interpretation of these and no ground truthing (e.g. via seabed imagery) of the sediments within the trenches. Similarly, there was little or no data on benthic communities within cable trenches, with most survey effort focussed on the wider cable corridor (i.e. indirect effects of cabling).

4.4.3 Overall Evidence Base with Respect to Seabed Impacts and Recoverability

- 4.4.3.1 The evidence reviewed as part of this project has indicated that EIA predictions largely align with the monitoring data that is available on seabed impacts and recovery. The monitoring data collated for the current desktop review has indicated that cabling results in disturbance to seabed sediments, with the level of initial disturbance dependent on the tool used (e.g. cable ploughs typically result in minimal displacement of sediments beyond the cable trench, while jetting may result in a greater sediment displacement; see paragraph 4.3.1.1). For most of the projects reviewed, monitoring data has shown that cable installation has resulted in trenches being recorded on the seabed in geophysical datasets, although the proportions of the cable lengths where these remnant trenches were observed was variable across the projects. The monitoring data did, however, show that where these trenches were recorded, they infilled over time and that where these are present on the seabed after a number of years, the large majority of trenches are shallow depressions on the seabed (e.g. up to a few 10s of cm).
- 4.4.3.2 As discussed in the previous sections, there has been little or no benthic ecology data from within the direct disturbance areas (with the exception of seabed imagery data for Humber Gateway), either in the form of seabed sediment sampling (see paragraph 4.3.2.12) or seabed imagery. However, based on information from the analogous industries, it has been reported that benthic communities associated with soft sediments (e.g. muds, sands and gravels) readily recover into areas if the sediment type is reflective of the baseline environment (see paragraph 4.3.1.10). Therefore, assuming the sediment composition within these shallow trenches is similar to the surrounding sediments, recovery of communities will also occur (as evidenced from other industries, e.g. aggregates).
- 4.4.3.3 This conclusion is broadly reflective of the conclusions of offshore wind farm Environmental Statements and previous industry reviews of evidence (e.g. BERR, 2008; MMO, 2014; RGI, 2015), including the broad summary of potential effects from cable installation presented by BERR (2008), noting that monitoring data reviewed in this report were from soft sediment habitats only. While this conclusion can be made from the monitoring data reviewed, the limitations set out in paragraph 4.4.2.1 should be considered, particularly the lack of targeted information (e.g. geophysical interpretation or seabed imagery ground truthing) on the sediment composition within the remnant trenches compared to surrounding areas.

4.4.4 Data Gaps and Potential Requirements for Future Study

- 4.4.4.1 As outlined above, one data gap with respect to recovery of seabed sediments following cable installation is in relation to the lack of targeted monitoring data within remnant trenches, compared to surrounding areas. As such, future monitoring programmes, where cable impacts are of particular concern, should be designed to collect geophysical and appropriate ground truthing (e.g. seabed imagery) within these areas of direct disturbance.
- 4.4.4.2 The monitoring data reviewed presented little or no information on the effects of cable protection either on the seabed or on associated benthic ecology communities (e.g. colonisation of installed protection measures). There were a few exceptions, particularly for a crossing on the London Array export cables, where shallow water and a mobile sediment transport regime resulted in a large scour pit adjacent to the cable crossing (see paragraph 4.3.2.16). This indicates that while minor scouring around cable protection may not have significant implications for seabed habitats and benthic communities, in certain circumstances, scour can be severe, with larger (although in this case highly localised) effects on seabed sediments and habitats.

- 4.4.4.3 The main data gap identified in the monitoring review was in relation to the effect of cable protection on benthic communities, e.g. colonisation of artificial substrate, with no monitoring data identified from the UK continental shelf. There is some evidence from other countries on the species expected to colonise rock protection (e.g. see paragraph 4.3.2.17 *et seq.*), however this largely focusses on scour protection around turbine foundations. While these types of infrastructure are somewhat analogous (i.e. scour protection usually comprises concrete mattresses or rock placement), scour protection is subtly different to cable protection as this is placed adjacent to other offshore infrastructure (e.g. turbine foundations) which will also be colonised by benthic communities. In contrast, cable protection is usually deployed in short, discrete sections of the cable route and therefore colonisation may be subtly different, although some colonisation would be expected to occur.
- 4.4.4.4 Further discussion of recommendations, including recommendations for further study to fill these data gaps, are presented in Section 5.

5 RECOMMENDATIONS

- 5.1.1.1 This section presents a number of recommendations based on the aims of the study (Section 1.2) and the conclusions presented in Section 3.4 (Effectiveness of Cable Installation Techniques) and Section 4.4 (Environmental Effects of Cabling).
- 5.1.1.2 As outlined in Section 1.5, given the remit of this project to support the Plan Level HRA for the Round 4 leasing, these recommendations are particularly relevant to cabling within SACs and other MPAs (e.g. MCZs).

5.2 Effectiveness of Cable Installation Techniques

5.2.1 Recommendation 1: Cable Protection Reporting

- 5.2.1.1 The concept of completing a full review of asset burial and protection in the UK has much merit and would be a considerable body of knowledge to feed back into the community for future developments with improved understanding of the local conditions, appropriate installation equipment and long-term successful protection of seabed cables. As outlined in paragraph 3.2.3.2, one of the secondary aims of this study was to produce a cross sectoral database and mapping of cable and pipeline protection across the Round 4 leasing regions.
- 5.2.1.2 Given the efforts made to request information to both developers and public bodies, it is clear that there is no central repository for key pieces of information such as cable locations, and locations and dimensions of installed protection measures. While information on cable protection measures may be provided to regulatory bodies (e.g. the MMO for offshore wind or BEIS for oil and gas), this information is not readily accessible. Consultation with BEIS during the current project has indicated that BEIS are currently progressing a project to gather information on oil and gas infrastructure (including pipeline protection) within designated sites on the UK continental shelf. As such, further data collection on oil and gas assets within the Round 4 leasing regions was not progressed in this project to avoid duplication of effort with BEIS. With respect to telecommunications cables, it is understood that operators do not routinely use cable protection (e.g. rock dumping or mattresses) to ensure adequate burial. Where faults or damage to telecommunications cables occur, these are repaired and reburied (S Dawe, ESCA, pers. comm.) as this is seen as a more cost-effective solution compared to non-burial protection. The only exception is at crossings with existing assets, where the requirement for cable protection is usually agreed with the asset owner.
- 5.2.1.3 With the ongoing growth of offshore infrastructure as well as historical assets (e.g. from the oil and gas industry), the availability of such information is important to ensure that cumulative effects can be accurately tracked by regulatory bodies and assessed within future consent applications without the need for overly conservative assumptions. The current project has collected some data on cable protection measures to allow mapping of these within the Round 4 leasing areas, although this is limited due to a lower than expected response to the questionnaire (see Section 3.2.4). In addition, some information sought from publicly available data sources may not be completely accurate (see paragraph 3.4.2) and would need to be validated by asset owners.
- 5.2.1.4 It is therefore recommended that all data on cable infrastructure (both within and outside marine protected areas) are submitted to a central repository. This information (e.g. cable protection locations, dimensions, materials used etc.) should be provided in an agreed format to a central database to be agreed with the relevant regulatory bodies and stakeholder groups. Ideally this would be provided in a format (e.g. ArcGIS) which allows for easy access of the information by stakeholder groups and to allow for the database to be regularly updated (e.g. new “as laid” cable locations where cable repair/replacement has been required). This database would ideally not be limited to offshore wind cables, but should be a cross sectoral database, including data from the interconnectors and telecommunications cabling. Where possible, this should be aligned with similar

efforts being made by BEIS for oil and gas infrastructure. As part of the current project, RPS has compiled some information on cable protection for offshore wind farm export cables, including locations, types of protection etc. This information has been compiled in ArcGIS format and provided to TCE, with the mapping outputs presented in Appendix D.

- 5.2.1.5 The requirement for this reporting of cable protection (and similar infrastructure) could be secured via marine licence conditions, with specific reference to the central repository included in those conditions which refer to reporting of placement of infrastructure.

5.2.2 Recommendation 2: Preliminary CBRA

- 5.2.2.1 As discussed in Section 3.4.5, there is the potential for an increase in the level of engineering input prior to a consent application. This may comprise a preliminary ground model and/or initial CBRA (or similar exercise). It is felt that development of a full BAS pre-consent would hinder improved burial techniques and tool development in the future. More detailed ground conditions information could be provided during consenting, based on the results of the initial seabed survey, where cabling impacts are of particular concern (e.g. within MPAs). This may include a preliminary assessment of the relative probability of burial or an initial CBRA (or similar exercise) based on the knowledge of the cable route and anthropogenic activities in the area. Development of a preliminary CBRA (or similar exercise) may therefore be informative during pre-application consultation to identify areas of increased risk of insufficient burial and/or risks to cables (e.g. due to fishing or anchoring) and therefore potential requirement for non-burial cable protection measures. It should be noted, however, that this may not necessarily result in a reduction in the project design envelope, or restrictions to non-burial cable protection within specific parts of cable routes. This would apply where developers feel the need to control for unforeseen ground conditions (see paragraph 3.4.5.10) or other factors which may lead to the requirement for non-burial cable protection (see Section 3.4.3).
- 5.2.2.2 The requirement to provide this additional information pre-consent would depend on the relative risk that cabling posed to the environment. Such information would be particularly useful to inform applications for cabling within MPAs, where a greater level of evidence is typically required to inform assessments.

5.2.3 Recommendation 3: Developer Engagement with Stakeholders

- 5.2.3.1 Alongside the provision of preliminary information (e.g. initial ground conditions information and preliminary CBRA) during the pre-consent phase discussed above, it is also recommended that the level of involvement of authorities, statutory consultees and other stakeholders (if deemed appropriate by the regulator) post consent could be increased. This may include consultation on the BAS and contractor discussions, with a view to ensuring that all parties have a full understanding of the approach to cable installation and the conditions in which non-burial cable protection may be deployed. This may include discussion of mitigation strategies with incentives for reducing the likelihood of the use of non-burial protection along cable routes, as agreed between the developer and the relevant authorities. The key aim of this process would be to ensure that the use of non-burial protection is agreed to be a last resort, with agreed mitigation to avoid use of these measures, but an acknowledgement from relevant authorities that this may need to be used in some circumstances.
- 5.2.3.2 This consultation process could be progressed alongside the normal consent compliance discussions and agreement of discharge of consents (e.g. discharge of the Cable Specification and Installation Plan) with more in-depth discussions for those projects where cabling is a particular concern (e.g. within marine protected areas). As such, it is envisaged that this additional engagement could be specified in consent conditions which relate to particular consent plans (e.g. Cable Specification and Installation Plan). The precise detail of how this consultation would be

undertaken would need to be discussed and agreed between developers and relevant stakeholders. As part of this more in-depth process within marine protected areas, this could include a review of asset burial and protection process to ensure lessons continue to be learned throughout the project programme.

5.3 Environmental Effects of Cabling

5.3.1 Recommendation 4: Future Monitoring of Seabed Recovery

- 5.3.1.1 As outlined in Section 4.4, the monitoring data collected to date largely reflects the assessments presented in offshore wind consent applications, with an initial period of disturbance to seabed habitats followed by a recovery period, the length of which is dependent on the sediments/habitats affected. As such, future monitoring of the effects of cabling in most soft sediment areas (particularly sandy sediments) would not be expected to add further to the evidence base. However, where cabling effects and associated recovery rates are of particular concern (e.g. in MPAs) it may be considered necessary to undertake post construction monitoring to assess the effects of cable installation in certain habitats (e.g. coarse and mixed sediments, reef habitats). Where such monitoring is undertaken, it is recommended that geophysical surveys should be scoped to ensure the data collected and the subsequent interpretation focusses on recovery of the seabed (e.g. width and depth of remnant trenches, rate of infill of trenches and sediment composition of sediment trenches). Ground truthing geophysical datasets within the trenches (e.g. seabed imagery) would also be useful to fill any data gaps.
- 5.3.1.2 These surveys would be secured via marine licence conditions, with the scope of these set out in an “in principle monitoring plan”, which usually accompany DCO applications.

5.3.2 Recommendation 5: Cable Protection Monitoring

- 5.3.2.1 As outlined in Section 4.4 above, the main data gap noted was on the effect of cable protection on benthic communities, particularly in the UK. As such, it is recommended that studies on colonisation of cable protection are undertaken to understand what effect this has on benthic communities. While most environmental assessments (e.g. EIA and HRA) assume total habitat loss beneath cable protection, there is some uncertainty as to whether some ecological function (e.g. infilling or colonisation of rock protection) may continue while protection measures are in place (e.g. see paragraph 4.3.2.17). Further, such studies may provide useful information as to whether different cable protection measures have a different level of effect, e.g. allowing ecological function to continue to different degrees, and whether there is potential for ecological improvements in protection measures.
- 5.3.2.2 These studies would comprise seabed imagery surveys to identify the level of colonisation of the protection measures, with appropriate comparison with adjacent areas of seabed to determine to degree to which these have been colonised by local fauna. Comparisons between different types of cable protection and/or in different environments (e.g. sediment types) would also be useful in order to determine the influence of environmental conditions and protection design on colonisation. These would need to give consideration to environmental factors such as water depth and water turbidity to ensure that the data captured addresses the identified data gap. Studies on the effect of cable protection on benthic communities could be delivered either through monitoring conditions for specific projects, or wider industry led studies, collecting data over existing cable protection deployed on operational cables.

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APPENDIX A

Example Questionnaire

REVIEW OF CABLE PROTECTION, INSTALLATION & HABITAT RECOVERABILITY

THE CROWN ESTATE

Developer/Operator Questionnaire



EOR0744
The Crown Estate:
Questionnaire
REV01
22 March 2019

QUESTIONNAIRE

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Prepared by:

RPS

Adam Crowther
Marine Consultant

Unit 10, Beaufort Park, Riverside Court
Chepstow, Monmouthshire NP16 5UH

T +44 1483 746 500
E TCStakeholders@rpsgroup.com

Prepared for:

The Crown Estate

Ed Salter
Marine Consents Manager

1, St. James's Market
London, SW1Y 4AH

T +44 (0) 20 7851 5225
E [REDACTED]

Confidentiality

Whilst it is The Crown Estate's intention to use the outputs of this questionnaire to inform a report on cable installation techniques, benthic habitats and recoverability from cable installation, the questionnaires in their entirety will not be published. All collated information used will be presented as asset neutral, except for the locations and coverage of cable protection, which we intend to present as a single GIS data layer.

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INTRODUCTION

In November 2017, The Crown Estate (TCE) announced plans to work with the offshore wind sector and stakeholders to consider making new seabed rights available to offshore wind developers. Five regions have been identified for inclusion in Round 4, with a further four regions under further consideration for inclusion (See **Figure 1**). TCE has identified that the Round 4 leasing activities could be classed as a 'plan' within the meaning of the Habitats Regulations, and that a plan level Habitats Regulations Assessment (HRA) may be required.

To support and build the evidence base for the plan-level HRA for Round 4, TCE has commissioned RPS to undertake a desk-based review of cable installation techniques and protection used for offshore wind projects. Also included in this study is a review of the environmental effects of cable installation and protection activities.

Purpose of this Questionnaire

The first step in this project is to collate information on the techniques used to install subsea infrastructure (e.g. cables and pipelines) in subtidal environments and the effectiveness of these techniques (i.e. successful burial) in different seabed types. The project also seeks to collate information on where cable protection has been placed up until now. As such, RPS has developed a questionnaire for developers which will help to:

- Collate information on cable installation techniques used to date;
- Examine the efficacy of the techniques used for achieving burial in different substrate types;
- Collate information on the requirement for protection measures in different seabed types/metoccean conditions; and
- Collate details of cable protection within the Round 4 regions, including materials, locations and volumes.

Notes to Developer

To support this initiative please can you provide all details as ESRI shapefiles, WGS 1984 (EPSG code 4326), enabling a reduction in any follow-on questions and efforts completing the questionnaire.

Should your organisation be operating multiple assets in different locations please generate a **separate** questionnaire per asset and save these files accordingly.

Where as part of the same project, for example HVAC export cables, assets are unbundled along the same corridor, please replicate any specific tables or comment boxes in each section where the cables have had different outcomes regards Depth of Lowering, Depth of Burial, or protection requirements/outcomes.

We greatly appreciate your input to this Questionnaire. This project is intended to provide future benefit to the development of the offshore wind sector.

QUESTIONNAIRE

Contact Name	
Company/Organisation Name (if applicable)	
Role / Job Title	
Address	
Telephone	
Email	

To complete the form digitally, please click on the appropriate check box i.e. ☐ or ☒.

Where additional space is required, either add additional rows to the tables or make the text boxes larger. All text and questions will move down accordingly.

Please provide all coordinates in the **WGS 1984** decimal degrees format (**EPSG code 4326**).

Examples have been provided in italics - please remove before inserting information.

Project Information

Developer / Operator	
Project	
Leasing Area (as per Appendix A figure)	
Cable System Design	HVAC ☐ or HVDC ☐ Bundled ☐ or Unbundled ☐

Q.1 Please provide details of the ground conditions as set out in the table below.

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QUESTIONNAIRE

- Q.2 Can you provide the Metocean conditions for the project?** Include only relevant Metocean information that influenced decisions on installation strategy, depth of lowering/burial and protection requirements, for example the information used as baseline for installation contractors.

Parameters	Conditions
Sediment mobility (incl. sediment depth to reach non-mobile seabed reference level)	<i>e.g. Low seabed mobility Single large sand wave 12m, migrating south easterly 2.0m/year Depth to non-mobile seabed 0.2m</i>
Wave climate	
Current	

Cable Lay and Burial

- Q.3 What was the burial strategy employed during the installation of the subsea infrastructure?** i.e. Pre-plough / Simultaneous Lay and Bury (SLB) / Post Lay Burial (PLB) / Natural backfill / None. Please provide a descriptive reasoning for the choices.

Burial Method	Installation Tool Name	Coordinate Start	Coordinate End	Tool Contact Footprint (width (m))	Trench Volume (m³)
Jet trenching	☐				
Mechanical Trenchers	☐				
Cable Ploughs	☐				
Jet Sleds	☐				
Vertical Injectors and Mass Flow	☐				
Excavator					
Other (please specify)					

[illegible]

QUESTIONNAIRE

Q.6 Please describe the perceived effectiveness of each of the installation tool(s) used? e.g. Capjets A/B / T3200 / T1100 / Excalibur, etc number of passes required, any additional mitigation steps etc to try and reach Depth of Lowering and Depth of Burial.

QUESTIONNAIRE

Cable Protection Licensed

Q.7 What was the volume / weight of cable protection licensed? (please specify in the list as a new line item where separate activities were consented e.g. within 12nm, outside 12nm, cable repair re-burial etc)

Activity	Permitted Volume / Weight	Coordinates Start	Coordinates End	Berm Height Above Seabed	Width of Footprint (m)
e.g. Cable protection	12,600m ³	0.39560, 53.37587	2.80195, 54.21794	2.5	12

Additional cable protection

Q.8 Have there been any further consent applications for cable protection as part of Operations/Maintenance and Repair?

Yes ☐

No ☐

If Yes, then what additional protection was required and location?

Reason for Cable Protection	Permitted Volume / Weight	Coordinates Start	Coordinates End	Berm Height Above Seabed	Width of Footprint (m)
e.g. Cable exposure	5,000m ³	1.18289, 53.90085	0.81510, 53.75816	0.4	1.5

QUESTIONNAIRE

Cable Protection Deployed

Q.9 What was the volume / weight deployed as part of each activity for cable protection?

Activity	Deployed Volume / Weight	Coordinates Start	Coordinates End	Height Above Seabed / Water Column Reduction	Width of Footprint (m)
<i>e.g. Cable protection</i>	<i>8,5000m³</i>	<i>0.39560, 53.37587</i>	<i>2.80195, 54.21794</i>	<i>2.5</i>	<i>12</i>

Q.10 What was the cable protection material used and their locations?

Material used	KP Start	KP End	Coordinates Start	Coordinates End
Mattress ☐				
Rock ☐				
Sand ☐				
Natural Backfill ☐				
Other ☐				

If other, please provide details:

Additional Information

Q.11 Is there any additional information you may think would be useful to inform the study? e.g. lessons learned.

APPENDIX A

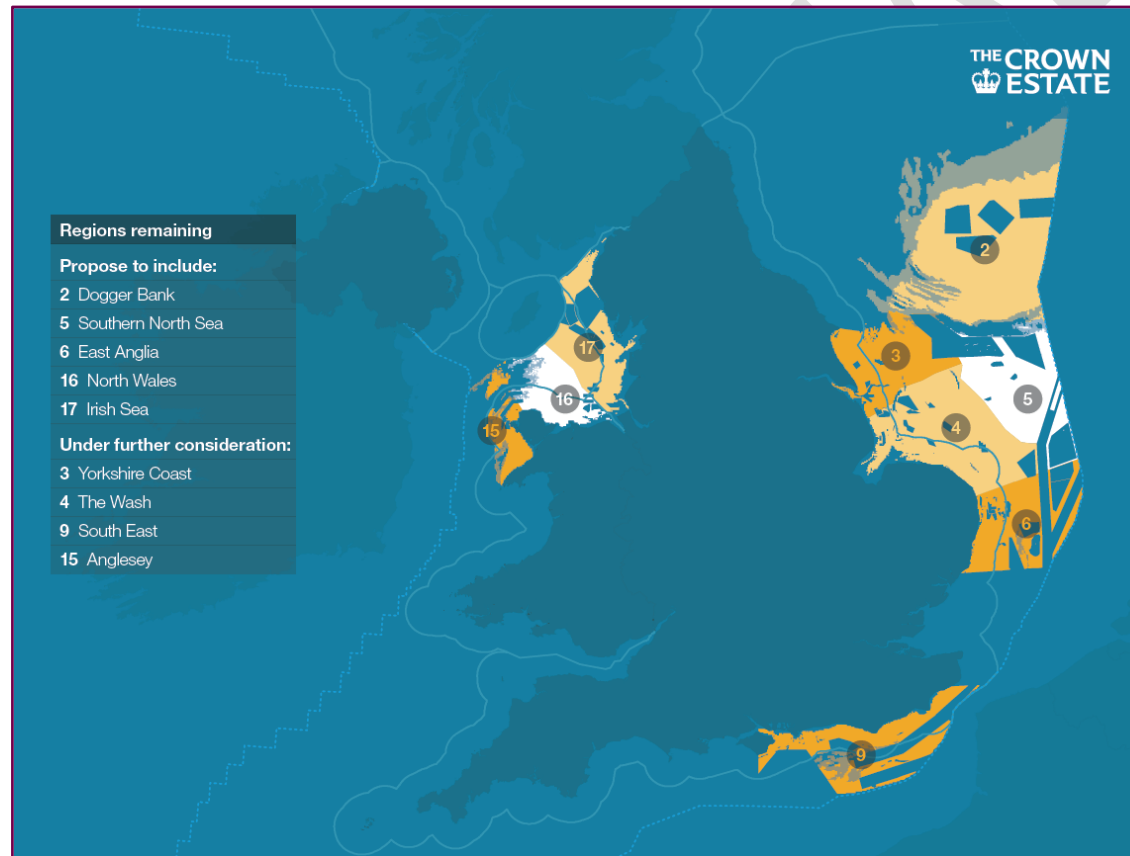


Figure 1: Proposed TCE regions for refinement.

APPENDIX B

Case Studies

APPENDIX B – CASE STUDIES

The Crown Estate

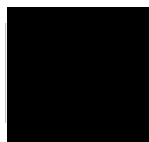
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Nicola Simpson



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Prepared by:

RPS

Kevin Linnane
Principal Marine Consultant

Unit 10, Beaufort Park, Riverside Court
Chepstow, Monmouthshire NP16 5UH

T +44 1483 746 500
E 

Prepared for:

The Crown Estate

Ed Salter
Marine Consents Manager

1, St. James's Market
London, SW1Y 4AH

T +44 (0) 20 7851 5225
E 

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CASE STUDIES

Summary

As described in the main report, case studies have been prepared to amalgamate and review the body of available data across combined TCE areas (Table 1; Figure 1).

Table 1: Case Study, TCE Areas and Project Information within Case Study Area.

Case Study		TCE Areas		No. of Projects Considered**	No. of Projects Requested**
01	North East	2	Dogger Bank	0 (No projects in this Area)	0
		3	Yorkshire Coast	1	3
		4	The Wash	5	6
		5	Southern North Sea	0 (Limited Projects in this Area)	0
02	East Anglia	6	East Anglia	2	3
03	The East	7	Kent Coast	4	7
		8	Thames Approach		
04	South East	9	South East	1	1
05	North West	15	Anglesey	0	0
		16	North Wales	2*	4
		17	Irish Sea	7*	8

*Note that Burbo Bank Extension export cable route carries across both Region 16 and Region 17

**Note: These indicate number of projects where questionnaire information was available to inform the study (i.e. Projects Considered) and the total number of offshore wind and interconnector projects where information was requested via the questionnaire (i.e. Projects Requested).

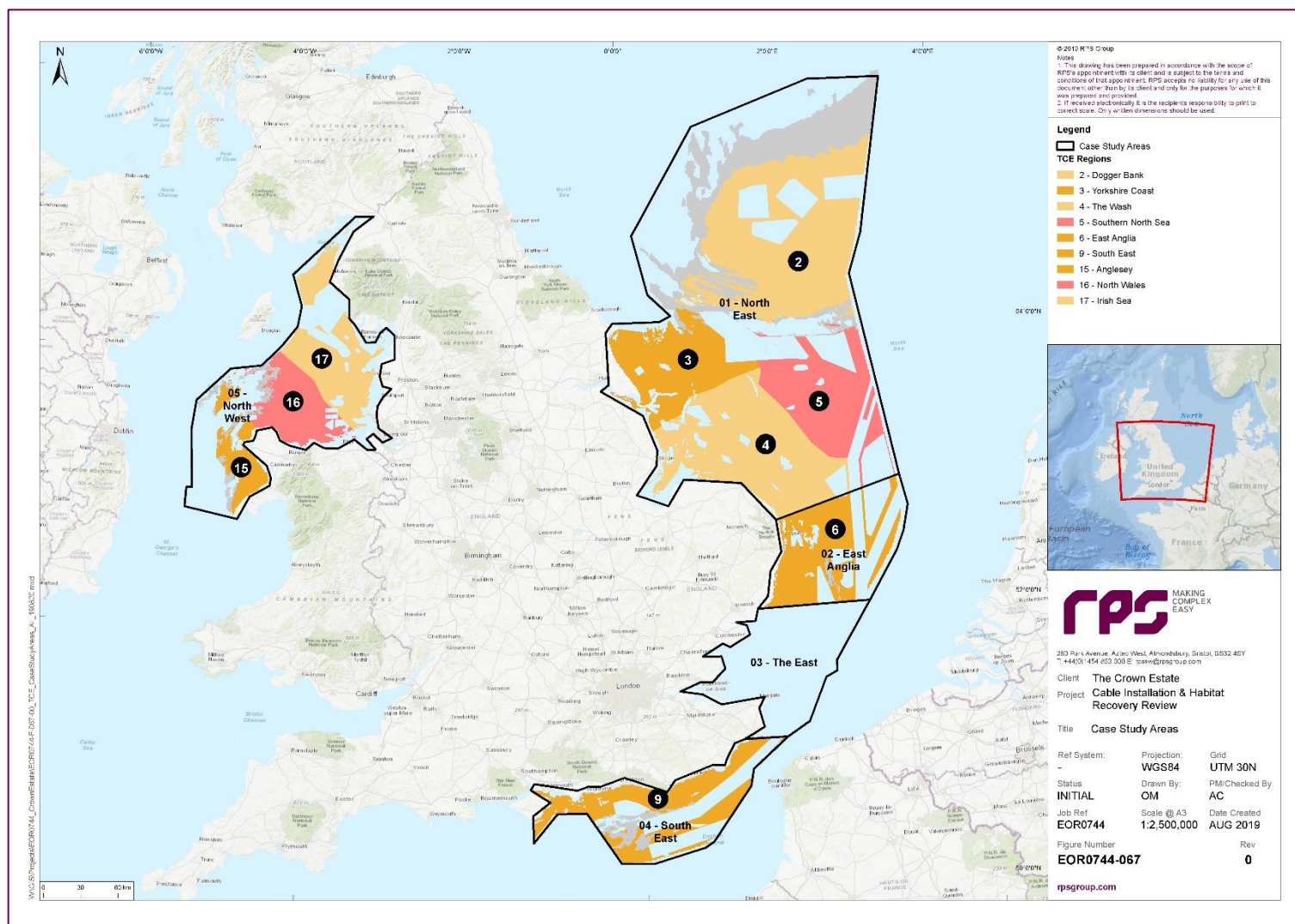


Figure 1: Case Study Areas.

North East - 01

Background Information

The North East case study area is located off the north east coast of England and encompasses TCE areas Dogger Bank, Yorkshire Coast, The Wash and the Southern North Sea (Table 1; Figure 1) .

Route Length

The total length of export cable routes within the Case Study area is approximately 251 km, across six projects.

Marine Bedrock

The summary bedrock profile for each of the regions within this Case Study are summarised in Table 2 and are shown in Figure 2. Where site specific project information on ground conditions were available, these were primarily in the areas nearer to shore, within Regions 3 and 4, where chalk is the main bedrock type for projects in the area. Looking further offshore, mudstone and sandstone are heavily featured in Regions 2 and 5.

Table 2: Marine Bedrock by Region for Case Study 01 – North East.

TCE Region	Bedrock Types
2 Dogger Bank	ROCK, SILICICLASTIC, ARGILLACEOUS and SANDSTONE
3 Yorkshire Coast	CHALK, MUDSTONE and LIMESTONE
4 The Wash	CHALK, MUDSTONE and SILTSTONE, MUDSTONE and SANDSTONE and ROCK, SILICICLASTIC, ARGILLACEOUS and SANDSTONE
5 Southern North Sea	MUDSTONE and SANDSTONE and ROCK, SILICICLASTIC, ARGILLACEOUS and SANDSTONE

Sediment

The sediment types for each of the regions within this Case Study are summarised in Table 3 and in Figure 3.

Where site specific project information on ground conditions were available, these were primarily in the areas nearer to shore, within Regions 3 and 4, where larger grained sandy gravel and gravelly sand is present for projects in the area. Looking further offshore small grain sands and muddy sands are featured in Regions 2 and 5.

Table 3: Marine Seabed Sediments by Region in Case Study 01 – North East.

TCE Region	Sediment Types
2 Dogger Bank	SAND, MUDDY SAND
3 Yorkshire Coast	SANDY GRAVEL, GRAVELLY SAND, SAND
4 The Wash	SANDY GRAVEL, GRAVELLY SAND, SAND, GRAVELLY MUDDY SAND
5 Southern North Sea	SAND, SLIGHTLY GRAVELLY SAND, GRAVELLY SAND

Project Information

Sediment Conditions

Site specific project information available for this case study suggested that the sea bed conditions were characterised as follows:

- Nearshore: Coarse Sand and Gravelly Sand with Shell fragments;
- Moving offshore: Coarse Sand and Gravelly sand; and
- Offshore: Gravelly Sand with Shell fragments.

Seabed Geology

Similarly, site specific project information indicated that sub-surface geology was characterised as follows:

- Nearshore: Botney Cut, Chalk and Holocene Formation; and
- Offshore: Boulders Bank Formation and Botney Cut.

The seabed conditions in these regions vary quite considerably dependant on the Depth of Burial relative to the sediment thickness and any bedrock penetration. The majority of the projects have avoided the need to install cable below the bedrock and have reported shear strength values of between 50 kPa and 175 kPa.

Installation Tools

The installation tools chosen to complete the export cable installations include the three principal types, cable plough, mechanical trencher and jet trencher:

- Cable ploughing accounting for 55% of the total cable length installed;
- Mechanical trenching accounting for 31% of the total cable installed; and
- Jet trenching accounting for 14% of the total cable installed.

Installation success per tool type is indicated in Table 4.

Table 4: Installation success per tool type for Case Study 01 – North East.

Installation Tool	Length (km)	Reached target DoB (%)
Cable Plough	137.31	91.7
Mechanical Trenching	78.35	78.3
Jet Trenching	35.5	58.6
Total	251.16	82.82 (average)

Protection Measures

In this Case Study area, the projects have utilised a number of methods to establish greater protection of the export cables following the initial installation (Table 5). These include:

- Mass flow excavation (MFE);
- Rock placement;
- Concrete mattresses; and
- Concrete bags.

Table 5: Protection measures utilised for projects within Case Study 01 – North East.

Protection Measure	Length (km)	As a percentage of cable installed (%)
Mass flow excavation (MFE)	19.3	7.68
Rock placement	1.700*	0.68
Concrete mattresses	0.200**	0.08
Concrete bags	0.05	0.02
Total	21.25	8.46

*this is not inclusive of rock materials used for export cables crossings.

** this is not inclusive of mattresses used at turbine interface.

Results Review

The direct comparison of the success of each tool as a percentage is shown in Table 5, where the cable ploughing has a good rate of success (i.e. 91.7%), significantly higher when compared to mechanical trenching (78.3%). Jet trenching success was somewhat lower (i.e. 58.6%), with almost half the cable length in these soil conditions have not reached the required level of protection via this installation method.

The predominant sediment types were sandy gravel, gravelly sand and sand, which typically trenchers should have the ability to succeed in full cable burial activities. However, the local sandy conditions also supported a remedial burial method that limited the volume of rock, concrete mattresses and rock bags to <1% of the cable length, by using MFE to complete 90% of all remedial protection activities.

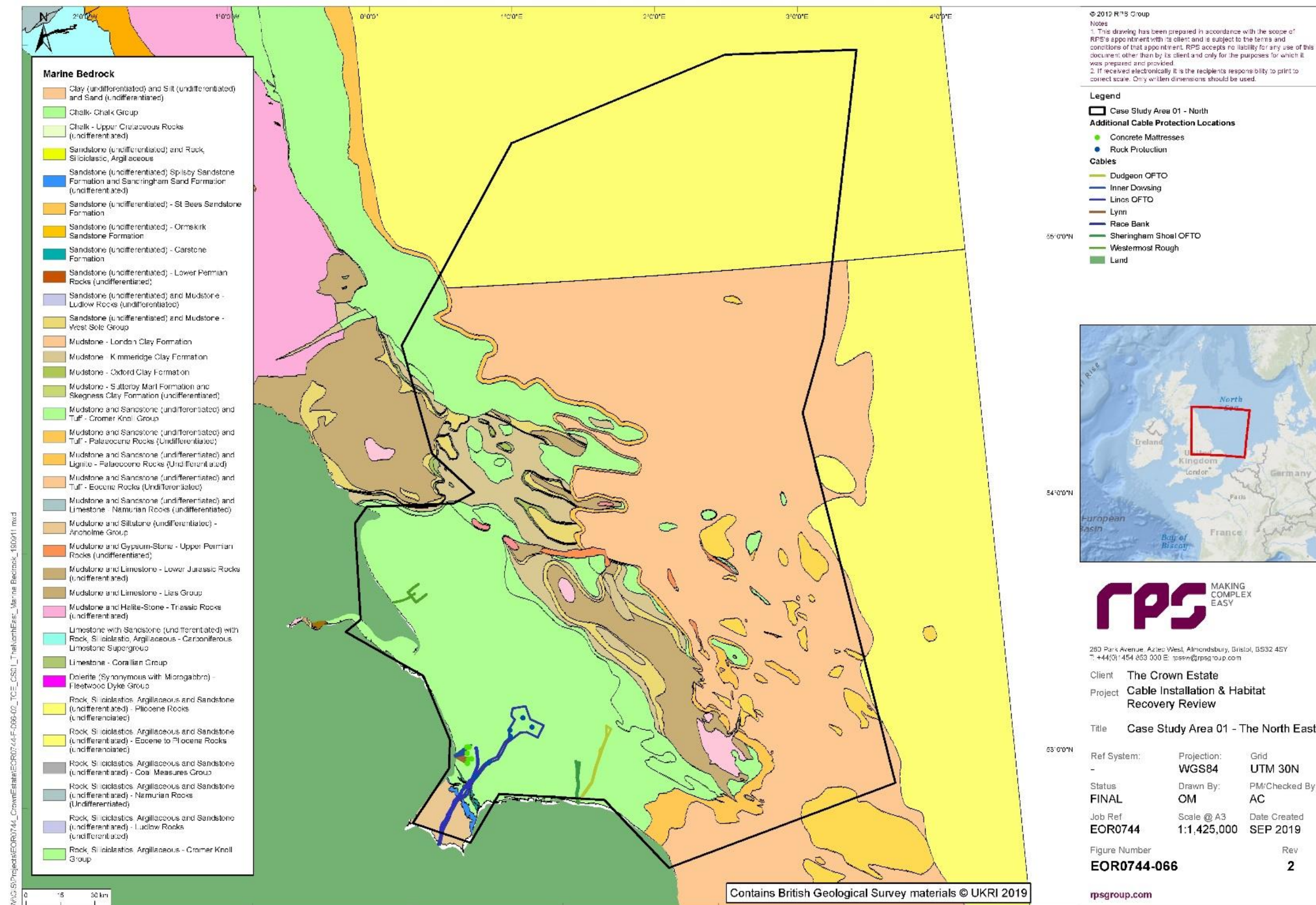


Figure 2: Case Study 01 – North East – Marine Bedrock.

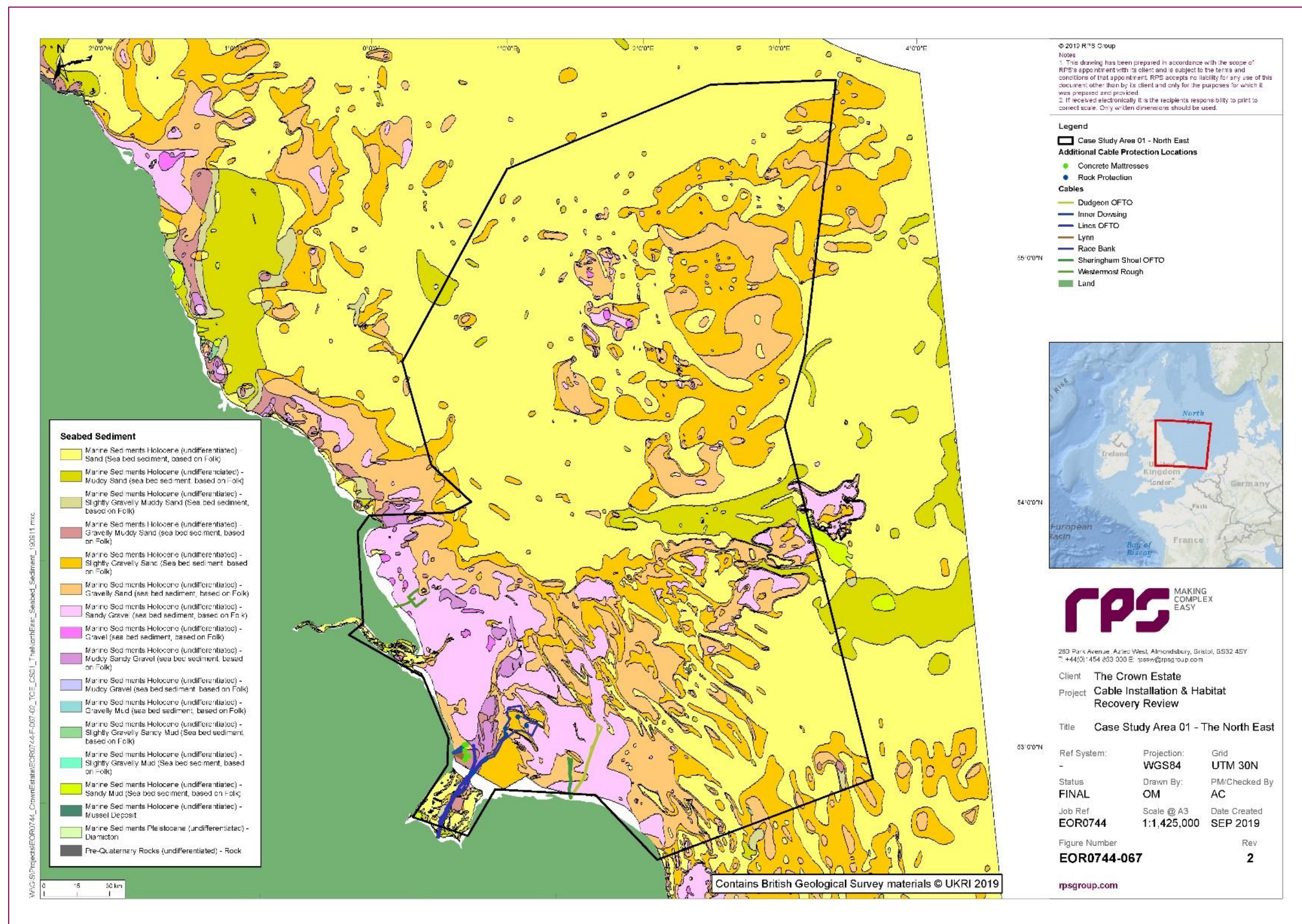


Figure 3: Case Study 01 – North East – Marine Seabed Sediment.

East Anglia - 02

Background Information

The East Anglia case study area is located off the east coast of Norwich, England, and encompasses TCE areas East Anglia (Table 1; Figure 1) .

Route Length

The total length of export cable routes within the Case Study area is approximately 135 km, across 2 projects.

Marine Bedrock

The summary bedrock profile for the East Anglia region (Region 6) in this Case Study is summarised in Table 6 below and are shown in Figure 4. The predominant areas are the areas near to shore of mudstone and sandstone.

Table 6: Marine Bedrock by Region for Case Study 02 – East Anglia.

TCE Region		Bedrock Types
6	East Anglia	MUDSTONE and SANDSTONE and ROCK, SILICICLASTIC, ARGILLACEOUS and SANDSTONE

Sediment

The summary sediment types within the East Anglia region (Region 6) in this Case Study are summarised in Table 7 below and are visually represented in Figure 5. These sediments are to be taken into consideration in combination with the bedrock formations when evaluating cable installation scenarios.

Where project information has been available these were in the areas nearer to shore, where larger grained sandy gravel and gravelly sand is present. Looking further offshore small grained sands and muddy sands are featured in Region 6.

Table 7: Marine Sediment within Case Study 02 – East Anglia.

TCE Region		Sediment Types
6	East Anglia	SAND, SLIGHTLY GRAVELLY SAND, GRAVELLY SAND, SANDY GRAVEL, GRAVEL

Project Information

Sediment Conditions

Site specific project information available for this Case Study suggested that the sea bed conditions were characterised as follows:

- Nearshore: Sand and Gravelly Sand; and
- Moving offshore: Sandy Gravel and Gravel.

Seabed Geology

Similarly, site specific project information indicated that sub-surface geology was characterised as follows:

- Nearshore: Holocene Formation, Sandstone; and
- Moving Offshore: Sandstone and Mudstone.

The seabed conditions in the region is fairly consistent with a thin non-mobile veneer, mobile sandwaves, often with London Clay making installation difficult. The projects have seen shear strength values of between 50kPa and 150kPa.

Installation Tools

The installation tools chosen to complete the export cable installations were as follows:

- Cable plough accounting for 100% of the total cable length installed.

Installation Success per tool type is indicated in Table 8.

Table 8: Installation Success per tool type for Case Study 02 – East Anglia

Installation Tool	Length (km)	Reached target DoB (%)
Cable Plough	137.31	98.6
Total	137.31	98.6

Protection Measures

In this Case Study area, the projects have utilised a number of methods to establish greater protection of the export cables, following the initial installation (Table 9). These include;

- Concrete mattresses.

Table 9: Protection measures utilised for projects within Case Study 02 – East Anglia.

Protection Measure	Length (km)	As a percentage of cable installed (%)
Concrete mattresses	1.971*	1.46
Total	1.971	1.46

*this is not inclusive of mattresses used for export cables crossings.

Results Review

In this Case Study area, the single installation tool used was the cable plough. This choice of tool has clearly been successful, with 98.6% of the cable length reaching the depth of burial (Table 8). The predominant sediment types were sandy gravel, gravelly sand and sand. The cable plough performed well, and the remedial protection was completed with concrete mattresses, with the total protection reported in this Case Study comprising a total of 1.5% of the total cable lengths.

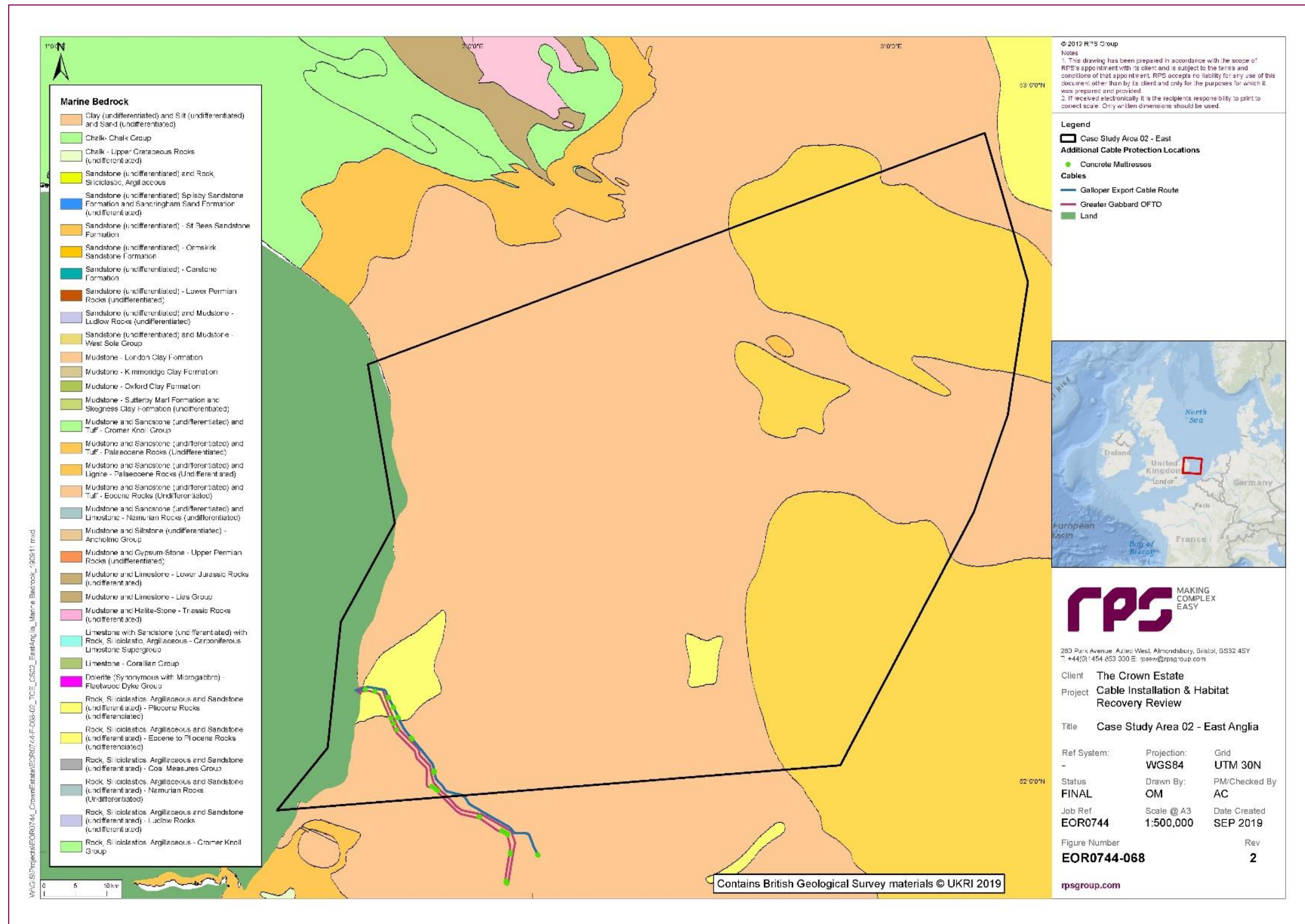


Figure 4: Case Study 02 – East Anglia – Marine Bedrock.

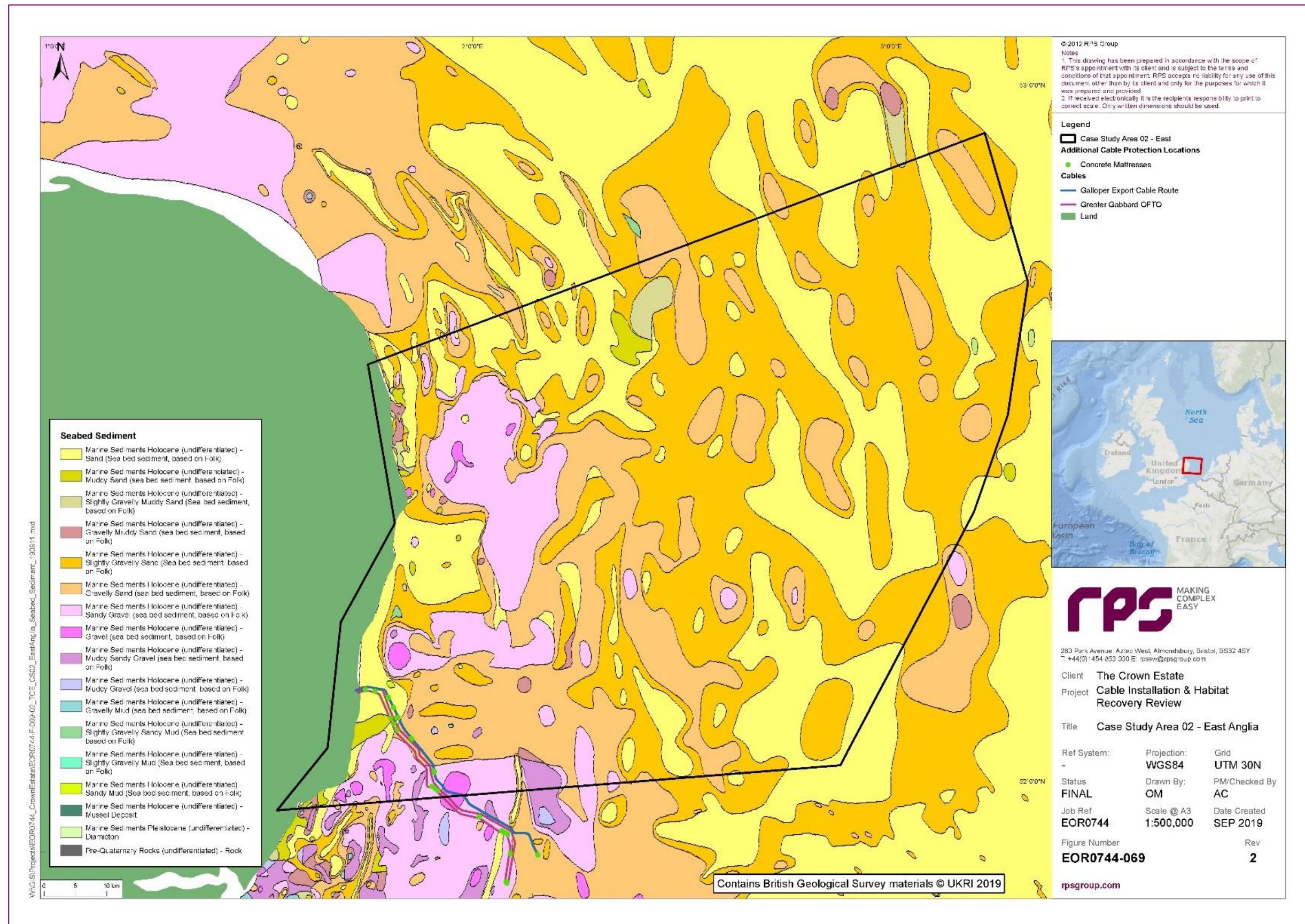


Figure 5: Case Study 02 – East Anglia – Marine Seabed Sediment.

East - 03

Background Information

The East case study area is located off the east coast of England and encompasses TCE areas Kent Coast and Thames Approach (Table 1; Figure 1).

Route Length

The total length of export cable routes within the Case Study area is approximately 285km, across 4 projects.

Marine Bedrock

The summary bedrock profile for each of the regions within this Case Study are summarised in Table 10 below and are shown in Figure 6. Where site specific project information on ground conditions were available, these were primarily in areas to the south where chalk is the main bedrock for project in the area. Looking further north in the Case Study area, mudstone and sandstone are heavily featured.

Table 10: Marine Bedrock by Region for Case Study 03 – East.

TCE Region	Bedrock Types
7 Kent Coast	MUDSTONE and SANDSTONE, ROCK, SILICICLASTIC, ARGILLACEOUS and SANDSTONE,
8 Thames Approach	CHALK, MUDSTONE and SANDSTONE, ROCK, SILICICLASTIC, ARGILLACEOUS and SANDSTONE,

Sediment

The summary sediment types for each of the regions within this case study are summarised in Table 11 below and shown in Figure 7. These sediments are to be taken into consideration in combination with the bedrock formations when evaluating cable installation scenarios.

Where site specific project information on ground conditions were available, these were characterised by larger grain sandy gravel and gravelly sand in the south and smaller grained sands and muddy sands further north.

Table 11: Marine Seabed Sediments by Region in Case Study 03 – East

TCE Region	Sediment Types
7 Kent Coast	SAND, SLIGHTLY GRAVELLY SAND, GRAVELLY SAND, SANDY GRAVEL, GRAVEL
8 Thames Approach	SAND, SLIGHTLY GRAVELLY SAND, GRAVELLY SAND, SANDY GRAVEL, GRAVEL

Project Information

Sediment Conditions

Site specific project information available for this case study suggested that the sea bed conditions were characterised as follows:

- South: Corse sand and Gravelly Sand; and
- North: Corse sand and Gravelly sand.

Seabed Geology

Similarly, site specific project information indicated that sub-surface geology was characterised as follows:

- South: Chalk; and
- North: Mudstone and Sandstone.

The seabed conditions in these regions vary quite considerably dependant on the depth of burial relative to the sediment thickness and any bedrock penetration. The majority of the projects reported shear strength values of between 50kPa and 175kPa.

Installation Tools

The installation tools chosen to complete the export cable installations included only a single installation tool type:

- Cable plough accounting for 100% of the total cable length installed.

Installation Success per tool type is indicated in Table 12.

Table 12: Installation success per tool type for Case Study 03 – East.

Installation Tool	Length (km)	Reached target DoB (%)
Cable Plough	285.3	99.56
Total	285.3	99.56

Protection Measures

In the Case Study area, the projects have utilised a number of methods to establish greater protection of the export cables (Table 13). These include:

- Rock placement; and
- Concrete mattresses.

Table 13: Protection measures utilised for projects within Case Study 03 – East.

Protection Measure	Length (km)	As a percentage of cable installed (%)
Rock placement	0.200km*	0.07
Concrete mattresses	1.045km**	0.37
Total	1.245	0.44

*this is not inclusive of rock materials used for export cables crossings

** this is not inclusive of mattresses used at turbine interface.

Results Review

In this Case Study area, the single installation tool used was the cable plough. This choice of tool has clearly been successful, with 99.56% of the cable length reaching the depth of burial (Table 12). In the predominant sediment types of coarse sand and gravely sand, the cable plough performed well. Remedial protection represented only a small proportion of the overall length of export cables (i.e. <0.5%), with mainly concrete mattresses and some rock protection.

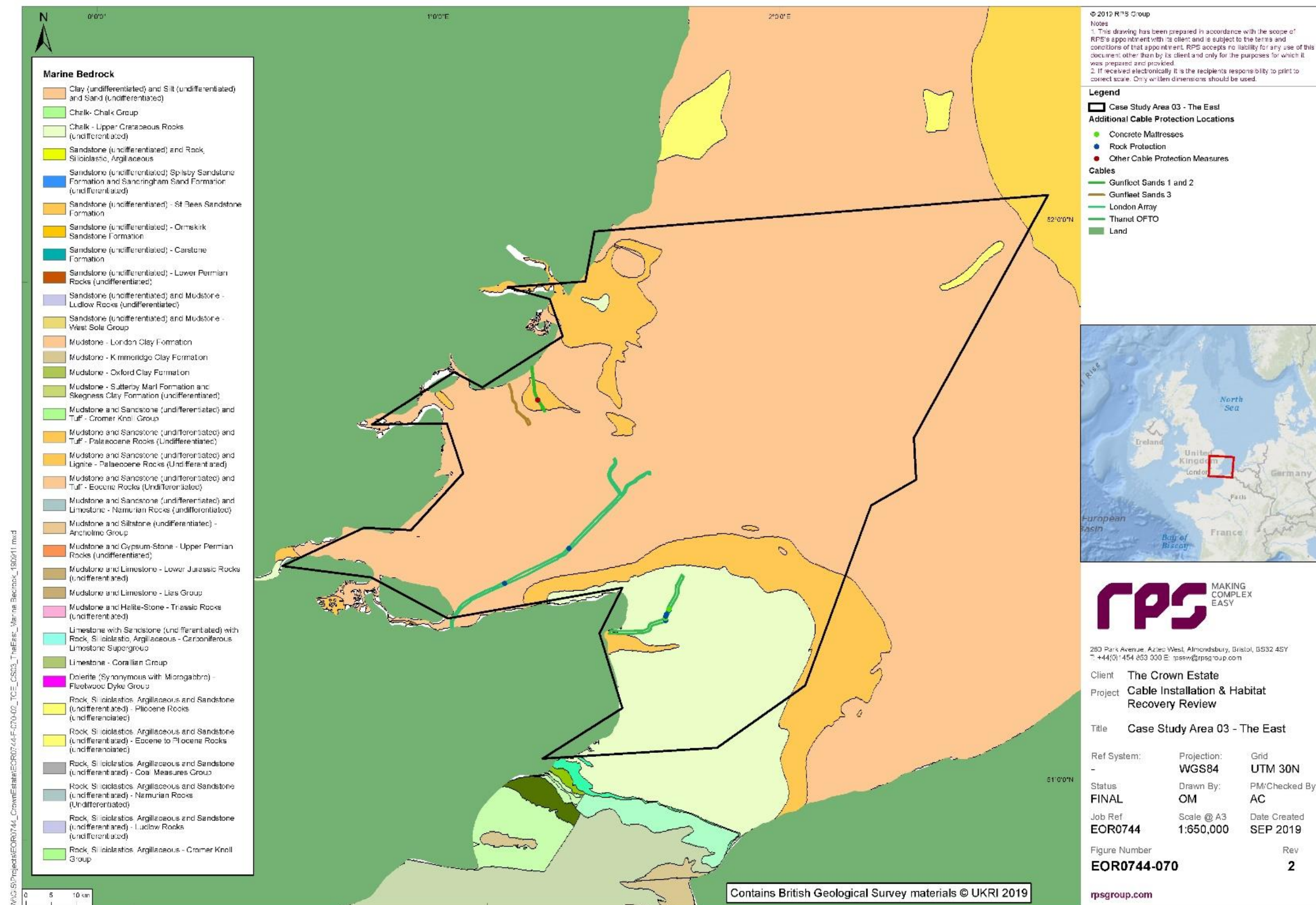


Figure 6: Case Study 03 – East – Marine Bedrock.

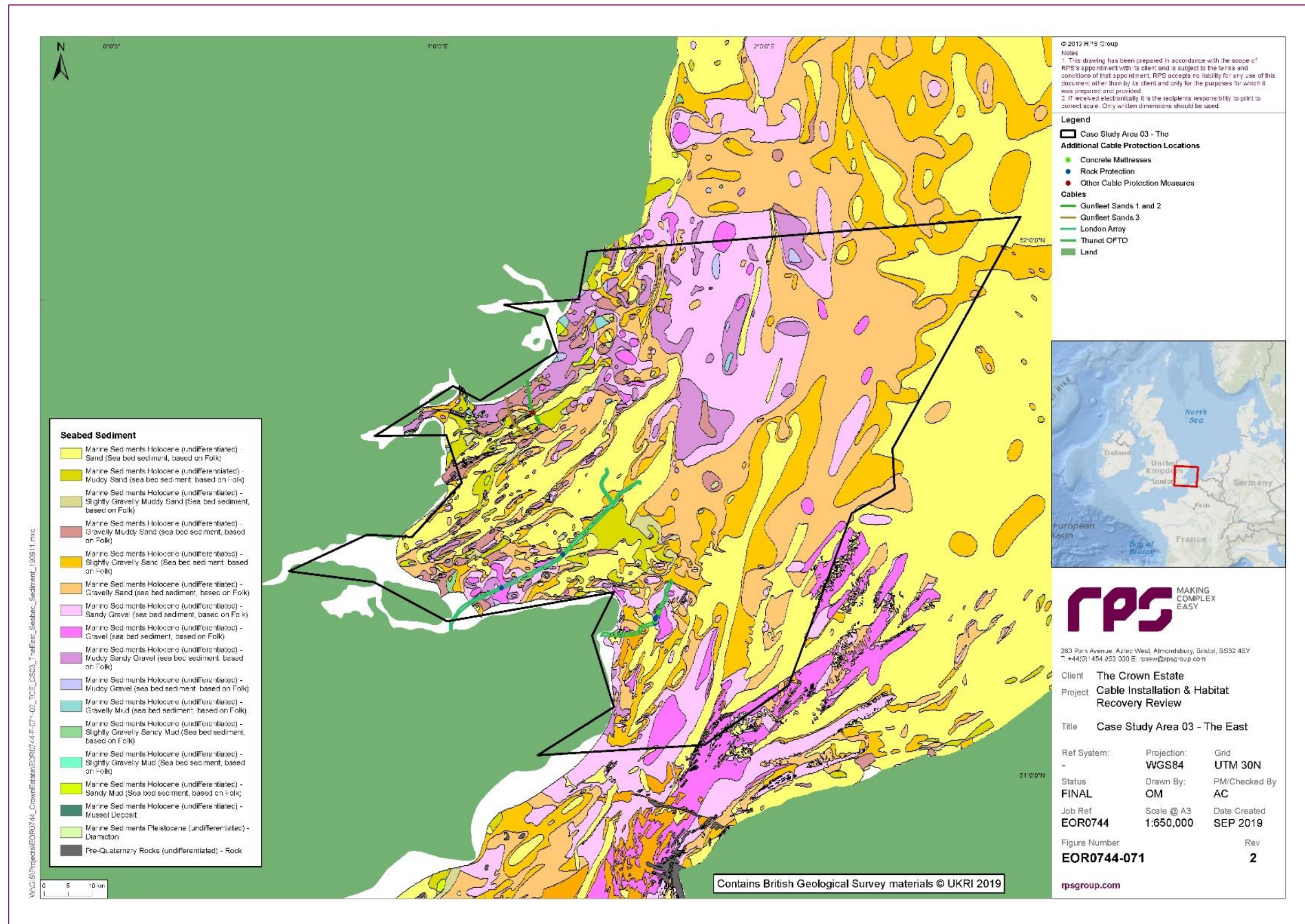


Figure 7: Case Study 03 – East – Marine Seabed Sediment.

South East - 04

Background Information

The South East case study area is located off the south east coast of England and encompasses TCE areas South East (Table 1; Figure 1).

Route Length

The total length of export cable routes within the Case Study area is approximately 45 km, with only 1 project within this Region.

Marine Bedrock

The summary bedrock profile for each of the regions within this Case Study are summarised in Table 14 below and are presented in Figure 8. Where site specific project information on ground conditions were available, these were primarily in areas near to shore, with of mudstone, sandstone and chalk characterising this area.

Table 14: Marine Bedrock for Case Study 04 – South East.

TCE Region	Bedrock Types
9 South East	ROCK, SILICICLASTIC, ARGILLACEOUS, CHALK, MUDSTONE,

Sediment

The summary sediment types for each of the regions within this Case Study are summarised in Table 15 below and presented in Figure 9. These sediments are to be taken into consideration in combination with the bedrock formations when evaluating cable installation scenarios.

Where site specific project information on ground conditions were available, these are from areas nearer to shore, with smaller grain sands and muddy sands, grading to larger grained sandy gravel and gravelly sand further offshore in Region 9.

Table 15: Marine Seabed Sediments in TCE Region 9 / Case Study 04 – South East.

TCE Region	Sediment Types
9 South East	ROCK AND SEDIMENT, SANDY GRAVEL, GRAVELLY SAND, GRAVEL,

Project Information

Sediment Conditions

Site specific project information available for this Case Study suggested that the sea bed conditions were characterised as follows:

- Nearshore: Slightly Gravelly Sand; and
- Moving offshore: Gravelly sand.

Seabed Geology

Similarly, site specific project information indicated that sub-surface geology was characterised as follows:

- Nearshore: Chalk; and

- Moving Offshore: Sandstone and Mudstone.

The seabed conditions in the region is fairly consistent with a thin mobile veneer over chalk making cable installation difficult. Shear strength values reported are between 34 kPa in Holocene deposits and 266 kPa in bedrock chalk.

Installation Tools

The installation tools chosen to complete the export cable installations include the three principal types:

- Cable plough accounting for 45% of the total cable length installed;
- Mechanical trenching accounting for 47% of the total cable length installed; and
- Jet trenching accounting for 13% as well as being utilised for mitigation activities for increased cable burial.

Installation success per tool type is indicated in Table 16.

Table 16: Installation success per tool type for Case Study 04 – South East.

Installation Tool	Length (km)	Reached target DoB (%)
Cable Plough	19.2	47.9
Mechanical Trenchers	20.0*	66.8*
Jet Trenchers	5.8*	39.8*
Total	45.0	55.3

*The mechanical and jet trenchers were supported with a total of 4.54km of remedial jet trenching supporting the depth of burial requirement

Protection Measures

In the Case Study area, to establish greater protection of the export cables, rock protection has been utilised in areas where DOB is less than 1.0m (Table 17).

Table 17: Protection measures utilised for projects within Case Study 04 – South East.

Protection Measure	Length (km)	As a percentage of cable installed (%)
Jet Trenching	4.54	10.1
Rock Protection	3.01	6.7
Total	7.55	16.8

Results Review

The direct comparison of the success of each tool as a percentage is shown in Table 17. In this Case Study, the relative successes of the tools are generally lower than for all other Case Studies. However, it is worth noting that the total route length of cabling is low and therefore may not necessarily be representative should other installation occur in this region in the vicinity.

The direct comparison of the success of each tool as a percentage is shown in Table 16, where the cable plough has relatively low rate of success (47.9%) compared to mechanical trenching (66.8%). Although jet trenching had a low level of success (39.8%), this method was used for remedial burial operations where the depth of burial was not achieved during initial installation.

The predominant seabed conditions experienced by the project was a thin mobile veneer over chalk with shear values up to 266kPa, which clearly made installation difficult, explaining the relatively low percentage success rates for the tools. The best success rate came from the mechanical trencher.

The depth of burial requirement was reviewed, given the local seabed conditions and difficulties with installation of the first pair of cables, from 1.5 m to 1.0 m. With this revised target depth of burial, upon completion of the installation, only cable lengths that had not reached 1.0m DoB were then subject to either remedial jet trenching or rock protection.

The revised depth of burial against the associate risk assessment of the local conditions means 10.1% of the cable length required jet trenching as backfill, and 6.7% with rock protection, the remainder of the previously unsuccessful installation was deemed acceptable.

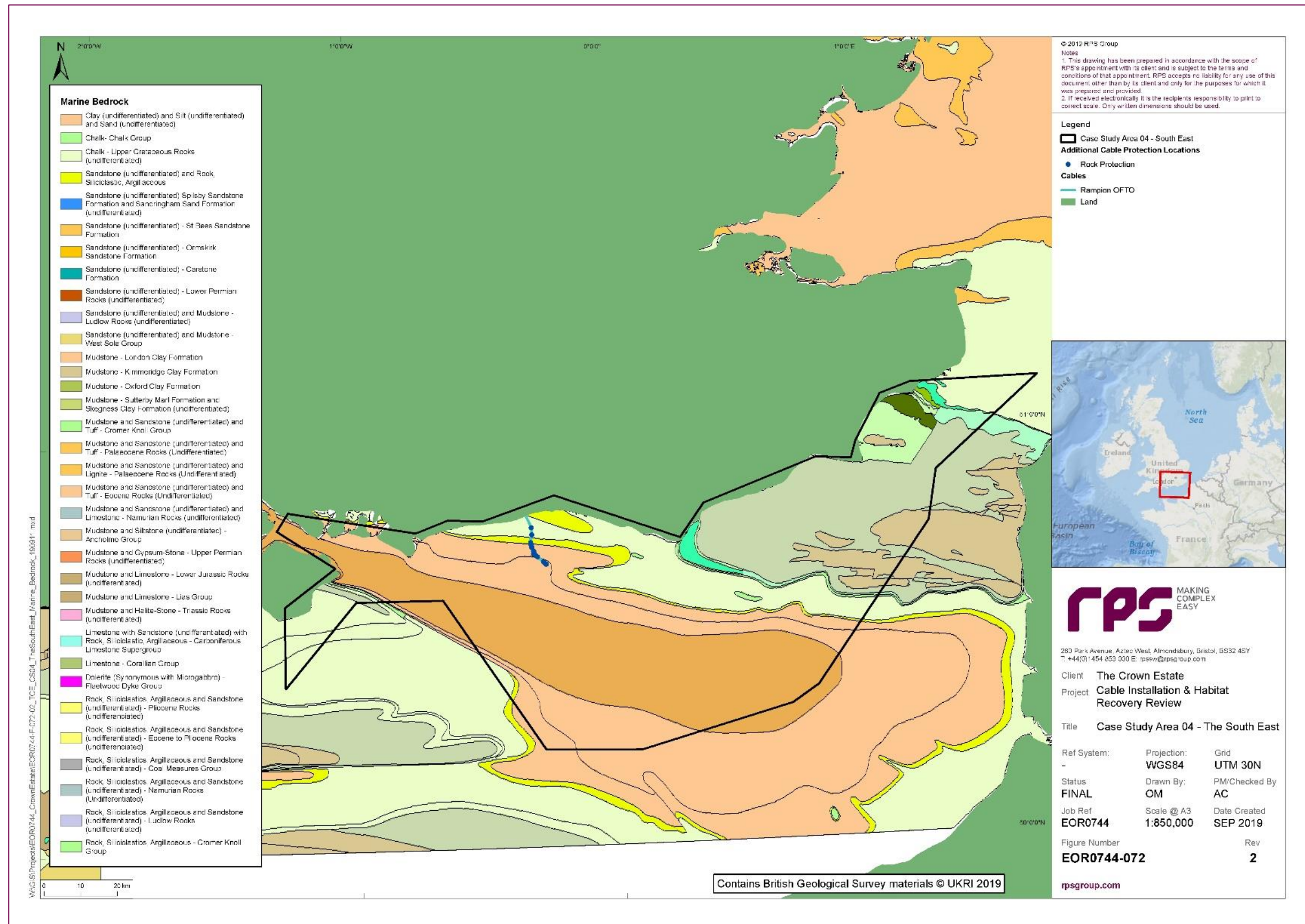


Figure 8: Case Study 04 – South East – Marine Bedrock.

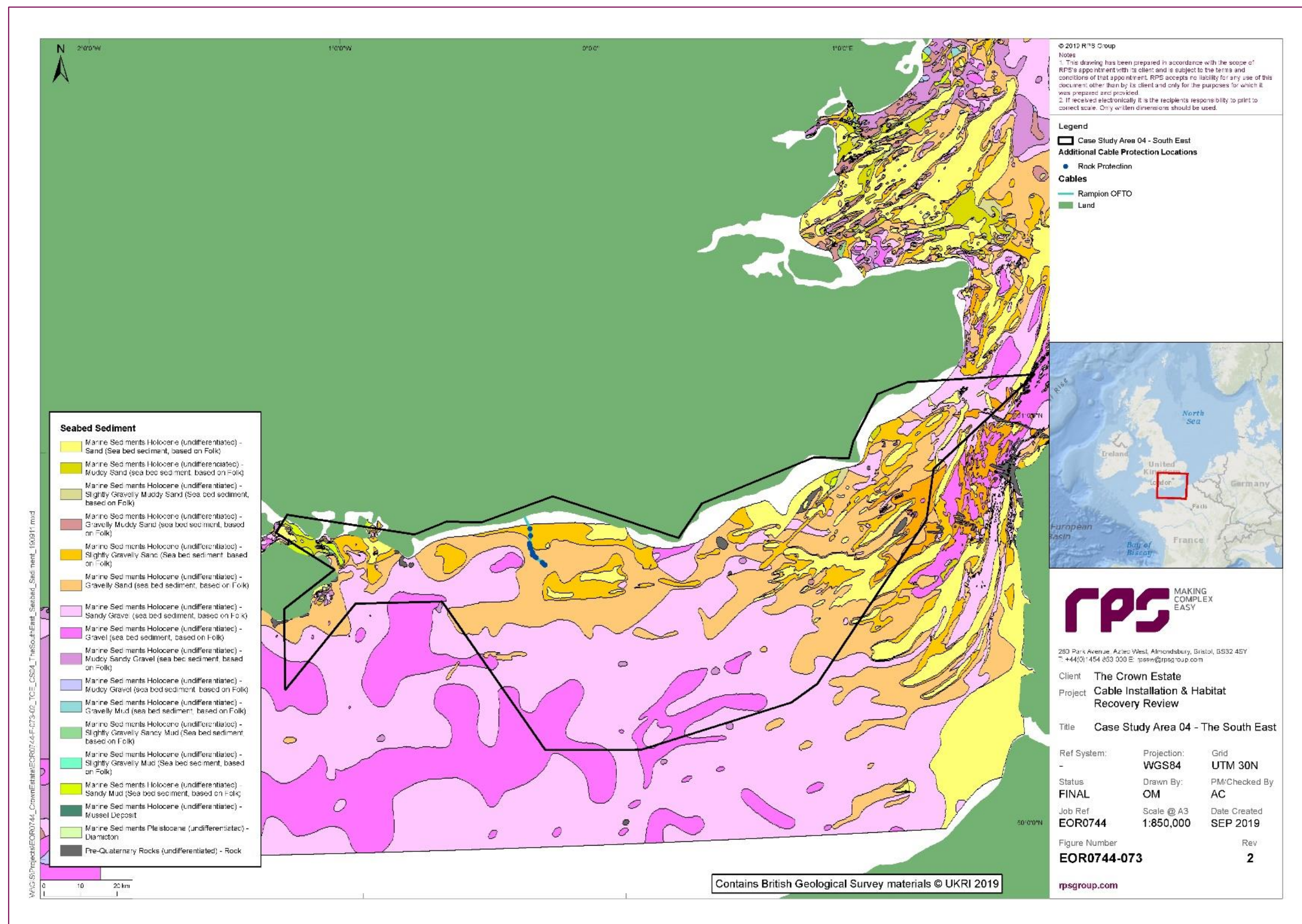


Figure 9: Case Study 04 – South East – Marine Seabed Sediment.

North West - 05

Background Information

The North West case study area is located off the North West coast of England and North of Wales and encompasses TCE areas Anglesey, North Wales and the Irish Sea (Table 1; Figure 1).

Route Length

The total length of export cable routes within the Case Study area is approximately 450.5 km, across 8 projects.

Marine Bedrock

The summary bedrock profile for each of the regions within this Case Study are summarised in Table 18 below, and presented in Figure 10.

Where site specific project information on ground conditions were available these are in the areas to the north, where mudstone and sandstone close to shore are the main bedforms. Looking further south of the Case Study area there are additionally significant areas of limestone and increased percentage of mudstone.

Table 18: Marine Bedrock by Region for Case Study 05 – North West.

TCE Region		Bedrock Types
15	Anglesey	ROCK, SILICICLASTIC, ARGILLACEOUS and SANDSTONE, MUDSTONE and HALITE-STONE, MUDSTONE and SANDSTONE, LIMESTONE
16	North Wales	MUDSTONE and HALITE-STONE, SANDSTONE, LIMESTONE
17	Irish Sea	MUDSTONE and HALITE-STONE, SANDSTONE, MUDSTONE and LIMESTONE

Sediment

The summary sediment types for each of the regions within this Case Study are summarised in Table 19 below, and presented in Figure 11. These sediments are to be taken into consideration in combination with the bedrock formations when evaluating cable installation scenarios.

Where site specific project information on ground conditions were available, these were predominantly in the north of the Case Study area, where the zones immediate to the coast comprise gravelly sand, swiftly changing to muddy sand and sandy mud. Larger grain sands and gravels are further offshore, whereas to the southern end of the Case Study area there are larger areas of sand and slightly gravelly sand.

Table 19: Marine Seabed Sediments by Region in Case Study 05 – North West.

TCE Region		Sediment Types
15	Anglesey	ROCK AND SEDIMENT, GRAVELLY SAND, SANDY GRAVEL, GRAVEL, MUDDY SAND
16	North Wales	ROCK AND SEDIMENT, GRAVELLY SAND, SANDY GRAVEL, GRAVEL, MUDDY SAND
17	Irish Sea	SANDY GRAVEL, GRAVEL,

Project Information

Sediment Conditions

Site specific project information available for this case study suggested that the sea bed conditions were characterised as follows:

- Nearshore: Overlain with recent deposits of silty or clayey sands with variable gravel content. Glacial till overlain very hard sediment.
- Moving offshore: Overlain by glacial deposits of stiff clays with sands and gravels of the Pleistocene age.

Seabed Geology

Similarly, site specific project information indicated that sub-surface geology was characterised as follows:

- Nearshore: Sandstones and mudstones or Permo-Triassic; and
- Offshore: Mudstone bedrock typically 10 m below sediment layer.

The seabed conditions in these regions vary quite considerably dependant on the depth of burial relative to the sediment thickness and any bedrock penetration. The majority of the projects have avoided the need to install cable below the bedrock and have reported shear strength values of between <75 kPa and up to 150 kPa.

Installation Tools

The installation tools chosen to complete the export cable installations include the following installation methods:

- Cable plough accounting for 59% of the total cable length installed;
- Mechanical Trenching accounting for 30% of the total cable installed;
- Trailing Suction Hopper accounting for 5.3% of the total cable installed; and
- Vertical injection accounting for 5.6% of the total cable installed.

Installation success per tool type is indicated in Table 20.

Table 20: Installation success per tool type for Case Study 05 – North West.

Installation Tool	Length (km)	Reached target DoB (%)
Cable Plough	264.7	92
Mechanical Trenching	136.6	99
Trailing Suction Hopper Dreger	24	97
Vertical Injection	25.2	95
Total	251.16	94.6 (average)

Protection Measures

In the Case Study area, the projects have utilised a number of methods to establish greater protection of the export cables (Table 21). These include:

- Jet trenching;
- Rock placement; and
- Concrete mattresses.

Table 21: Protection measures utilised for projects within Case Study 05 – North West.

Protection Measure	Length (km)	As a percentage of cable installed (%)
Jet Trenching	41km	9.1
Rock placement	21.54km*	4.8
Concrete mattresses	0.520km**	0.12
Total	63.06	14.0

*this is not inclusive of rock materials used for export cables crossings.

** this is not inclusive of mattresses used at turbine interface.

Results review

The direct comparison of the success of each tool as a percentage is shown in Table 20, where the cable plough was reported as having a good rate of success (92%) and completed the majority of the installation lengths. The other tools were successful in their installation campaigns, with mechanical trenching at 99%, suction hopper dredger at 97% and vertical injection at 95%, whilst having the deepest depth of burial requirement.

For this Case Study area, the average percentage successful completion of the installation tool reaching the depth of burial is relatively high compared to the other Case Studies. Yet, the information available indicates a large amount of rock placement and remedial jet trenching.

The information available indicates that a survey performed showed significant cable exposures and where possible jet trenching allowed 9% of the route length to be remedially buried, along with 4.92% receiving rock protection and concrete mattresses.

The predominant geology was Sandstones and mudstones with a varying depth of sediment cover. It is the authors' understanding that this region of the UK coast has high seabed mobility, perhaps higher than anticipated. As such, it can be surmised that the required depth of burial identified was perhaps not below the non-mobile level at some points along the route corridors.

Where one developer recently revised the likely seabed mobility description to state:

- The superimposed sand waves are formed by wind driven currents and ocean waves and are 0.7 m to 3 m high and 100 m to 400 m long and the calculated migration rates are within the range 10 m/year.

The predominant depth of burial was 1.0m, which would provide the required risk mitigation via sediment cover. However, this assumes static conditions and given the level of seabed mobility, the cables have become exposed and remedial jet trenching, rock and mattress protection has been required in some areas.

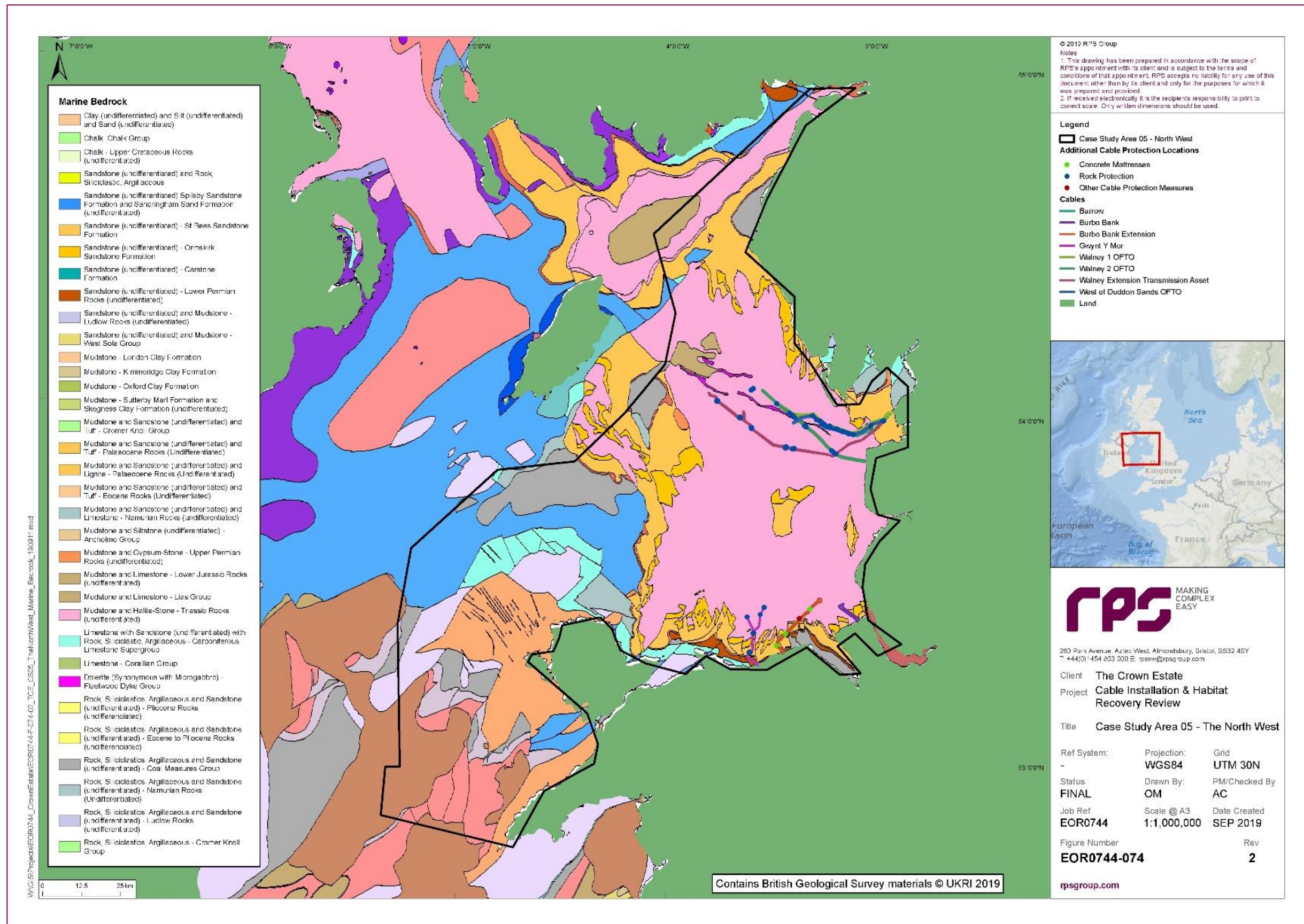


Figure 10: Case Study 05 – North West – Marine Bedrock.

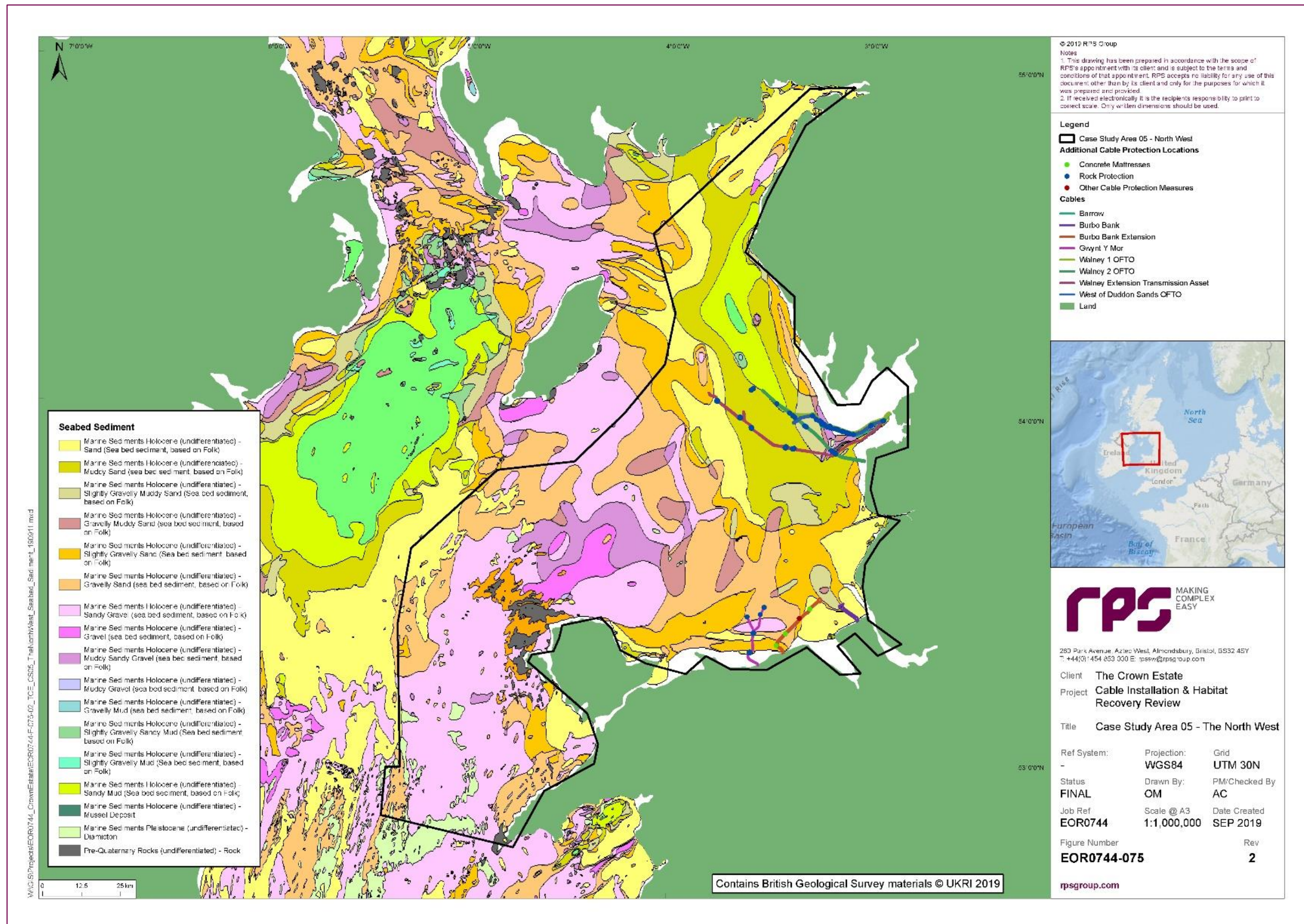


Figure 11: Case Study 05 – North West – Marine Seabed Sediment

APPENDIX C

Environmental Impacts and Recovery - Summary of Monitoring

Summary of offshore wind farm monitoring studies reviewed.

* Information on cable installation tools for these projects was obtained or derived through publicly available sources, so would require confirmation from developers.

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
Barrow	Twice-yearly post-construction scour surveys (bathymetry and SSS) of the cable route and turbines (including inter-array cables) between 2005 and 2009 (BOWL, 2005; BOWL, 2009a).	Sandy gravel	Cable plough *	Seabed is generally characterised by sandy gravel sediments, with till outcrops in places. During the first post-construction scour survey (November 2006 – immediately after construction), inter-array cable trenches and seabed depressions related to the inter-array cables installation were visible in the bathymetric data with some depressions up to 0.5 m deeper than the surrounding seabed. During the second post-construction bathymetric survey (April 2007), these depressions had been either partially or almost completely infilled by natural sedimentation processes. In some cases the remnants of the inter-array cable installation process had completely disappeared. During the subsequent November 2007 and May 2008 scour surveys, these features associated with inter-array cable installation were no longer visible in the bathymetric data.
	2012 post-construction bathymetric and SSS survey of the wind farm (BOWL, 2012).			The 2012 post-construction bathymetric and SSS survey (~6 years post-construction) of the wind farm site identified areas of inter-array cable trenches which were indicated as 'remnant', although the extent of these as a proportion of the overall array cables was not reported. These remnant trenches were defined based on an indication that the 'trench' has been infilled with sediment, although these had little relief visible in the SSS data. Cable lay scars were visible in areas of coarse grained sediment only (none in areas of finer, sandy sediment). The sediment within the remnant trenches has a lower reflectivity than the surrounding sediments, enabling these areas to be interpreted.
	2016 export cable inspection survey (BOWL, 2016).			During the 2016 export cable inspection survey (bathymetry and SSS), 17 trench scars (trenches which have not been fully backfilled) were visible in SSS data along export cable route. The length of each trench scar ranged from 1 m to approximately 200 m in length, with a total length of visible trench scars of approximately 765 m, which was a relatively small proportion of the total length of the export cables (i.e. approximately 26 km).
	Two years post-construction benthic grab monitoring (2007 and 2009) (BOWL, 2008; BOWL, 2009b).			Two years of benthic post-construction monitoring (in 2007 and 2009) included three sample locations along the export cable route, although not directly over the cable trench (i.e. monitoring for indirect effects only). Although there were differences recorded in the physical sediments and benthic communities present compared to the pre-construction survey the same changes were observed at reference sites and therefore these changes were not attributable to the construction/operation of the wind farm.
Burbo Bank	Post construction Year 1 (2008) and Year 2 (2009) environmental monitoring reports (BBOWF 2008; BBOWF, 2009).	Sandy sediments	Jet trencher, vertical injection and mass flow excavator *	Export cable installed Summer 2006 with a target depth of 3m.
	2002 pre-construction bathymetric report (BBOWF, 2002).			The 2002 pre-construction bathymetry survey found that the export cable route passes through gently sloping sediment bathymetry, with water depths of generally <10 m. There was reported to be little variation in seabed sediment along the cable route, comprising primarily sandy sediments, with varying proportions of coarser fractions including shell, pebbles and cobbles. Post construction bathymetry surveys indicated that sediments types and seabed forms were similar across pre and post construction surveys, indicating that the seabed has recovered from cable installation.
	2008 post construction bathymetry and SSS survey (BBOWF, 2008).			Pre and post construction benthic monitoring included sampling along the export cable route. Analysis of sediment (i.e. particle size analysis) and benthic infaunal data over the post construction surveys indicated that any changes to either community composition or sediment type along the export cable route were within natural variability and were not attributed to cable installation. As outlined above, however, it should be noted that samples along the export cable corridor were not likely within the direct disturbance footprint for cable installation.
	2006 Construction phase benthic survey (BBOWF, 2006).			The 2007 cable burial depth survey showed that 95-98% of the cables had been buried to 3-4m with no cable sections with burial less than 3m observed more than 40m from the turbines. No scour was observed along the route. The 2010 cable inspection survey also found that the export cable inter array cables were buried across their entire routes.
	Year 1 (2007), Year 2 (2008) and Year 3 (2009) benthic monitoring survey (BBOWF, 2007a; BBOWF, 2009a; BBOWF, 2009b).			

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
	2007 cable burial depth monitoring (BBOWF, 2007b) and the 2010 export and inter array cable inspection survey report (BBOWF, 2010).			
Burbo Bank Extension	Information within Hornsea Project Three DCO application (Ørsted, 2018d).	Gravelly sand and sand	Jet trencher and mechanical trencher *	Geophysical survey data from the Burbo Bank Extension export cable were presented as evidence in the proposed Hornsea Three DCO application. The data presented focussed on cable protection at two crossings of the Burbo Bank Extension export cables and effects of this protection on sediment transport (e.g. accumulation of sediment or localised scour). These indicated localised scour of up to 0.5 m deep extending 10-20 m from the cable protection and no wider morphological changes to sediment transport pathways.
Dudgeon	First (2017) and second (2018) post-construction bathymetry surveys (DOWF, 2017; DOWF, 2018). Information within Hornsea Project Three DCO application (Ørsted, 2018c).	Gravelly sand and sandy gravel.	Cable plough	The seabed sediments along the Dudgeon export cable were characterised primarily by a mixture of sands and gravels in varying proportions (i.e. gravelly sand and sandy gravel), with discrete areas of sand in small sections. The Dudgeon array area was characterised by gravels and sands, with sandwave fields occurring in parts of the array. During the 2017 survey campaign, some infield cables were identified to be in shallow open trenches. These trenches were however less pronounced in the 2018 survey with only 'faint' trench visible. Cable trenches were also visible in some areas along the export cable route. A geophysical survey undertaken along the proposed Hornsea Three offshore cable corridor in 2016 included a short section of the Dudgeon export cable, approximately 8.5km offshore from the North Norfolk coast. This survey recorded remnant trenches, approximately 10 m in width and 10-20 cm depth. This survey was completed less than one year following cable installation and indicated rapid recovery of the seabed (i.e. infilling of trenches) following cable installation in this area (it should be noted, however, that conclusions from this are limited due to the small extent of the export cable route surveyed).
Greater Gabbard	Year 1 (2013) post-construction benthic monitoring survey (GGOWF, 2013).	Sandy gravel	Jet trenching *	Comparison of the 2013 survey data with the 2009 baseline report, concluded that the sediments along the export cable were unchanged (i.e. muddy inshore and gravelly offshore in both years). Weak to moderate significant differences in benthic communities recorded in 2009 compared to other years, but a broadly similar suite of the most important species were present. Biotopes assigned throughout the Project area were reasonably similar both in terms of type and distribution. Changes observed unlikely to be due to the construction and operation of the wind farm, and more likely due to wave action and storm events.
Gunfleet Sands 1 and 2	2010, 2011 and 2012 post-construction geophysical survey reports (MBES and SSS) (GSW1&2, 2010b; GSW1&2, 2011b; GSW1&2, 2012b). Year 1 (2010), Year 2 (2011) and Year 3 (2012) post-construction benthic monitoring surveys (GSW1&2, 2010a; GSW1&2, 2011a; GSW1&2, 2012a). Year 3 Marine Licence Environmental Monitoring Report (GSW1&2, 2015b).	Gravelly muddy sand, sand and muddy sand	Jet trenching *	Sediments along the export cable are broadly clays and shells inshore, muds, sands and shells in the central part and sand and shells further offshore. The export cable was installed in 2009. In the 2010 geophysical data (MBES and SSS) a trench is visible along the export cable route between KP0.35-0.4, KP2.85-6.7 and KP7.0-7.4. Numerous features were seen along the length of the surveyed corridor that appear to be anchor drag marks that could possibly result from cable laying operations. The drag marks were approximately 0.1-0.3 m deep. There were also several linear features along the length of the cable route (up to several hundred metres long) that appeared to be associated with the drag mark. Trenches along the export cable corridor were also observed during the 2011 and 2012 geophysical surveys in broadly the same locations as during the 2010 survey, as were the drag marks. The drag marks are noted as remaining stable and do not appear to have changed over the three years of survey. The inter-array cable burial route was clearly visible in the 2013 survey data (only the cable between turbines G01 and G02 was monitored). There was a trench visible as a ~0.2 – 0.3 m deep depression along the charted cable route. The benthic grab sample monitoring programme has shown that the construction and operation of the Gunfleet Sands wind farm (Gunfleet I and II and export cable) has had no detectable effect on the mean particle size or diversity of taxa in any of the sampling areas. Equally, there have only been subtle changes to faunal communities (e.g. small increases and decreases in abundances/species richness across all treatment zones) with no evidence to suggest large scale impacts. The faunal communities remain similar to the baseline conditions and

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
Gunfleet Sands 3	Export cable Bathymetry report 2015 (GSW1&2, 2015a).			therefore, effects are in line with the predictions of the environmental statement (GE Wind Energy, 2002). Changes identified by the monitoring programme are either within the measurable baseline variation or not significant. Export cable trenching scour was visible at numerous locations in the 2015 bathymetry report. These were recorded along four stretches of the export cable route, ranging in length between 150 m and 1.3 km, totalling 3.6 km of the export cable route (i.e. between KP 0.4-1.05, KP1.25-1.40, KP1.54-2.85 and KP4.05-5.20). Depth of burial data was collected across approximately 5km of the export cable (i.e. 54% of the cable route) and showed a range from 0.2 m to 3.4 m, with an average depth of burial of 2.6 m.
	2013, Spring 2014, Autumn 2014, June 2015 and December 2016 export cable and WTG geophysical surveys (GSW3, 2013a; GSW3, 2014a; GSW3, 2014b; GSW3, 2015; GSW3, 2016a; GSW3 2016 b).	Sand and muddy sand	Jet trenching *	The sediment types along the export cable route have been classified as sands and muddy sands. In the 2013 geophysical data (MBES and SSS) a trench is visible along the export cable route between KP0.4-5.125 and KP5.9-6.4) and as a shallow (<5 cm) trench between KP5.125-5.9 and KP6.4-7.1 and KP9.3-9.4. The seabed is disturbed in several areas with drag marks believed to be associated with cable laying operations. Trenches along the export cable corridor were also observed during the spring 2014 geophysical survey in broadly the same locations as during the 2013 survey. The maximum depth of the trench was recorded as 20 cm with other areas of shallow trench less than 5 cm in depth. During the autumn 2014 survey, the trench was only observed between KP0.853-4.57 and KP4.86-5.2. During the June 2015 survey, the trench was only visible between KP0.853-4.54. During the December 2016 survey the trench was only recorded as visible between KP0.85-4.54 and KP6.71-6.95.
	Year 1 post-construction (2013) benthic monitoring (grab and DDV) of export cable (GSW3, 2013b).			The Year 1 post-construction benthic monitoring along the export cable (unlikely to have been taken directly within trenches) revealed significant changes in the benthic communities over time (i.e. between baseline and post construction) at both the cable route and reference stations. Furthermore, very few significant differences were observed between baseline and cable route sites over time indicating changes observed at the cable route are in line with reference stations. As a result of this, the changes could not be attributed to the installation or operation of the export cable, suggesting instead that the changes detected were a result of natural fluctuations occurring on a greater scale than the cable route. The results indicated that any impacts resulting from the installation and operation of the export cable route were within natural variation of the infaunal communities within the vicinity of the cable route.
Humber Gateway	Post-construction monitoring of Annex I cobble reef and boulder clay via bathymetric survey and video survey impacted during export and inter-array cable installation (E.ON, 2013).	Sandy gravel with cobbles/boulders and boulder clay	Cable plough *	Monitoring results of three areas of Annex I cobble reef habitat along the export cable route highlighted short sections within the original Annex I cobble reef features approximately 10 to 20 m wide along the northern and southern export cables where seabed material has been excavated resulting in direct loss of Annex I habitat. Seabed in these areas were generally flatter areas of exposed clay or stones. However, adjacent to the excavated sections between and either side of the export cables were areas of Annex I stony reef comprising of clast supported medium to large cobble or small boulder which are colonised by a patchy epibiotic assemblage (typically barnacles, hydroids, bryozoans and sponges or ascidians). The post-construction reef features were broadly similar to those recorded pre-construction, but the morphology of the features had been modified during construction – changing from more discrete linear features to wider, more variable areas extending further along the export cable than previously and grade into adjacent non reef stony habitats to the east and west. Interspersed within these sections of Annex I stony reef were areas of exposed boulder clay often represented by elevated sheets or mounds, particularly along the edges of the excavated sections which were presumably spoil from the construction activity. Further north or south from the export cables (>50m) areas of Annex I reef remain which were unaffected by construction activity and retained similar characteristics to those recorded pre-construction. Adjacent habitats away from the immediate vicinity of the Annex I feature comprised of flatter mixed coarse stony sediment (i.e. non-reef habitat) and patches of clay. These tended to show less variation or evidence of cable installation. The monitoring surveys did not indicate any substantial disturbance to the main reef feature located to the west of installed inter-array cable and there was minimal disruption to the transitional stony/cobble habitat along the array cable itself with video data indicating habitats in these areas (and in the main reef to the west) to be broadly similar to those recorded pre-construction. The exposed boulder clay ridges inshore on the export route were subject to habitat loss directly along the northern and southern export cable where clay material has been excavated with minimal disruption to habitats either side or between the export cables.

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
Kentish Flats	6th post-construction bathymetry and SSS survey (2007) (KFOWF, 2008).	Gravelly sand	Cable plough *	Sediments across the array area were largely characterised by stable sands and within the export cable corridor by gravelly sand and then muddy sand in the more inshore regions.
	FEPA Monitoring Summary Report 2007 (KFOWF, 2007).			The construction debris survey undertaken in 2005 (construction was completed in 2004) recorded no significant changes in depths across the area, with the data comparing well with the pre-construction survey. Relics of cable trenching were however detected as seabed features in the bathymetry data but were recorded as having very low relief and essentially showing as slight scars in the seabed. The SSS data also detected linear cable trenches running between the turbines. These surveys confirmed that cable installation did not result in significant change in the seabed.
	FEPA Monitoring Summary Report 2009 (KFOWF, 2009).			The results from the third (i.e. final; 2007) benthic monitoring survey indicated that the pattern of sediment distribution across the survey area has been maintained over time. No changes to the physical nature of the seabed were evident from the benthic sampling programme that could be attributable to the construction or operation of the Kentish Flats Offshore Wind Farm. Similarly, the general distribution of the main macrofaunal assemblages had not changed over the monitoring period. No evidence of change attributable to the construction of the Kentish Flats wind farm was evident from the monitoring data. The physical monitoring studies described above were considered to add weight to the conclusions drawn by the benthic monitoring studies that no gross changes to the seabed had occurred and where effects were seen (for example cable routes, jack up depressions) the nature of the seabed means that benthic recovery would be expected.
Lynn and Inner Dowsing	Pre-construction (2002) and post-construction (2009, 2010, 2011) geophysical (MBES and SSS) surveys over the LID sites and export cable corridors (L&IDOW, 2009; L&IDOW, 2011a).	Gravelly sand and sandy gravel	Cable plough	Three years post-construction, relic plough features from inter-array cable installation are still visible in the MBES data. This is more apparent for cables aligned east-west than north-south which may be due to the north-south current direction. Sediment accumulation was recorded relative to the surrounding seabed between the Year 1 (2009) and Year 3 (2011) postconstruction surveys. The largest difference observed was where scour of up to 0.4 m has occurred adjacent to accumulation of up to 0.4 m.
	Pre-construction (2005) and post-construction (2009, 2010, 2011) benthic sampling and Annex I habitat surveys at the LID wind farm sites and export cable route corridors (L&IDOW, 2011b).			Sediment accumulation, relative to the surrounding seabed, between the 2011, 2010 and 2009 survey years was observed along all of the export cables, although in some areas there has been no apparent change in seabed elevation between the survey years. For one of the inter array cables there has been scour of up to 0.4 m adjacent to accumulation of 0.4 m. Three years of pre-construction and post-construction surveys, including both sediment and seabed imagery sampling, showed that communities within the LID offshore wind farms, i.e. within the sphere of influence of cable laying operations, were not significantly different from unimpacted reference locations. Post-construction surveys undertaken in Year 1 showed potential Annex I habitats (low reefs of <i>S. spinulosa</i> and a <i>Mytilus edulis</i> seed bed) at a number of locations along the export cable routes and in areas where array cables were installed. <i>Ampelisca</i> reef habitats (not Annex I) was also recorded through geophysical datasets, ground truthed by seabed imagery. The results indicate that cable laying operations affected a limited area and that recolonisation by benthic species (including reef forming species) occurred quickly following disturbance (i.e. within 2-3 years, though possibly within 1 year).
Lincs	Year 2 (2014) post-construction geophysical survey of the export cables and array cables (LOWF, 2014b).	Sandy gravel, gravelly muddy sand and sand	Cable plough *	Along the west export cable route (between KP7.9 and KP8.1; area of sand to sandy gravel sediments), a remnant cable trench was recorded during the 2012 survey and this was still visible in places during the 2014 although with a reduced depression of 0.5 m from the surrounding seabed. Survey data indicated that sediment accumulation had occurred within the trench since the 2012 survey.
	Year 2 (2014) and Year 3 (2015) post-construction benthic grab and DDV surveys within the array area (LOWF, 2014a; LOWF 2015).			For inter-array cables, visible trenching was recorded in inter array cable circuit B (area of sand to sandy gravel sediments); overall seabed has become deeper by 0.6 m between 2012 and 2014 between LS63 and LS64. In inter array circuit C (area of sand to sandy gravel sediments), sections between LS41 and LS42, and LS58 and LS59 appear to have become deeper since the EGS 2010 survey, with a maximum difference of approximately 0.7m. This is within an area of visible cable trenching. Elsewhere within the array there were minimal variations in the depth of the seabed between the 2014 and all previous surveys. Sediment classifications over the site in the 2014 survey were largely unchanged from previous surveys. No specific benthic samples taken at array cable locations during post-construction monitoring. In Year 2 and Year 3 post-construction (2014 and 2015), large changes were recorded in a few dominant faunal species (in particular <i>S. spinulosa</i> and <i>M. edulis</i>) compared to the 2010 pre-construction survey but these were interpreted as being the result of large scale instability within the surface sediments and naturally high mortality within these ephemeral populations.

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
				In the Year 3 survey, sediment distribution across the site was equivalent to the 2010 baseline, demonstrating that conditions had returned to a pre-construction state.
London Array	Four post-construction bathymetric surveys undertaken in Aug 2013 and April 2014 (Year 1 post-construction survey) and spring and summer 2015 (i.e. Year 2 post-construction survey) (LAOWF, 2013; LAOWF, 2015b, LAOWF, 2016).	Gravelly sand and sand	Cable plough and jet trenching *	Within the inshore section of the cable route, within the Swale Estuary, bathymetric data from both the Year 1 and Year 2 surveys showed trenching on all four export cables. Comparison with the 2011 pre-construction data indicated that the maximum level of change was -2.3 m for one of the cables (~3 years following construction).
	Two years post-construction benthic surveys (2014 and 2015) (LAOWF, 2015a; LAOWF, 2015c).			The 2013 survey identified scour associated with the BritNed crossing area, with the deepest scour ~9 m the surrounding seabed between cables. Scour protection works were completed in Q4 2014 and in April 2015 a maximum difference of 3.26 m below 2011 seabed level corresponds to seabed scour in the areas surrounding cable protection. Remnant trenching at either end of the rock dump associated with the Kentish Flats OWF export cable crossing observed in 2013 but accumulation of sediment in parts of the remnant trench was visible in April 2014. During Nov 2014 survey, trenches were observed extending ~450 m to the west of the rock dumped section. The area directly surrounding the Kentish Flats cable crossing showed a mean difference of 0.31 m compared to 2011 seabed levels, with a maximum difference of 3.02 m above (i.e. rock protection) and 0.67 m below (i.e. remnant trenching) seabed levels. Remnant trenching was evident in the intertidal in April 2014. The data demonstrated accretion of up to 1 m at the base of the remnant trench and slight erosion or slumping of the trench wall along the full length of the trench, suggesting that the sides of the trench may be slumping inwards. Trenching was also observed on all cables during the April 2015 Year 2 survey. The survey report noted that in most cases the trenches were not continuous. Benthic monitoring indicated little change in the composition of sediments or benthic infaunal community structure within the cable route throughout the post-construction surveys. Sediments in this area were predominantly sands, slightly gravelly sands or gravelly sands. Although areas of scour along the cable route were not specifically monitored, the localised effects of scour around WTGs did not have a consequential effect on nearby sediment composition or benthic community structure.
North Hoyle	During construction (2003) benthic survey (NHOWF, 2003).	Gravelly sand	Cable plough *	Benthic communities data were collected at sites along the cable route in 2003 (although not directly over the cable), in areas of gravelly sand. These were very similar to other inshore control sites indicating no significant impact.
	Year 2 (2005) post-construction benthic survey (NHOWF, 2005).			The absence of any identifiable trend in sediment particle size characteristics associated with construction suggests that there has been no effect on the benthic invertebrate communities
Ormonde	Single post-construction (2013) bathymetric and geophysical survey of site and export cable routes.	Muddy sandy gravel	Cable plough *	Three years since construction, several sections of remnant array cable trench were interpreted within the wind farm area using a combination of bathymetric and SSS data. Sediments across the wind farm area were largely characterised as muddy sands.
	Two years (2012 and 2013) of post-construction benthic monitoring (OOWF, 2012; OOWF, 2013).			Statistical analyses undertaken indicate limited change in the benthic communities sampled at export cable route stations between pre-construction and post-construction surveys, with individual stations on the cable route showing some level of similarity between years, despite the natural variability. This suggests that there have been no significant effects of cable installation and presence of cable infrastructure on the benthic ecology of the cable route corridor, beyond those expected due to the high natural variability expected within and close to Morecambe Bay.

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
Race Bank	Sandwave recovery report - bathymetric data acquired in 2018 was compared with bathymetric data from 2016/2017 (after sandwave clearance and cable installation) and with bathymetric data from 2015 (prior to construction). Information within Hornsea Project Three DCO application (Ørsted, 2018e).	Slightly gravelly sand and gravelly muddy sand	Jet trenching and mechanical trenching *	Race Bank sandwave recovery report consistently reports nearly full or partial recovery of seabed topography in areas of sandwaves approximately two years following clearance at all of the nine study areas. Measurable recovery is shown to have occurred at all the locations observed at the end of the second year (>75% recovery in all areas). Three separate locations/examples within the Race Bank array area where sandwaves described as '~5m' or '>5m' in height locally levelled in 2016 have subsequently recovered within one to two years to a similar pattern and also nearly to the pre-construction height (3 to 4 m height). Sandwave clearance data from different monitoring locations along the Race Bank wind farm and export cable route corridor were presented as part of the Hornsea Three Examination. These showed similar patterns as those discussed above, although the post sandwave levelling monitoring was undertaken less than 1 year following cable installation. Comparisons were made between datasets from three time periods: the pre-levelling baseline, immediately following levelling and <1 year post levelling. These showed clear evidence of recovery of sandwaves within this timescale, although to a lesser extent than the 2018 dataset discussed above.
Robin Rigg	2013 geophysical survey of export cable route (RROWF, 2013). Year 1 (2010) and Year 2 (2011) post-construction benthic grab survey (RROWF, 2010; RROWF, 2011).	Sand and sandy gravel	Cable plough and jet trenching *	During the 2013 geophysical survey of the export cable, fairly continuous cable trenching remnants were observed along sections of the route of both export cables, stretching from KP0.820 to KP 2.855 and KP0.950 to KP2.950 along the route of the RRW export cable. This was in an area characterised by a veneer of sands and gravels over till. Further continuous trenching remnants were seen along the RRE export cable between KP3.380 and KP4.630 and along the RRW export cable from KP3.500 to KP4.690 in areas of coarse sands and gravels. Evidence of trenching was also present between KP4.68 and KP6.57 predominantly in areas of coarse sands and gravels. No evidence of trenching apparent in areas further offshore of featureless sand/megarippled sand/generally featureless sand. Year 1 (2010) and Year 2 (2011) post-construction benthic grab surveys recorded the predominant biotope in the array area as <i>Nephtys cirrosa</i> and <i>Bathyporeia</i> spp. in infralittoral sand (SS.SSa.IFiSa.NcirBat) which was also the predominant biotope in the baseline survey (2001/2002). Over the construction years there was a spatial shift in biotopes, with <i>Abra prismatica</i>, and polychaetes in circalittoral fine sand (SS.SSa.CFiSa.ApriBatPo) biotope emerging during the construction period (2008-2009) although NcirBat was still the predominant biotope. Shifts in biotopes were also noted along the cable route over time, this could be attributed to shifting seabed morphology (e.g. sandwaves) over time. Up until Year 1 post-construction, the main biotope present along the cable route was SS.SSa.IFiSa.NcirBat. In construction year one, the biotope SS.SSa.CFiSa.ApriBatPo was also present and in Year 2 post-construction, two biotopes were present: SS.SSa.IMuSa and SS.SSa.IFiSa.IMoSa. It should be noted, however, that although samples were collected in the cable corridor, these were unlikely to have been within the immediate vicinity of the cable trench.
Scroby Sands	Post-construction (2005) benthic grab survey (SSOWF, Sandy sediment 2005).	Sandy sediment	Cable plough *	In the post-construction survey, there was a reduction in the fauna present at most stations compared to the pre-construction survey (1998), corresponding to changes in the dominant cluster groups but not usually the dominant biotope. Report concludes that the observed changes are most likely due to natural fluctuations, although this is hard to conclude in the absence of reference stations. Sediments sampled in the post construction benthic report were found to be fairly clean, fine sand, with varying coarser components.
Sheringham Shoal	2013 post-construction geophysical survey report (ShSOWF, 2013). First (2012) post-construction benthic monitoring survey (ShSOWF, 2012). Second (2014) post-construction benthic grab,	Gravelly sand and sandy gravel	Cable plough	The 2013 geophysical survey found that the inter-array cables were visible (where present) as discontinuous shallow, flat-bottomed trenches, 4.33 m to 15.64 m wide and up to 0.7 m deep. Trenches were visible over the majority of the survey area, which was characterised by mixed and coarse sediments. Trenches were not, however, present in the shallow sandy areas of the survey areas, in the south-eastern section and areas coinciding with shoal features (i.e. Sheringham Shoal sandbank and a shoal approximately 2.8 km from the landfall). The two export cables were visible as discontinuous trenches. Export cable A was visible as a trench 4.1 to 15 m wide and up to 1.2 m deep and Export cable B was visible as a trench 2 to 20 m wide and up to 1.1 m deep. Trenches were deepest in the north, in areas of mixed sediment, and were not visible over the sandy sediments of the Sheringham Shoal sandbank. In some sections mounds could be seen in the centre of the trenches, these were interpreted as collapse/infill of the trenches rather than exposed cable. The trenches were more obvious across the cobble and gravel dominated habitats than the sand dominated habitats.

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings						
	DDV and trawl monitoring survey (ShSOWF, 2014). Information within Hornsea Project Three DCO application (Ørsted, 2018c).			Benthic monitoring along the export cable corridor included five grab sample stations within the export cable corridor (unlikely that grab samples were collected directly within the cable trenches). The 2012 and 2014 post-construction survey did not reveal any apparent impacts due to the installation or presence of the cables of the Sheringham Shoal OWF on the seabed and its macrofaunal communities. Geophysical surveys undertaken along the proposed Hornsea Three offshore cable corridor in 2016 and 2017 included a section of the Sheringham Shoal export cable corridor (i.e. from the landfall to approximately 6 km offshore). This reported remnant trenches along short sections of the export cables in the nearshore areas, with the majority of the export cables found to be buried with no evidence of remnant trenches on the seabed. In areas where remnant trenches were recorded these features ranged in dimensions of up to 20 m width, with typical depths of <10 cm and up to 40-60 cm in some areas. In general, side scan sonar data indicated that the sediments (as represented by reflectivity) within the trenches were found to be similar to surrounding areas. found no changes in sediment types associated with the export cable remnant trenches.						
Thanet	Post construction benthic ecology monitoring (2012) (TOWF, 2012).	Sandy gravel and sand	Cable plough, vertical injectors and mass flow excavator	The post construction benthic ecology monitoring data had limited information on cabling impacts, with the main focus of monitoring on changes in benthic communities across the wind farm area. However, there were records of <i>S. spinulosa</i> aggregations communities across the wind farm site, with dense aggregations (i.e. potential Annex I reef) recorded in areas where both turbines and inter array cables had been installed. This suggests that <i>S. spinulosa</i> communities have recolonised areas affected by cable installation.						
Walney 1 and 2	Year 1 (May and Nov 2012), Year 2 (June/July 2013 and Mar 2014) and Year 3 (Sep 2014) post-construction geophysical survey (WOWF, 2012b; WOWF, 2013b; WOWF2014b). Year 1 (2012), Year 2 (2013) and Year 3 (2014) post-construction benthic monitoring (WOWF, 2012a; WOWF, 2013a; WOWF, 2014a). 2016 Export cable inspection survey (WOWF, 2016).	Gravelly muddy sand and muddy sand	Cable plough and jet trenching *	Sediments recorded in benthic surveys were found to be largely dominated by fine sands and muds with little or no gravel content. In the first post-construction geophysical survey (May 2012), two types of cable trenches were recorded: “inter array cable trenches” and “inter array remnant cable trenches”. The majority of cable trenches were identified as ‘remnant’. This is an indication that the ‘trench’ had been back-filled and has little relief visible in the SSS data. The reworked sediments within the remnant trenches display a lower reflectivity than the surrounding sediments, enabling these areas to be easily identified. The array area coincides with predominantly sandy mud sediments. Remnant trenches and cable lay scars were also visible along the export cable routes in the first post-construction survey. Prior to the year 2 post-construction survey (June/July 2013), a new array cable trench was installed (between WTG E03 and substation 01) which was observed 2013 geophysical survey data as a trench of up to 1 m in depth. With respect to the cable route, linear anomalies were observed along Export Cable Route 1 which were interpreted as jetting scars in areas where post-lay jetting had taken place to ensure further cable burial and the remnant trench in these areas is naturally back filling with sediment. These features were not visible in the bathymetry data three years later in the 2016 export cable inspection survey. In year 3 post-construction (September 2014), there was minimal change in seabed elevation along the array cable route and surrounding seabed between the March 2014 and the September 2014 survey. Localised areas of sediment accumulation have however been recorded. An increase in seabed level (from 0.1m to 0.3m) was recorded within an array cable trench monitored (between OSS 01 and WTG F02). With respect to the trench between WTG E03 and substation 01, the September 2014 survey noted that this had not been completely infilled and the cable was noted as appearing exposed within the trench. The post construction benthic monitoring (grab and DDV) provided no evidence of any effect associated with the installation of export cables. Although unclear whether samples were collected from within trenches, this is considered unlikely.						
Westermost Rough	1 st (2015) geophysical (SSC and bathymetry) survey of the export cable route (WROWF, 2015a). 2 nd (2016) geophysical survey of the turbines and array cables (WROWF, 2016). 3 rd (2017) geophysical survey of the turbines, array cables	Sandy gravel and gravelly sand	Cable plough and jet trenching *	The seabed in the vicinity of the OWF is characterised by sandy gravel surface deposits, interspersed with gravel and gravelly sands. The first (2015) and second (2017) post-construction geophysical surveys of the export cable demonstrated that the export cable trench is being infilled with sediment (see summary table below). By the time of the first survey, the HDD exit pit had infilled with sediment by up to 1 m since installation of the export cable in 2014 and the SSS data suggests that infill sediment was finer grained sediment than surrounding areas. By the second survey in 2017, the HDD pit had infilled locally by up to 2 m since the installation of the cable and on average by 0.74 m across its whole area. Full comparison along the cable route is summarised in the table below. <table><tr><th>Export cables</th><th>2015 (1st post-construction)</th><th>2017 (2nd post-construction)</th></tr><tr><td>HDD exit pit</td><td>A well-defined trench axis is visible characterised by a central furrow bounded on either side by small berms</td><td>Maximum deepening of -0.9 m in comparison to the baseline 2013 dataset.</td></tr></table>	Export cables	2015 (1st post-construction)	2017 (2nd post-construction)	HDD exit pit	A well-defined trench axis is visible characterised by a central furrow bounded on either side by small berms	Maximum deepening of -0.9 m in comparison to the baseline 2013 dataset.
Export cables	2015 (1st post-construction)	2017 (2nd post-construction)								
HDD exit pit	A well-defined trench axis is visible characterised by a central furrow bounded on either side by small berms	Maximum deepening of -0.9 m in comparison to the baseline 2013 dataset.								

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
	and export cable (WROWF, 2017). Post Construction Benthic Survey 2015 (WROWF, 2015b).			approximately 0.1-0.2 m in height. Maximum deepening of -1.3 m in comparison to the baseline 2013 dataset (compared with maximum deepening of -2.3 m immediately following excavation of the HDD exit pit)
				KP1-3 A well-defined trench axis is visible characterised by a central furrow bounded on either side by small berms approximately 0.1-0.2 m in height.
				Trench axis can still be identified along most sections of the route (extent not defined), although it is less well defined than in 2015. Still characterised by a central furrow bounded on either side by small berms approximately 0.1-0.2 m in height; however these berms have undergone erosion of around 0.05-0.10 m since 2015.
				KP 3-5 Trench depths of up to -0.5 m and berm heights of up to 0.4 m coinciding. Shallow seabed depressions associated with pre-construction boulder removal.
				The trench has become much less well defined than observed in 2015, with trench depths of up to -0.34 m coinciding with the steeper undulations of the seabed. The trench berms either side of the trench in general are now less than 0.1 m in height.
				KP 5-7 Trench axis was less well defined in this section, with trench depths of -0.3 m and berm heights of up to 0.2 m. A number of seabed differences when compared with the pre-construction data of up to -1.04 m associated with boulder removal.
				The trench axis in this section was very shallow in relief and in large sections was almost too shallow to be determined, with typical trench depths of 0.05-0.10 m and with no discernible berms to either side of the cable trench.
				KP 7-9 Trench depths of up to -0.3 m and berm heights of up to 0.2 m and high frequency of depressions associated with boulder removal activities.
				The trench axis was barely discernible for much of this section, and in some cases not observable at all. The maximum difference associated with the trench itself was -0.2 m and the berms either side were generally less than 0.05 m in height or not present at all.
				KP 9-11 The section of cable on the approach to the offshore substation (OSS) was surface laid during installation and subsequently buried via jetting and the trench has infilled relatively slowly. This region is characterised by a steep-sided trench, up to 5 m wide and -0.98 m deeper than the pre-installation 2013 bathymetry. Accumulation in this section of the cable has been approximately 0.1 m since installation in 2014 (i.e. within ~1 year) and the jetted trench has widened slightly.
				The jetted trench, clearly visible in the 2017 bathymetry, is up to 7 m wide and -0.78 m deeper than the pre-installation 2013 bathymetry. It has undergone further sediment infill since 2015 and has also widened slightly as the steep-side trench walls have eroded into the base of the trench. The rate of sediment infill at the base of the trench is on the order of 0.1 m per year and at what appears to be a fairly consistent rate year-on-year.

With respect to the array cables, the second post-construction geophysical survey (2016) of the array demonstrated that all array cable trenches have undergone a degree of sediment infill since the previous 2015 post-construction survey and a shoaling of approximately 0.10 m is considered to be broadly representative. All array cable routes were pre-swept for boulders prior to cable installation and these corridors are the predominant feature with a lowering of 0.05-0.15 m compared to pre-construction (2013) and berms of up to 0.45 m. By the time of the 2017 survey, all array cable trenches had undergone a degree of sediment infill since 2016 and a shoaling of approximately 0.1-0.2 m was broadly representative. Many cables trenches were almost completely infilled with sediment during the 2017 survey and in places could not be distinguished from the surrounding seabed.

Benthic sampling data of little use as only a single grab sample successfully collected from the export cable in 2015.

Asset	Monitoring sources used	Broadscale Surface Sediment Type (Folk classification)	Cable Installation Tool(s)	Summary of monitoring findings
				No monitoring reports relevant to export or array cables were available for this project.
West of Duddon Sands	Information within Hornsea Project Three DCO application (Ørsted, 2018d).	Muddy sandy gravel and gravelly muddy sand	Cable plough *	Geophysical survey data from the West of Duddon Sands export cable were presented as evidence in the proposed Hornsea Three DCO application. The data presented focussed on cable protection measures at three points along the export cables (between 500 m and 750 m lengths) and effects of this protection on sediment transport (e.g. accumulation of sediment or localised scour). Each rock berm was approximately 2 m high and comparison of pre and post installation datasets indicated no evidence of erosion or accretion of sediments in the vicinity of the berms.

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APPENDIX D

Mapping of Non-Burial Cable Protection from Offshore Wind Export Cables

