BERR | Department for Business Enterprise & Regulatory Reform

REVIEW OF CABLING TECHNIQUES AND ENVIRONMENTAL EFFECTS APPLICABLE TO THE OFFSHORE WIND FARM INDUSTRY

Technical Report

JANUARY 2008

IN ASSOCIATION WITH

defra

Contents

1 Introduction 11
- 1.1 Background 11
- 1.2 Study Description 12
- 1.3 Report Format 13

2 Legislation 15
- 2.1 Introduction 15
- 2.2 Licences and Consents 15

3 Cable types and installation techniques 18
- 3.1 Introduction 18
- 3.2 Cable Types 18
- 3.3 Offshore Wind Farm Cables 18
- 3.4 Telecoms Cables 22
- 3.5 Power Cables 26
- 3.6 Flowlines, Umbilicals and Small Diameter Pipelines 27
- 3.7 Background to Safe Installation and Protection of Subsea Cables 27
- 3.8 Cable Protection Methods 34
- 3.9 Cable Protection for Offshore Wind Farm Developments 70
- 3.10 Burial Assessment and General Survey Techniques 77
- 3.11 Decommissioning 78

4 Physical change 80
- 4.1 Introduction 80
- 4.2 Site Conditions 80
- 4.3 Level of Sediment Disturbance 82
- 4.4 Seabed Disturbance by Other Activities 89
- 4.5 Dispersal and Re-Deposition of Sediment 90
- 4.6 Mitigation Measures 99

5 Potential impacts and mitigation measures 101
- 5.1 Introduction 101
- 5.2 Subtidal Ecology 102
- 5.3 Intertidal Habitats 110
- 5.4 Natural Fish Resource 113
- 5.5 Commercial Fisheries 121
- 5.6 Marine Mammals 125
- 5.7 Ornithology 128
- 5.8 Shipping and Navigation 131
- 5.9 Seascape and Visual Character 133
- 5.10 Marine and Coastal Archaeology 134

6 Good practice measures 138

7 Gaps in understanding 140

8 References 142

Appendix A: Standards and codes of practice relevant to cable installation & the Offshore wind industry 154

Acknowledgements

This report was prepared by consultants from Royal Haskoning and BOMEL Ltd. The principal contributors from Royal Haskoning were Dr Samantha Vize, Christine Adnitt, Robert Staniland, Julia Everard, Alec Sleigh, Rod Cappell, Sean McNulty and Dr Martin Budd. From BOMEL Ltd, the principal contributors were Ian Bonnon and John Carey.

This report has benefited from assistance from Adrian Judd at the Centre of Fisheries, Environment and Aquaculture Science (CEFAS). The authors also wish to thank the following consultees:

Natural England (Louise Burton, Victoria Copley, Keith Henson, Sarah Soffe and Michael Young)

English Heritage (Dr Chris Pater)

Countryside Council for Wales (Dr Sarah Wood)

Joint Nature Conservation Committee (Zoe Crutchfield and Andrew Prior)

These consultees have assisted in providing comments on the principles of the study via correspondence. Their citation here does not indicate current agreement or support of the study outputs.

The research leading to the publication of this report was funded by:

- Department for Business, Enterprise and Regulatory Reform; and
- Department for Environment, Food and Rural Affairs.

The project was managed by Dr John Hartley of Hartley Anderson Ltd on behalf of the Department Business, Enterprise and Regulatory Reform.

The Target Audience

This report is intended to provide technical details on subsea cable installation techniques and associated potential environmental effects, particularly relating to the offshore wind farm industry. It aims to inform wind farm developers (and their consultants), stakeholders and regulators during the Environmental Impact Assessment (EIA) stage and consents process.

Summary

In the UK today, wind farms are the most developed technology for the large scale production of renewable energy offshore. Given their position away from land-based urban development, offshore wind farms can be more substantial in terms of their area and power generation, compared to their land-based counterparts. Public support for offshore wind farms is generally high, particularly where evidence is presented through the formal consenting and consultation processes that developments are sited in an appropriate location, where environmental and negative economic effects are minimal or can be effectively managed.

Integral to offshore wind farm development is the installation, operation and maintenance of the supporting electrical infrastructure of intra-array and export cables. This document aims to provide an information resource, intended for use by wind farm developers, consultants and regulators, on the range of cable installation techniques available, their likely environmental effects and potential mitigation, drawing on wind farm and other marine industry practice and experience. Through the collation of existing information and experience from a range of sources, the report will assist government, developers, stakeholders and regulators during the formal Environmental Impact Assessment and consenting process including stages of information provision, review and approval of such information. Importantly, an understanding of the difficulties and constraints of cable installation has been provided such that impacts can be avoided, reduced or minimised. This document also deals with the practical application of the installation and mitigation techniques available to developers so that the most relevant and up-to-date technology can be applied in the most appropriate situation.

This document covers:

- The range of types of cables and small diameter pipelines currently installed in the EU shelf marine environment. Details are given for the types of cable typically used for offshore wind farms and also the types of cable commonly used in the telecommunications and power cable industries.
- The range of techniques used to install and maintain the aforementioned cables and pipelines. Information is provided on a range of commonly applied cable protection measures, and also of the burial assessment survey techniques, commonly used before cable installation.
- The physical changes or effects to the seabed and sub-surface sediments expected to occur during cabling activities. The range of sediment types likely to be encountered during cable burial operations is discussed, with the level of sediment disturbance that is likely to occur during cable burial for each technique.

- The potential environmental impacts that could occur during the installation and maintenance of subsea cables. Impacts are described and discussed for intertidal habitats, subtidal ecology, natural fish resources, commercial fisheries, marine mammals, ornithology, shipping and navigation, seascape and visual character, and marine and coastal archaeology. Impacts are divided into those that could cause potentially significant impacts and those that may arise but are unlikely to cause significant effects.
- Mitigation measures that can be used to reduce the level of significance of environmental effects.
- Examples of good practice measures that could be adopted during all phases of project planning and used in conjunction with mitigation measures to reduce potential disturbance from cabling activities; and
- Knowledge gaps identified during this review, including gaps in understanding of the actual environmental impacts resulting from cable burial activities.

The key impacts relating to cable laying in the marine environment occur during the installation process. Cable burial and other protection measures (i.e. outer protective cable armouring, concrete and frond mattresses, rock dumping, and grout / sand bags) are used in order to reduce the risk of damage to the cable and to ensure the safety of other users of the sea. Where cables are not afforded adequate protection, damage can occur through abrasion (i.e. on rocky seabed types) and interaction with human activities such as snagging or entanglement from bottom trawl fishing gear, anchoring or navigational dredging.

Dependant upon prevailing conditions of depth, seabed morphology, hydrodynamics and geology, a range of cable burial technology is available to developers, such as cable ploughs, tracked burial machines, free swimming remotely operated vehicles (ROVs) and burial sleds.

Induced changes to the prevailing physical conditions of an area, such as the suspension, dispersal and subsequent deposition of seabed sediments, changes to seabed morphology and the direct impacts associated with the presence and operation of cable burial equipment can lead to a range of potential environmental impacts. The nature, extent and significance of these impacts will be a function of site specific characteristics (i.e. seabed type, tidal and wave conditions) and the chosen installation method. The key potential environmental impacts, which can, in specific circumstances, be associated with cable burial, include:

- Disturbance to sessile, encrusting, and attached fauna and flora which can be dislodged/disturbed;
- Smothering of sessile species due to increased sediment deposition and side-cast;
- Damage to the filtering mechanisms of certain species, the gills of sensitive fish species and eggs and larvae from increases in suspended sediment and subsequent deposition;

- The potential release of contaminants, previously retained in the sediment;
- Disturbance to important fisheries habitats such as spawning grounds, nursery grounds, feeding grounds, over-wintering areas for crustaceans, migration routes and shellfish beds;
- Disturbance to sensitive habitats, such as saltmarshes, biogenic reefs and eel grass beds;
- Noise and vibration impacts to fish and marine mammals;
- Electromagnetic field generation impacts to benthic species, fish and marine mammals;
- Risk of collision of marine mammals with cable installation vessels / support vessels; marine mammals may be disturbed by the presence of vessels and cable burial equipment; and, cable entanglement with marine mammals;
- Marine and coastal bird species, particularly at sites of importance to nature conservation, may be disturbed by the presence of vessels and human activities;
- Navigational risks such as collision with cable installation vessels;
- Direct loss or disturbance to artefacts of importance to marine and coastal archaeology and cultural heritage; and
- Seascape and visual impacts related to the cable installation activities and the presence of cable installation vessels; and possible sea surface aesthetic effects arising from sediment plumes, particularly in areas of chalk bedrock.

This study concludes that, although cabling can cover large areas of seabed, the associated environmental impacts are highly transitory, localised in extent and temporary in duration. Although the corridor for cable installation impacts can be long, the footprint of impact is narrow, generally restricted to 2-3m width. For the majority of installation scenarios, the seabed and associated fauna and flora would be expected to return to a state similar to the pre-disturbance conditions. Exceptions could occur in hard clays and rock seabed types, where the cable trench would not naturally backfill, requiring intervention to backfill as part of construction works or else leaving permanent scarring of the seabed.

The environmental impacts associated with the installation, operation and maintenance of cables associated with offshore wind farms must be considered in the context of other influencing factors. Natural perturbations such as storm activity can have a significant effect on the structure and functioning of the seabed, as can other activities such as oil and gas exploration and infrastructure, telecommunication cable installations, certain fishing activities, aggregate extraction, and other sources of change to the physical environment. In many cases, such influencing factors may lead to related environmental impacts of greater extent, duration and significance than those observed or suspected to arise as a result of the installation of offshore wind farm cable infrastructure.

Abbreviations

AIS	Automatic Identification System
AONB	Area of Outstanding Natural Beauty
AoSP	Areas of Special Protection
BAS	Burial Assessment Survey
BERR	Department for Business, Enterprise and Regulatory Reform
BETTA	British Trading and Transmission Arrangements
BWEA	British Wind Energy Association
BS	British Standards
BSC	Balancing and Settlement Code
CEFAS	Centre for Environment, Fisheries and Aquaculture
CIRIA	Construction Industry Research and Information Association
CIWEM	Chartered Institute of Water and Environmental Management
CMACS	Centre for Marine and Coastal Studies
COWRIE	Collaborative Offshore Wind Research into the Environment
CPA	Coast Protection Act (1949)
CRoW	Countryside and Rights of Way Act (2000)
CUSC	Connection and Use of Systems Code
DEFRA	Department for Environment, Food and Rural Affairs
DNO	Distribution Network Operator
DNV	Det Norske Veritas
DSV	Dive Support Vessel
DTI	Department of Trade and Industry
EA	Electricity Act (1989)
EHS	Environment and Heritage Service (Northern Ireland)
EIA	Environmental Impact Assessment
EMF	Electro Magnetic Field
ENA	Electricity Networks Association
ES	Environmental Statement
EU	European Union
FEPA	Food and Environment Protection Act (1985)
GCR	Geological Conservation Review

HAP	Habitat Action Plan
HSE	Health & Safety Executive
HVDC	High Voltage Direct Current
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organisation for Standardisation
JNAPC	Joint Nautical Archaeology Policy Committee
JNCC	Joint Nature Conservation Committee
LWM	Low Water Mark
MCA	Maritime and Coastguard Agency
MCEU	Marine Consents and Environment Unit
MCGA	Marine and Coastguard Agency
MEHRA	Marine Environmental High Risk Area
MESH	Mapped European Seabed Habitats
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
MNR	Marine Nature Reserve
MSPP	Marine Spatial Planning Pilot
NNR	National Nature Reserve
ORCU	Offshore Renewables Consents Unit
OREI	Offshore Renewable Energy Installations
PIANC	Permanent International Association of Navigation Congresses
REZ	Renewable Energy Zone
ROV	Remotely Operated Vehicle
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SAP	Species Action Plan
SEA	Strategic Environmental Assessment
SMA	Sensitive Marine Area
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest

TTS	Temporary Threshold Shift
TWA	Transport and Works Act
UKBAP	UK Biodiversity Action Plan
UKOOA	United Kingdom Offshore Operators Association
VTS	Vessel Traffic Services
WAG	Welsh Assembly Government
WSI	Written Scheme of Investigation
WTG	Wind Turbine Generator

1 Introduction

1.1 Background

The UK is committed to working towards a 60% reduction in CO_2 emissions by 2050 and the development of renewable energy technologies, such as wind, is a core part of achieving this aim. As a carbon free source of energy, wind power contributes positively to the UK's efforts to reduce our carbon emissions to tackle the threat of climate change (Sustainable Development Commission, 2005). The UK's offshore wind energy resource is substantial, estimated at around 100,000 GWh of practical resource (Sinden, 2004). Other marine renewables, such as wave and tidal are also rapidly developing sectors of the renewable energy industry.

Whilst many of the impacts of offshore wind farm developments are becoming increasingly accepted and understood, concerns have been raised about the potential environmental effects of certain cable installation techniques (including by fishermen and country conservation agencies). There is a range of potential cable installation and protection technologies but to date, there has been limited centralised knowledge sharing both within the offshore wind industry and from other more established marine industries, such as subsea telecommunications and oil and gas. This lack of review and synthesis can hinder the consideration of Environmental Statements and adoption of best practice by developers involved in the area of marine renewables.

The installation, operation and maintenance of the supporting electrical infrastructure of inter-array and export cables are integral to offshore wind farm development. A range of methods for cable installation are available to wind farm operators, the most applicable being dependant upon prevailing conditions of depth, seabed morphology, hydrodynamics and geology. These site specific characteristics and the chosen installation method subsequently manifest a range of impacts on the surrounding environment, the nature and extent of which can vary significantly.

Figure 1.0 Scroby Sands offshore wind farm

(Photo courtesy of Vestas Wind Systems A/S)

1.2 Study Description

A large number of cables associated with energy production, telecommunications and oil and gas extraction are already located on or under the seabed of the UK continental shelf. The effects of laying these cables have been investigated to varying degrees and, as such, a great deal of experience and previous knowledge has already been gathered and is held by various industries, government departments and research organisations etc. As with many sectoral developments, particularly in the marine environment, this information has not been widely disseminated, reviewed or synthesised for a wider audience or been made publicly available.

Consequently, the Research Advisory Group on Offshore Renewable Installations identified a need for Guidance on seabed installation techniques and their potential environmental effects. This guidance is required principally to inform wind farm developers and others during the Environmental Impact Assessment (EIA) and determination stages of the consents process. The guidance will be equally of use to other burgeoning marine renewable energy technologies, such as wave and tidal.

1.2.1 STUDY AIMS

The study aims to provide an information resource and guidance to government and developers on the range of cable installation techniques available, their likely environmental effects and potential mitigation, drawing on wind farm and other marine industry practice and experience.

Through the collation of existing information and experience from a range of sources, the guidance will assist government, developers, stakeholders and regulators during the EIA and consenting process including stages of information provision, review and approval of such information. Importantly, an understanding of the difficulties and constraints of cable installation has been provided such that impacts can be avoided, reduced or minimised. This document also deals with the practical application of the installation and mitigation techniques available to developers so that the most relevant and up-to-date technology can be applied in the most appropriate situation.

In summary, the specific objectives for this project are as follows:

- To summarise the range of types of cables and small diameter pipelines currently installed in the EU shelf marine environment;
- To discuss the range of techniques used to install and maintain the aforementioned cables and pipelines;
- To summarise the environmental impacts that could arise as a result of these installation and maintenance techniques (both reported and potential impacts); and
- To produce a technical report document which reviews cabling techniques and their environmental effects for use in the development of wind farm projects (and other marine renewable technologies).

1.3 Report Format

Section 1 describes the project's background, aims and objectives.

Section 2 outlines the relevant legislation applicable to the development of offshore wind farms and the installation/maintenance of cables/pipelines.

Section 3 summarises the types of cables and pipelines that are currently installed in the marine environment and the range of installation techniques that are available. The relevant characteristics of each type are provided, such as dimensions, construction material, armouring, depth of burial, additional protection measures, normal service life and decommissioning. The range of installation techniques that are available are also described as well as the type of engineering standards and constraints that might be of relevance (i.e. depth of burial in areas of sediment movement or where beam trawling occurs).

Section 4 outlines the physical changes or effects to the seabed and surface sediments that could be expected to occur during cabling activity and the key characteristics that influence the extent of change.

Section 5 describes the potential environmental impacts expected during cabling activities together with possible mitigation measures that could be used to reduce their scale of effect. Impacts are described and discussed for:

- Intertidal habitats;
- Subtidal ecology;
- Natural fish resource;
- Commercial fisheries;
- Marine mammals;
- Ornithology;
- Shipping and navigation;
- Seascape and visual character; and
- Marine and coastal archaeology.

Section 6 provides examples of good practice measures during cabling activities which could be adopted in conjunction with mitigation measures to minimise the magnitude and significance of effects on the local environment.

Section 7 outlines the gaps in understanding and data identified as part of this project.

Section 8 provides a full reference list.

2 Legislation

2.1 Introduction

This section provides an overview of the key UK legislation regulating developmental activities during the construction, operation and decommissioning phases of cabling activities associated with offshore wind farm developments.

2.2 Licences and Consents

A statutory consenting process exists through which offshore renewable development applications are considered in relation to UK policy aims and international obligations. The consenting process is designed to ensure that each development decision is made on the basis of a comprehensive balanced consideration of impacts, both positive and negative.

The consents process in England and Wales is managed by the Department for Business, Enterprise and Regulatory Reform's (BERR) Offshore Renewables Consents Unit (ORCU) and other statutory consenting authorities (the Department for the Environment, Food and Rural Affairs (Defra), the Department for Transport (DfT) and the National Assembly for Wales (NAW)). The Scottish Executive is responsible for administering the consents process for offshore wind farms in Scottish waters, and in Northern Ireland, the Department for Enterprise, Trade and Industry (DETI). The above organisations deal with consents received under the Electricity Act (EA), the Transport and Works Act (TWA), Food and Environment Protection Act (FEPA) and Coast Protection Act (CPA).

The consents process for offshore wind farms, in England, Scotland and Wales, is explained in the DTI's (now BERR) Strategic Planning Framework consultation paper (2002) and full guidance for the consents process is provided within DTI (now BERR) guidance notes (2004). National Planning Policy Guidelines (NPPG) 6 sets out national planning guidance for renewable energy developments in Scotland (Scottish Natural Heritage, 2004). In Northern Ireland, the DETI has produced a Strategic Energy Framework for Northern Ireland (DETI, 2004) and the Department of the Environment within the Northern Ireland Assembly has published details on planning process in Planning Policy Statement 1 – 'General Principles' (Department of the Environment, 1998).

Under the auspices of the Electricity Works (Environmental Impact Assessment) Regulations 2000 (SI 2000/1927), applications for consent for offshore wind farms (greater than 1MW) must be accompanied by an Environmental Statement (ES), the formal presentation of the Environmental Impact Assessment process. In Scotland, this falls under the Electricity Works (Environmental Assessment (Scotland) 2000 Regulations (SI 2000/320) and in Northern Ireland, the Electricity (Northern Ireland) Order 1992 (SI 1992/231). The ES details the nature and extent of the potential impacts of each aspect of the construction, operation and eventual decommissioning of the wind farm and associated infrastructure.

It is from the evidence presented in the ES, and subsequent critical analysis by a range of appropriate authorities, that the necessary consents are granted and any conditions with regard to mitigation, monitoring and best practice are applied.

Offshore cabling applications and offshore wind farm applications require developers to obtain a number of consents. A summary of these consents are set out in **Table 2.1**. The standards and codes of practice necessary for subsea cabling activities for the development of an offshore wind farm are provided in **Appendix A**.

Specifically, for cabling activities associated with the offshore wind farm industry, a FEPA and CPA licence is required for:

- Installation of cables; and
- Deposition of material for cable/scour protection purposes such as rock armouring and grout bags.

Under FEPA, the decision as to whether a licence will be granted will depend on the assessment by the Licensing Authority of potential hydrological effects, risk to fish, mammals and other marine life from contaminants, noise and vibration, effects from potential increases in turbidity, smothering and burial of marine life, any adverse implications to designated marine conservation areas or interference to other marine and coastal users.

Under CPA, the Secretary of State must determine whether marine works will be detrimental to the safety of navigation in relation to the cabling installation/removal activities.

Guidance for EIA in respect of FEPA and CPA requirements is provided by CEFAS (CEFAS, 2004).

If an offshore wind farm development is planning a high voltage electrical connection to the onshore grid, then use of the transmission assets involved – the offshore substations, related electrical plant, and export cables – will require a transmission licence under the Electricity Act 1989. A distribution licence would be required if the electrical connection is at low voltage. These licensing regimes are currently under development and are likely to be introduced in 2008 and 2007 respectively. Further information on obtaining licences for offshore transmission and/or distribution can be obtained from the Offshore Transmission Team at BERR and on the BERR website.

Table 2.1: Statutory licences and consents for offshore wind farms

Act of Parliament	Consent type	Competent Authority
Section 36 – Electricity Act (EA) 1989 (as amended by the Energy Act 2004) Electricity (Northern Ireland) Order 1992 Section 37 – Electricity Act (EA) 1989	For offshore wind power generating stations within territorial waters adjacent to England and Wales. For overhead electric power lines associated with offshore wind farm projects.	BERR (England & Wales) Scottish Executive (Scotland) DETI (Northern Ireland)
Section 5 and 6 – Electricity Act (EA) 1989	For the transmission or distribution of electricity.	Ofgem
Section 5 – Food & Environment Protection Act (FEPA) (Part II) 1985	For depositing articles or material in the sea/tidal waters below mean high water springs (MHWS), including the placement of construction material or disposal of waste dredging.	Marine Consents Environment Unit (MCEU) of DEFRA Environment and Heritage Service (EHS) of the Department of the Environment (DOENI) Scottish Office of Agriculture, Environment and Fisheries Department (SOAEFD)
Section 34 – Coast Protection Act (CPA) 1949	Construction under or over the seashore lying below MHWS. To make provision for the safety of navigation in relation to the export cable route and inter-turbine cabling network	MCEU EHS (DOENI) SOAEFD
Section 90 or Section 57 – Town and Country Planning Act 1990 Section 57 or Section 28 – Town and Country Planning (Scotland) Act 1997	Deemed planning permission sought as part of the Section 36 applications for the onshore elements of the cable route. Section 57 – planning permission is sought separately, from the relevant local planning authority.	BERR (England & Wales) Scottish Executive (Scotland) DETINI (Northern Ireland)
Section 109 – Water Resource Act 1991 Section 20 – Water Environment and Water Services (Scotland) Act 2003	To erect a structure e.g. cabling in, over or under a water course that is part of a main river	Environment Agency (England and Wales) Scottish Environment Protection Agency (SEPA) (Scotland) Rivers Agency (Northern Ireland)
Transport and Works Act 1992	Relating to offshore generating stations and works which may interfere with rights of navigation.	BERR (England & Wales) Scottish Executive (Scotland) DETINI (Northern Ireland)

Source: Adapted from DTI guidance (2004)

3 Cable types and installation techniques

3.1 Introduction

This section of the report lists all of the cable types which are anticipated to be used in the near future for offshore wind farm development work and sets the background to the methodologies which have been developed in other industries for the safe installation and protection of subsea cables. It then outlines the various cable protection methods, including all of the various cable burial methodologies together with details of alternative external cable protection systems. This includes details of the cable protection methods which are most applicable and relevant for the offshore wind farm industry. Information on burial assessment survey techniques which are commonly used as a pre-survey activity before the main cable installation is included. Finally, this section reviews how legislation on decommissioning of the installed cable systems could also give rise to procedures which could have an impact on the environment.

3.2 Cable Types

3.2.1 GENERAL

This section of the report contains details of offshore subsea cables which would typically be used for offshore wind farms. It also contains details of the cables which are commonly used in the subsea telecommunications and power cable industries.

The design and construction of a particular subsea cable will be directly governed by the functionality of the cable and any requirement to protect the cable from any potential hostile seabed intervention. **Figure 3.1** illustrates a typical range and size of cables which can be used for a variety of different applications. Some of the cables included in this figure are not all subsea cables.

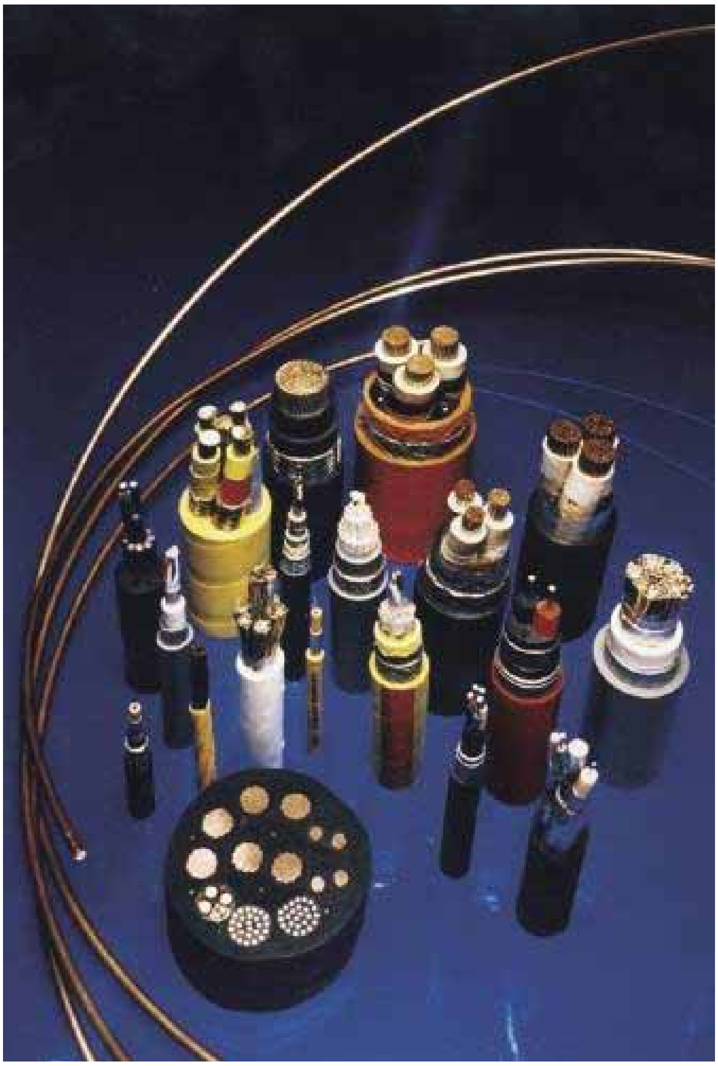
3.3 Offshore Wind Farm Cables

3.3.1 GENERAL

The design of subsea cable systems for offshore wind farms will be influenced by a number of factors. Some of the factors are generic, while others are project-specific:

- Connection voltage – Offshore wind farm projects need to be connected to regional distribution networks, rather than to the national transmission system. In England and Wales, these distribution networks currently include 132kV and 33kV systems. Some of the early Round 1 offshore wind farm projects have made connections at 33kV while several others have connections at 132kV. It is probable that all Round 2 sites will secure connections at 132kV.
- Cable design – Three-core subsea cables using solid insulation (ERP or XLPE) are typically used for operation at voltages up to 132kV. Higher voltage cables that use oil as an insulating medium are not deemed to be environmentally acceptable owing to the potential risks associated with oil leakage in the near shore environment. The cables are typically designed to give a power transmission capacity of up to 40MW for a single 33kV cable and 160MW for a single 132kV cable.
- Turbine size – Offshore wind farm developers are continually looking to the turbine manufacturers to develop larger and more energy efficient turbines. The early UK Round 1 developments such as North Hoyle, used 2.5MW wind turbine generators (WTGs). Current offshore wind farm developments are planning to use 3.0MW and 3.6MW machines and plans for a 5.0MW machine are already well advanced.
- Distance from shore – The use of a single 132kV cable to shore provides a cost-effective alternative to the use of three or four 33kV cables. The installed cost (per kilometre) of a single 132kV cable is considerably lower than the installed cost of three 33kV cables, but this solution requires an offshore substation in order to step up to 132kV from the wind farm collection voltage (usually 33kV). Some of the current projects under consideration have more than one 132kV export cable to link the offshore wind farm to shore.

Figure 3.1: Diverse Range of Different Cable Types



3.3.2 EXPORT CABLES

The function of the export cables is to transmit the electrical power from the offshore wind farm to the appropriate cable connection facility at the shoreline or landfall. The electrical parameters of these cables will depend on the choice made between two options:

Option 1 – No voltage step-up offshore. The power produced from the offshore wind farm is transmitted to shore at the collection system voltage. With this option there is no need for an offshore substation. A number of the offshore turbine structures act as a localised hub from which the export cables then transmit the generated power back to shore.

Option 2 – Voltage step-up offshore. The power produced by the wind farm is transmitted to shore at a different voltage level, greater than the collection voltage. An offshore substation, containing one or more step-up transformers, is required. The offshore substation acts as the collection point within the wind farm. The export cables then run from the offshore substation to shore.

High voltage direct current (HVDC) is not economically viable at present due to the high cost of HVDC converters, however it may, in the future, be used for sites situated further offshore.

The current and future generation of export cables are likely to be rated with a voltage of 132kV. The cable is likely to be constructed with 3 core copper conductors, insulation and conductor screening, steel wire armour and either ERP or XLPE insulation with a lead sheath. The copper conductor size is typically estimated at between 300mm^2 and 1200mm^2. The cables will contain optical fibres embedded between the cores for data transmission and communications. The range of indicative cable conductor sizes and overall dimensions which could be used for a 132kV export cable for an offshore wind farm are shown in **Table 3.1**.

Table 3.1: Typical Cable Characteristics For 132kv Cable

Details	132kV Cable Type				
	300 mm^2	500 mm^2	800 mm^2	1000 mm^2	1200 mm^2
Overall Diameter (mm)	185	193	214	227	232
Weight (kg/m)	58	68	88	100	108
MVA (approx)	127	157	187	200	233

3.3.3 INTER-TURBINE ARRAY CABLES

The inter-turbine array cables are the cables which connect the offshore turbines into arrays and also connect the various arrays together. It is normal practice to cable several turbines together in an array, with each cable providing a link between two adjacent turbines. Each end of the cable is terminated onto the high voltage (HV) switchgear located within the turbine tower. Because they connect to the HV switchgear at the turbines, the operating voltage for the inter-turbine cables is limited to 36kV. These cables would also connect any offshore substation to the offshore WTG arrays. The cables between WTGs are relatively short in length (typically in the range 500m to 950m). However, the cables between the offshore substation and the WTG arrays could be longer and possibly up to 3.0km.

The inter-turbine array cables will typically be 33kV, 3-core copper conductors with insulation/conductor screening and steel wire armoured. The insulation will be either dry type XLPE, wet type XLPE or a combination of both. All cables will contain optical fibres embedded between the cores. A number of conductor sizes would be used depending on the load current that the cable is required to carry. The ranges of indicative cable conductor sizes and overall diameters that may be used are shown in **Table 3.2**.

Table 3.2: Typical Cable Characteristics for 33kV cables

Details	33kV Cable Type				
	95 mm²	240 mm²	400 mm²	630 mm²	800 mm²
Overall Diameter (mm)	89	104	127	143	153
Weight (kg/m)	12.2	18.6	38	49	59
MVA (approx)	18	29	36	44	48

3.4 Telecoms Cables

This section outlines the types of cables which are commonly used by the subsea telecommunications industry to install their networks on a worldwide basis. It is normal practice for the subsea telecommunications industry to conduct a Burial Assessment Survey in advance of the design of the cable type along the full route of the cable (see **Section 3.10**). The Burial Assessment Survey will be used to assess the level of armouring required for a section of the cable length together with the proposed depth of burial. Many of these cable systems can be in excess of thousands of kilometres in length, therefore, the design of armouring for the cable can have a significant influence on the overall cost of the cable. There is also a relationship between the design of outer protective armouring and the proposed depth of burial to protect the cable in its in-service condition. Hence, the results of the Burial Assessment Survey are used to identify what level of burial can be achieved along the cable route. This assessment will take into account the burial system to be employed on the project together with the design armouring for the cable.

Section 3.10 of this report reviews Burial Assessment Surveys in more detail.

Table 3.3 gives typical armoured cable characteristics for a number of subsea telecommunication cables. The characteristics of these cables are set out in detail in the following sub-sections.

Table 3.3: Typical Characteristic for Subsea Telecommunication Cables

Characteristic	Unit	Lightweight Armour (AL)	Single Armour (A)	Double Armour (AA)
Lightweight cable diameter	mm	21.5	21.5	21.5
First lay steel wire diameter	mm	4.0	4.9	4.9
Number of steel armour wires in the lay		19	16	16
Pitch of armour wire	mm	530	539	539
Second lay mild steel wire diameter	mm	-	-	7.0
Number of steel wires in the lay (left hand)		-	-	18
Pitch	mm	-	-	610
Outside diameter	mm	36.7	38.5	57.7
Weight in air	kg/m	3.0	3.5	9.7
Weight in water	kg/m	1.9	2.9	7.0

3.4.1 LIGHTWEIGHT CABLE

Lightweight cable, as its name suggests, is cable which does not have any form of outer protective armouring. This type of cable is typically used in very deep water (usually in excess of 1000m) where the cable risk assessment has identified that the cable is highly unlikely to be subject to any form of hostile seabed intervention (e.g. anchoring or trawling).

3.4.2 'SHARK BITE' CABLE

Shark Bite cable was initially developed by AT&T in the USA when they discovered that the electromagnetic field emanating from the power feed system in their subsea telecommunication cables was agitating the local shark population. The sharks would then attempt to bite any surface laid sections of cable. To protect the cable, a new design, which provided a light single armour around the cable adequate to repel any potential shark attack, was derived. The cable also had additional screening installed in the cross sectional make-up in an attempt to reduce the amount of electro magnetic field propagation.

3.4.3 LIGHTWEIGHT ARMOURED CABLE

Lightweight armoured cable is a lighter version of single armoured cable where the steel armour wires would typically be 4mm in diameter, as opposed to the 4.9mm diameter steel wires which are used in the conventional armoured cable (**Figure 3.2**). A typical application of lightweight armour would be for a deep sea section of cable which was going to be laid over a rocky seabed area and where the risk of abrasion damage to a lightweight type cable was considered to be high.

3.4.4 SINGLE ARMOURED CABLE

Single armoured cable is a cable type which is typically used in conjunction with cable burial as a means of providing overall protection for the installed cable (**Figure 3.3**). This type of cable would be employed in areas where the risk from hostile seabed intervention such as fishing had been identified. This may occur in water depths anywhere between 50m to 1000m.

3.4.5 DOUBLE ARMOURED CABLE

Double armoured cable would typically consist of an inner armoured layer (similar to the single armoured cable type) with steel wires of 4.9mm in diameter, which would then be overlaid with a second layer of armouring with steel wires of 7mm in diameter (**Figure 3.4**). Double armoured cable is significantly heavier and more inflexible than the single armoured cable which makes it more difficult and expensive to produce and install. Double armoured cable would typically be employed where there is a perceived high risk that the cable may not achieve the target depth of burial, where there is risk of crush damage in areas which are known to be heavily trawled, or across busy shipping lanes or navigational channels (i.e. at any location where the perceived risk of hostile seabed intervention is high).

Figure 3.2: Typical Cross Section of a Lightweight Armoured Cable (used in deepwater (>1000m) with low risk of hostile seabed intervention)

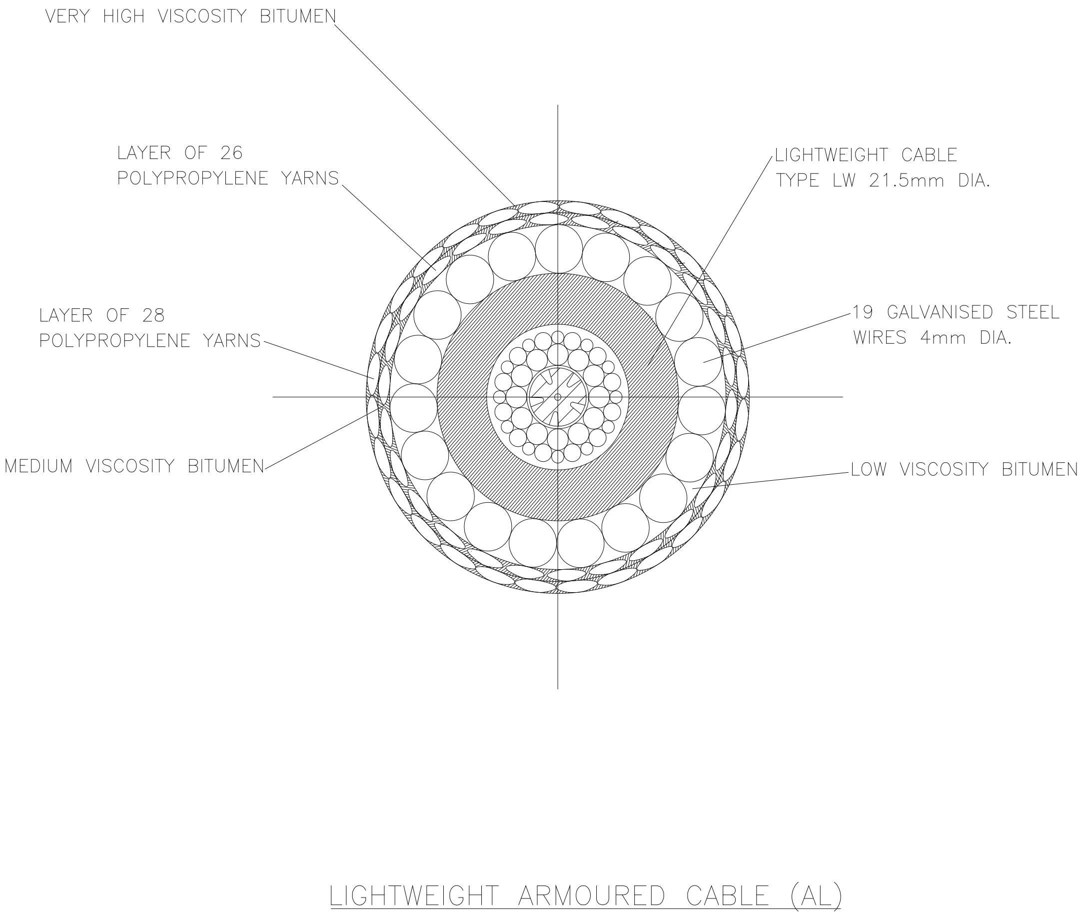
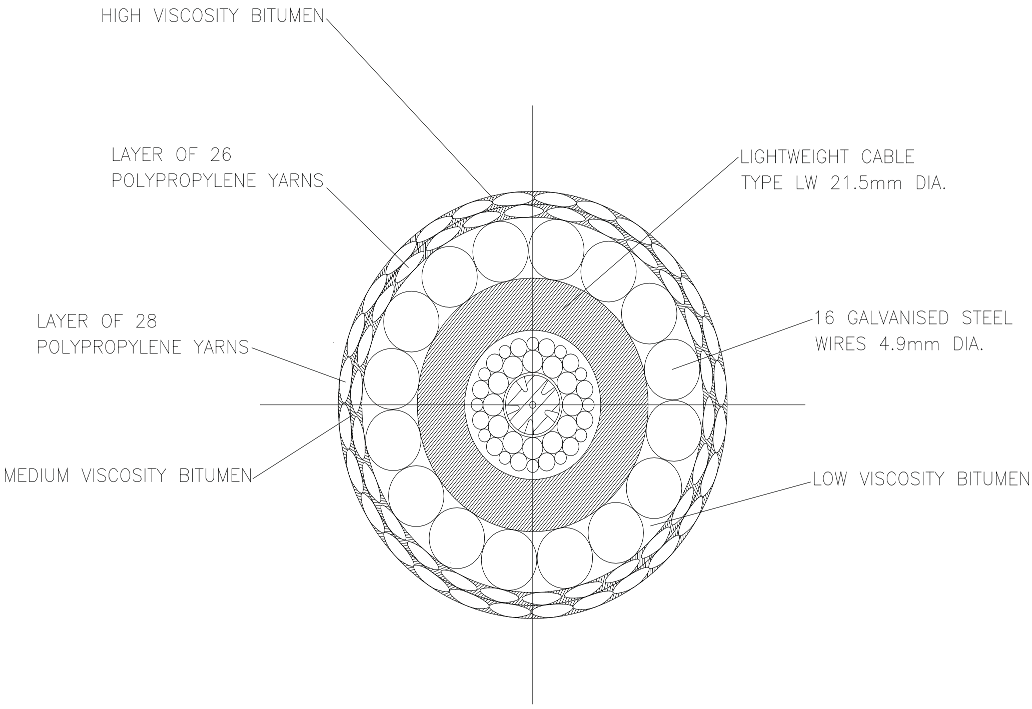
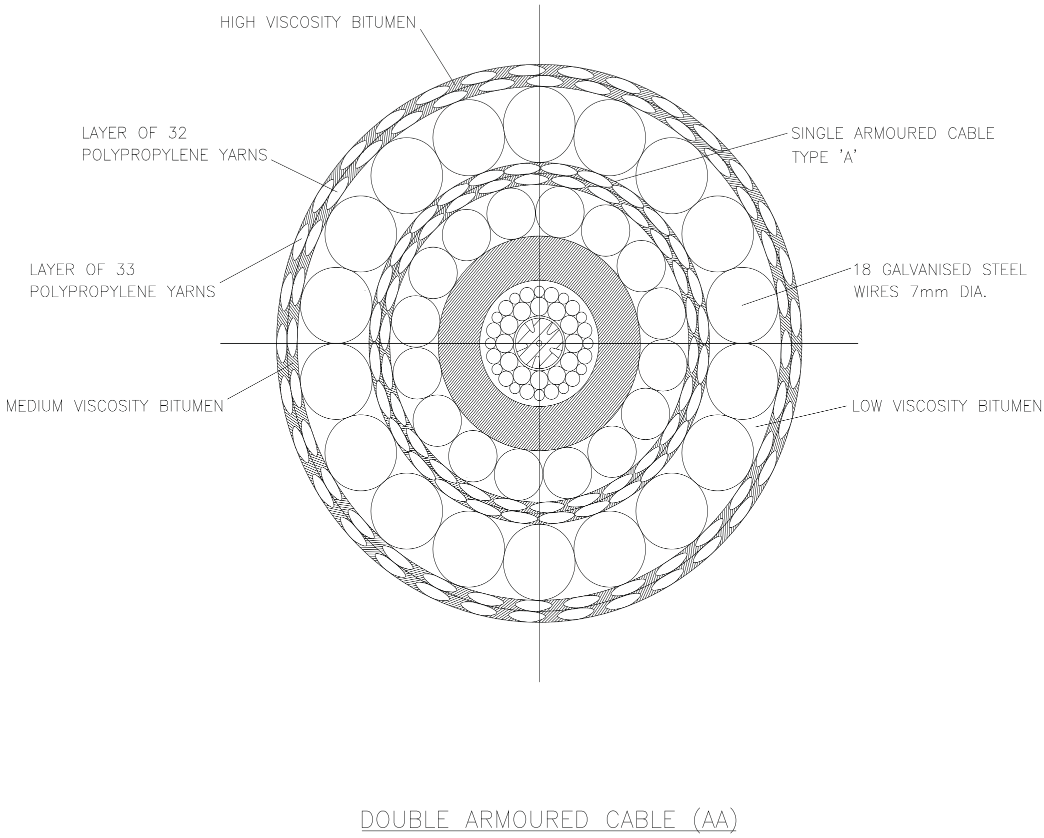


Figure 3.3: Typical Cross Section of a Single Armoured Cable (used in water depths of 50-1000m, where hostile seabed intervention is an identified risk)



SINGLE ARMOURED CABLE (A)

Figure 3.4: Typical Cross Section of a Double Armoured Cable (used in areas subject to a high risk of hostile seabed intervention)



3.4.6 ROCK ARMOURED CABLE

Rock armoured cable is a double armoured cable where the outer layer of contra-helically laid armour has a tight pitch angle which results in a tight packing of the armour wire around the cable. This armour type provides a very stiff outer protection to the cable core and this type of cable would typically be employed where the cable would be laid over rocky outcrops in shallow water, where the cable was perceived to be at high risk from abrasion damage, or other localised risks resulting from a surface laid cable in a shallow water environment.

3.5 Power Cables

Power cables are defined as subsea cables which are used to either import or export power capacity. For example, there are a number of installed subsea power cables between the UK and France which allow for such power exports and imports. Similar systems are used to connect island settlements around the UK such as the Scottish Isles and the Isle of Wight. These cables are large diameter cables with similar characteristics and behaviour to the export cables associated with offshore wind farm developments.

Power cable diameters can range from 75mm in diameter up to 240mm in diameter. The larger size being associated with 132kV export cables from offshore wind farm developments currently under consideration for Round 2 developments.

3.6 Flowlines, Umbilicals and Small Diameter Pipelines

Flowlines, umbilicals and small diameter pipelines have been included in this review on the basis that some of the burial systems and other cable protection methods are commonly applied to this group of subsea products.

These products fall into the larger diameter category (usually at least 200mm diameter) and are typically used to connect remote wellheads to offshore platforms and to provide interconnect facilities between offshore installations. As well as containing fibre optics and power cores, these products have tubing within the make-up of the product which can be used for chemical injection and hydraulic power.

The flowlines and umbilicals, by the nature of their make-up, are constructed using a specialist manufacturing process, are heavy, have stiff properties and also have a large minimum bend radius.

3.7 Background to Safe Installation and Protection of Subsea Cables

This section sets out the history and background to the need for protection methods for subsea cables.

3.7.1 THE NEED FOR CABLE PROTECTION

Cable burial and other protection measures are used to ensure cables are adequately protected from all forms of hostile seabed intervention. If a cable is not adequately protected, damage can and will occur. **Figure 3.5** illustrates the results of seabed deployed fishing gear becoming entangled with an unprotected cable system. **Figure 3.6** shows a typical deployment of bottom trawl fishing gear and **Figure 3.7** shows how a trawl or otter board can potentially engage and snag a subsea cable giving rise to the damage as illustrated in **Figure 3.5**.

Figure 3.5: Fishing Gear Entangled with an Unprotected Cable System

Figure 3.6: Typical Deployment of Bottom Trawl Gear

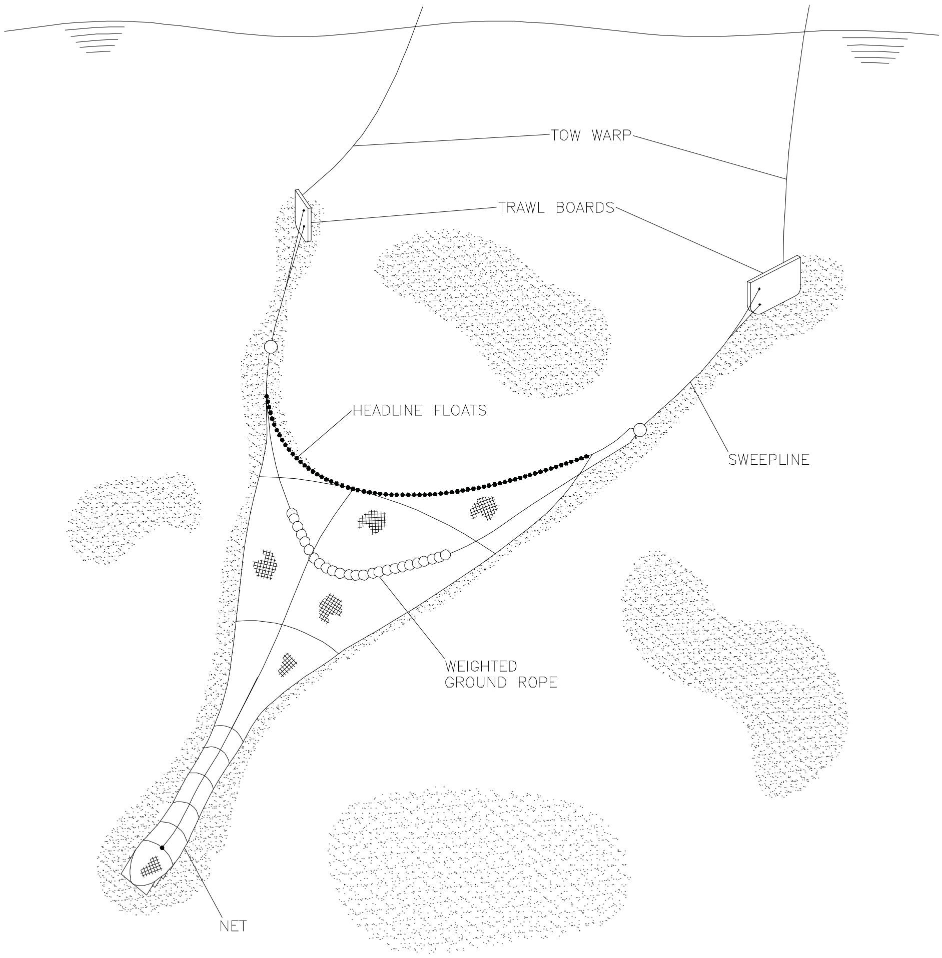
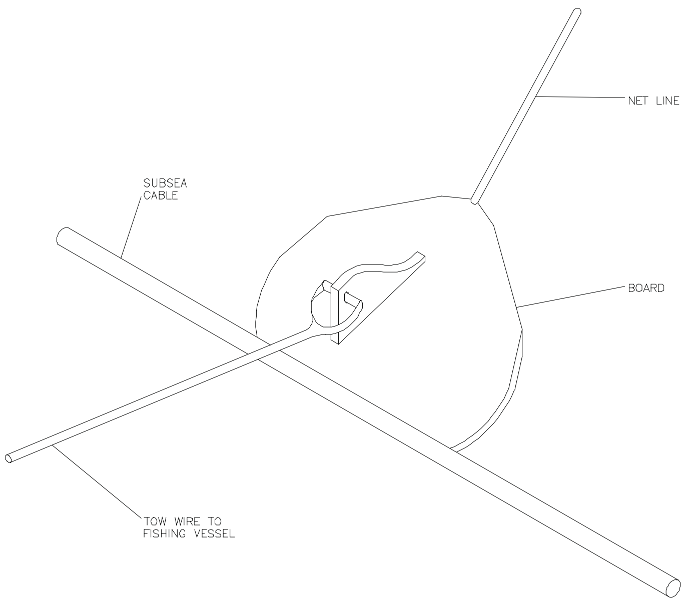


Figure 3.7: Schematic to Illustrate Potential Damage to Cable as a Trawl / Otter Board Engages a Subsea Cable



3.7.2 HISTORY

The history of safe installation and protection of subsea cables dates back to the 19th Century when early telegraph cables across both the North Sea and the Atlantic were subject to frequent damage from the local fishing activity and other vessels dragging their anchors across the seabed. In this respect, little has changed in over 250 years and all seabed cables and pipelines must be assessed in terms of the risks of potential damage.

It was only in the early 1980s that effective cable burial became a primary method for protecting subsea cables. The pioneers in this field were the owners of the various offshore submarine telecommunication networks who realised that the new fibre optic systems would require a robust protection system to prevent costly interruptions to service. The new cables were being designed to carry many thousand more circuits than their old analogue predecessors. British Telecom conducted extensive research programmes through their Martlesham Research Facility, where a number of onshore and offshore trials were undertaken to establish the effectiveness of cable burial with varying depths of burial and cover. The tests involved the use of different types of fishing gear, commonly used both in shallow and deep water applications, to simulate the real conditions of fishing gear passing over cables from different angles of approach. At the same time, Shell UK Exploration and Production (Shell) were conducting parallel tests to establish the potential effects of bottom trawl gear on medium to small diameter pipelines in the northern North Sea. The Shell study programme was subsequently supported by seven other North Sea oil and gas operators as a joint venture.

3.7.3 SHELL STUDY PROGRAMME ON PIPELINES

The results of the pipeline research showed that the concrete coated pipelines with diameters of 16 inches and above could be designed to tolerate trawl gear loads without the need to lower or cover the pipelines. However for smaller pipelines, or in the case where there was pipeline spanning, it was recognised that pipeline protection requirements for individual pipelines needed to be determined on a case by case basis. Subsequent to this research, a number of specialist pipeline ploughs and large track burial vehicles were developed, built and commissioned and put to effective use in the North Sea burying pipelines and flowlines for the offshore oil and gas industry.

3.7.4 BRITISH TELECOM RESEARCH

The British Telecom research, having focused on the much smaller targets of subsea cables, came to very positive conclusions that cables lowered into open trenches stood a much improved likelihood of being protected from seabed trawler gear. However, the best form of protection was afforded when a degree of cover was placed back over the trenched cable. In this latter condition the otter boards and trawl gear can easily pass over the cable without running the risk of snagging the cable and hence causing a fault. The early research showed that depths of trenching up to 300mm, with cover over the cable, would give a high level of protection to the subsea cable. However, the confidence in protection increased significantly with depth of burial and hence British Telecom initially specified a 600mm depth of burial for the early Trans-Atlantic, Cross Channel and North Sea cables. **Figure 3.8** shows some of the research undertaken by British Telecom with a beam trawl passing over a telecom cable lowered in an open trench which is approximately 750mm wide and the cable is in the trench to a depth of approximately 250mm.

Figure 3.8: Early Depth of Burial Research

3.7.5 DEVELOPMENT OF SUBSEA CABLE PLOUGHS

To achieve the target depth of burial of 600mm, as identified by the early British Telecom research, a number of narrow blade subsea ploughs were developed. These ploughs were designed to lift a wedge of soil, place the cable in the bottom of the cut trench and allow the displaced wedge of soil to naturally backfill over the cable. This concept is similar to the method used by British Rail to bury cables adjacent to railway tracks using a narrow blade plough deployed from a rail bogey.

The new generation of subsea telecom cable ploughs were extensively land tested and then also trialled offshore before being put into active service. They became an instant success. The ploughs are towed by the cable laying vessel which simultaneously pays out cable as the ship makes forward progress thus ensuring the cable is simultaneously buried as the cable ship and cable plough make forward progress. The cable plough is fully instrumented and has hydraulically activated functions to allow for varying depth of burial. In addition, the instrumentation package ensures that all critical aspects of the operation can be controlled and monitored back on the host vessel as a real time operation.

Between the late 1980s and the early 2000s, technologies improved the types and range of plough systems and these various types are described in detail in subsequent sections. During this same period of time, a number of tracked, remotely operated vehicles (ROVs) and free swimming ROVs were also introduced into the market. These vehicles were primarily used on projects where shorter lengths of cable burial were specified or where work in shallow water was required. They were also used where the ground conditions were beyond the capabilities of a conventional subsea plough and specialist cutting tools were required to cut into rock strata.

3.7.6 CABLE FAULT ANALYSIS

A number of studies have reviewed cable fault rates based on the depth of burial of the installed system. This research has shown that, on average, most 'hits' on cables result from fishing activity and that surface laid cables would be regularly hit with fault occurrence directly related to the level of fishing activity. Cables buried to 0.6m depth are likely to only experience one or two hits in a 10 to 15 year lifetime (probably in areas of shallow burial or where sand-waves are mobile) and cables buried to 1.0m are likely to have a high probability of remaining fault free. These statistics (which have been extracted from various papers submitted at SubOptic 1997 and SubOptic 2001) only provide guideline information and some systems are likely to remain fault free for their operational life.

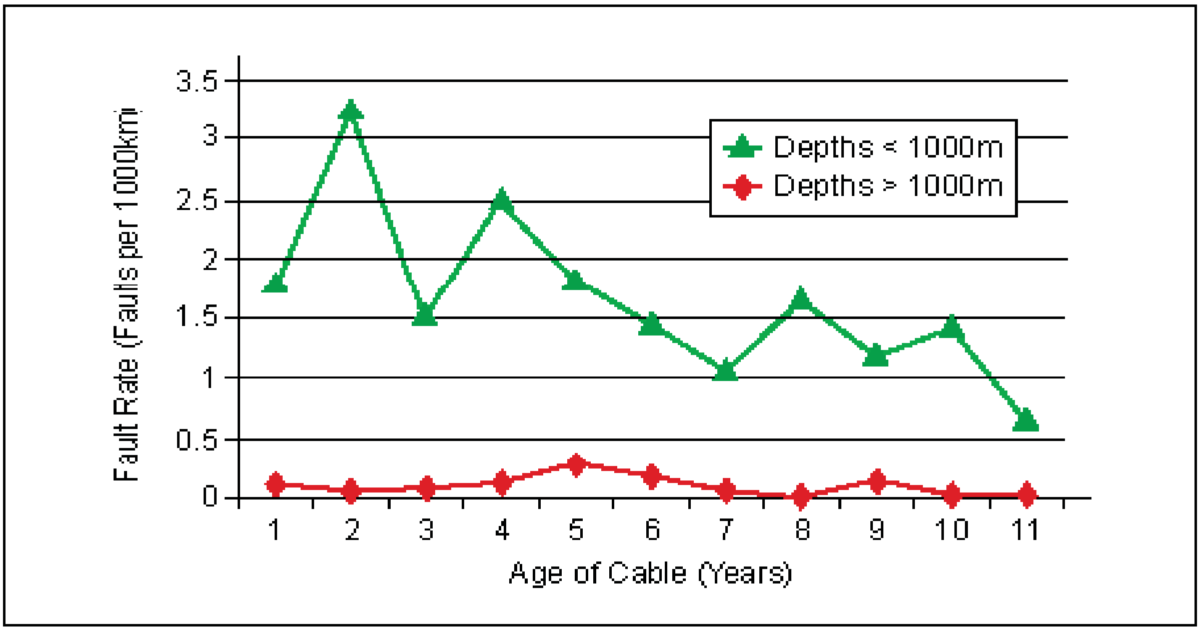
Various research has now resulted in some guidelines for the depth of burial when using ploughs, depending on the threat which the installed cable system may encounter during its operational life. **Table 3.4** presents the target burial depth for subsea ploughs to place cables below the 'threat line' for the different hazards which are expected to pass over the installed cable and for varying seabed conditions. The figures quoted in the table include a 33% safety factor which recognises that the target depth of burial is not always achieved in the field for operational reasons.

Figure 3.9 shows an average fibre optic fault rate (normalised per 1000km length), plotted against the age of the cables, for global cable systems installed in the period 1990 to 1999. Trends are plotted for cables installed in water depths up to 1000m and also for cables installed in water depths greater than 1000m. The decreasing trend in cable faults with the age of the cable is probably attributable to any exposed sections of cable being buried during the life of the cable.

Table 3.4: Recommended Target Cable Burial Depths for Subsea Ploughs for Varying Seabed Conditions and Threats

Threat	Hard Ground (clay > 72kPa, rock)	Soft – firm soils (sand, gravel, clay 18-72kPa)	Very soft – soft soils (mud, silt, clay 2-18kPa)
Trawl boards, beam trawls, scallop dredges	< 0.4m	0.5m	> 0.5m
Hydraulic dredges	< 0.4m	0.6m	N/A
Slow net fishing anchors	N/A	2.0m	> 2.0m
Ships' anchors Up to 10,000t DWT (50% of world fleet)	< 1.5m	2.1m	7.3m
Ships' anchors Up to 100,000t DWT (95% of world fleet)	< 2.2m	2.9m	9.2m

Figure 3.9: Plot of Average Fibre Optic Fault Rate against the age of Installed Cable



Source: Taken from Sub Optic 2001 Paper 'Recent Trends in Submarine Cable Faults, Featherstone, Cronin, Kordahi and Shapiro'

3.7.7 SPECIALIST BURIAL TECHNIQUES

In certain locations, highly specialist cable burial techniques have been developed to suit the exacting requirements of that particular location. For example, in places such as Hong Kong and Singapore Harbours where a number of subsea cables enter these communication hubs, it is vital that cables are protected from the potentially damaging effects of numerous anchor deployments. In these locations cable burial to depths of 5m and beyond have been specified, and achieved, using highly specialised burial equipment.

3.7.8 CURRENT BURIAL TARGETS FOR THE OFFSHORE WIND FARM INDUSTRY

The offshore wind farm industry has generally recognised that the main risks posed to the subsea cables derives largely from inshore fishing activity and dragging anchors from coastal vessel traffic. Typical target depths of burial between 1m and 2m have been specified for the majority of the Round 1 sites which have been developed to date. However, as the Round 2 developments move into deeper water, cable risk assessment may identify the need for increased burial depths as the possibility of anchor damage from larger seagoing vessels has to be considered.

The use of burial assessment surveys may increasingly be used to establish target burial depths for cables. This procedure is explained in more detail in **Section 3.10** of this report.

3.7.9 REMEDIAL MEASURES

Cable burial is the primary method for protecting subsea cables. Providing the correct burial machine is selected for the designated burial task, the target depth of burial is likely to be achieved. However, occasionally reduced burial or zero burial occurs. This will usually result as a consequence of an unforeseen event such as extreme weather; the departure from the scheduled installation procedure; extreme ground conditions which were not anticipated from the original survey; or equipment failure. Remedial measures will be required if the perceived risk for the installed cable is considered too high. In many cases it will not be possible to re-engage the cable with the original cable burial machine (i.e. subsea cable plough or tracked cable burial machine with enclosed cable path). In such cases the only remedial burial option available will be post lay burial by other means. Most post lay burial machines only utilise jetting systems which straddle the surface laid section of cable and these machines have limited capability when working in hard seabeds. Alternative cable protection methodologies which are reviewed in **Section 3.8.6** can also be employed as a means of remedial protection for the installed subsea cable.

3.8 Cable Protection Methods

This section describes the methods which are currently used to protect subsea cables in the subsea telecommunications, power cable and oil and gas industries worldwide.

Section 3.9 of this report focuses specifically on the cable protection methods which are relevant to the offshore wind farm industry. **Section 3.9** does not repeat the methodologies as chronologically listed in this **Section 3.8**, but summarises the methodologies used on wind farms installed to date and also lists the cable protection methodologies considered relevant for current and future offshore wind farm developments.

This section is divided into 2 sub-sections as follows:

- A review of all cable burial methods employed by all industries worldwide to protect subsea cables **Sections 3.8.1 to 3.8.5 inclusive**; and
- A review of alternative cable protection methodologies such as rock dumping, concrete mattresses, fronds, grout bags etc. **Section 3.8.6.**

Each cable protection method is described in detail together with explanations of which methods are commonly employed for varying seabed condition. Illustrations and figures for the methods and equipment are provided to illustrate the methodology under review.

3.8.1 CABLE BURIAL METHODS

There are a diverse range of cable burial machines available in the market capable of burying and protecting offshore cables. This section of the report presents and describes these cable burial machines whilst also indicating the range of application and capabilities of each machine. This is always a subjective and sometimes controversial topic, as the performance of a cable burial machine in the offshore environment can vary from the supplier/owner specification which can tend towards more optimistic performance criteria. Therefore, the performance statements in this section of the report are based more on performance observed in the field by the authors and independent associates consulted, as opposed to the published performance criteria.

In order to allow a comprehensive review of the various cable burial machines, and to be able to investigate the environmental effects associated with each machine, four categories have been established for the cable burial machines:

- Cable Burial Ploughs;
- Tracked Cable Burial Machines;
- Free Swimming ROVs with Cable Burial Capability; and
- Burial Sleds.

All of the cable burial methods and cable protection methodologies which are described are used on a worldwide basis and on all different types of subsea cable systems.

Table 3.5 sets out the various burial method options associated with each cable burial methodology and also provides a summary of the mode of operation.

Table 3.5: Overview of Cable Burial Machines

OVERVIEW OF CABLE BURIAL MACHINES		
Burial Machine Type	**Burial Machine Options**	**Mode of Operation**
Cable Burial Ploughs	Cable ploughs are available in varying types: ● Conventional narrow share cable ploughs ● Advanced cable ploughs ● Modular cable ploughs ● Rock ripping ploughs ● Vibrating share ploughs	Cable ploughs are towed from the host vessel with sufficient bollard pull to ensure continuous progress through the seabed with the cable being simultaneously buried as part of the lay process. The plough lifts a wedge of soil and places the cable at the base of the trench before the wedge of soil then naturally (via gravity) backfills over the cable. Cable ploughs are capable of working in a wide range of soils and are typically deployed where longer lengths of cable burial are required. Ploughs can operate in shallow water and in water depths up to 1500m.
Tracked Cable Burial Machines	Tracked cable burial machines can be equipped with the following burial tools: ● Jetting systems ● Rock wheel cutters ● Chain excavators ● Dredging systems	Tracked cable burial vehicles are usually operated and controlled from a host vessel such as a Dive Support Vessel (DSV) or a barge, have subsea power packs, and are controlled via an umbilical cable back to the host vessel. They usually operate in post lay burial mode (although one machine, the LT1, simultaneously lays cable from a reel mounted in the vehicle) and they are equipped with either jetting tools or mechanical cutting tools depending on the seabed conditions which are anticipated. The tracked cable burial vehicles are typically used on shorter lengths of cable burial work. Divers are often required to assist in the loading and unloading of cable into and out of the vehicle in the shallow water machines. However, some vehicles have fully automated cable loading/in-loading equipment. Some vehicles track over cables and straddle the cable with jetting forks. Tracked cable burial machines can be operated in shallow waters (providing motors and power packs can be cooled) and in water depths to 2000m.
Free Swimming ROVs with Cable Burial Capability	Free swimming ROVs can be equipped with the following burial tools: ● Jetting systems ● Dredging systems	Free swimming ROVs are operated and controlled from a host vessel such as a DSV or a barge. They will always operate in post lay burial mode and use either jetting or dredging system to bury subsea cables. Their range of application is limited to sands and clays (performance in clay will be directly related to available jetting power). ROVs are typically used on shorter lengths of subsea cable and can operate in water depths of 10m to 2500m.
Burial Sleds	Burial sleds can be equipped with the following burial tools: ● Jetting systems ● Rock wheel cutters ● Chain excavators ● Dredging systems	Burial sleds are usually operated in shallow waters for work in ports, estuaries, river crossings and shore-ends for cable systems. They are often deployed from barges or jack-ups and either have subsea power or utilise power systems which are mounted on the host vessel. The range of burial tools allows the varying types of burial sled to work in most seabed conditions from sands, gravels, clays and softer rock.

3.8.2 CABLE BURIAL PLOUGHS

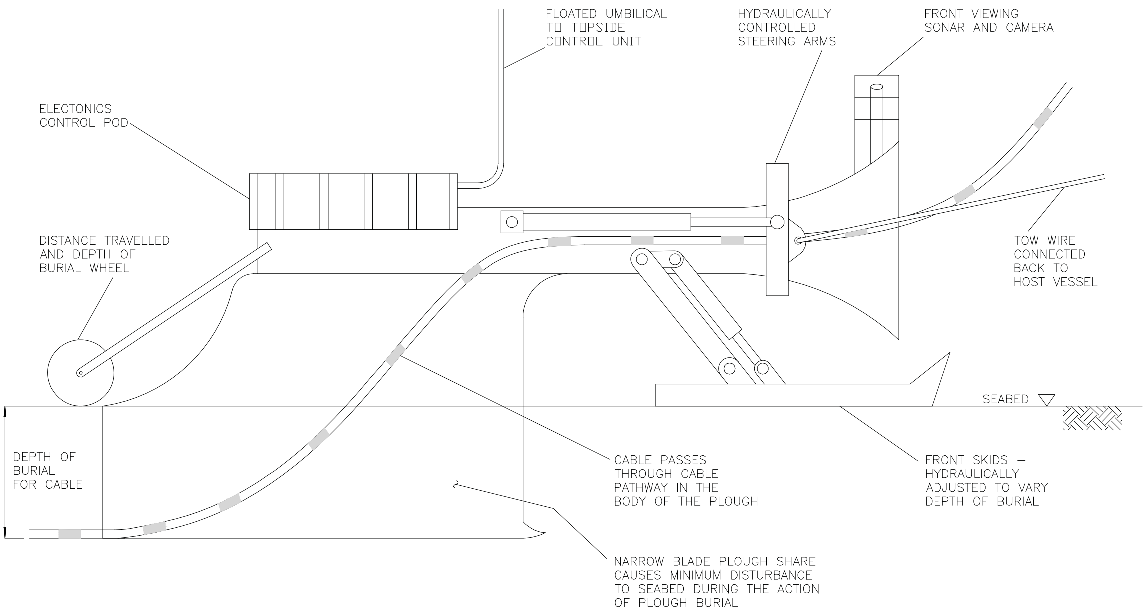
This section of the report reviews the various types of cable burial plough which are available for the burial of subsea cables. The mode of operation of each plough is described together with example types of each plough including details of manufacturers and owners.

The different types of cable burial ploughs which are reviewed are as follows:

- Conventional Narrow Share Cable Ploughs;
- Advanced Cable Ploughs (including Modular Cable Ploughs);
- Rock Ripping Ploughs; and
- Vibrating Share Ploughs.

The general principle of operation of a cable plough is illustrated in **Figure 3.10**.

Figure 3.10: Illustration of Cable Burial through a Subsea Cable Plough

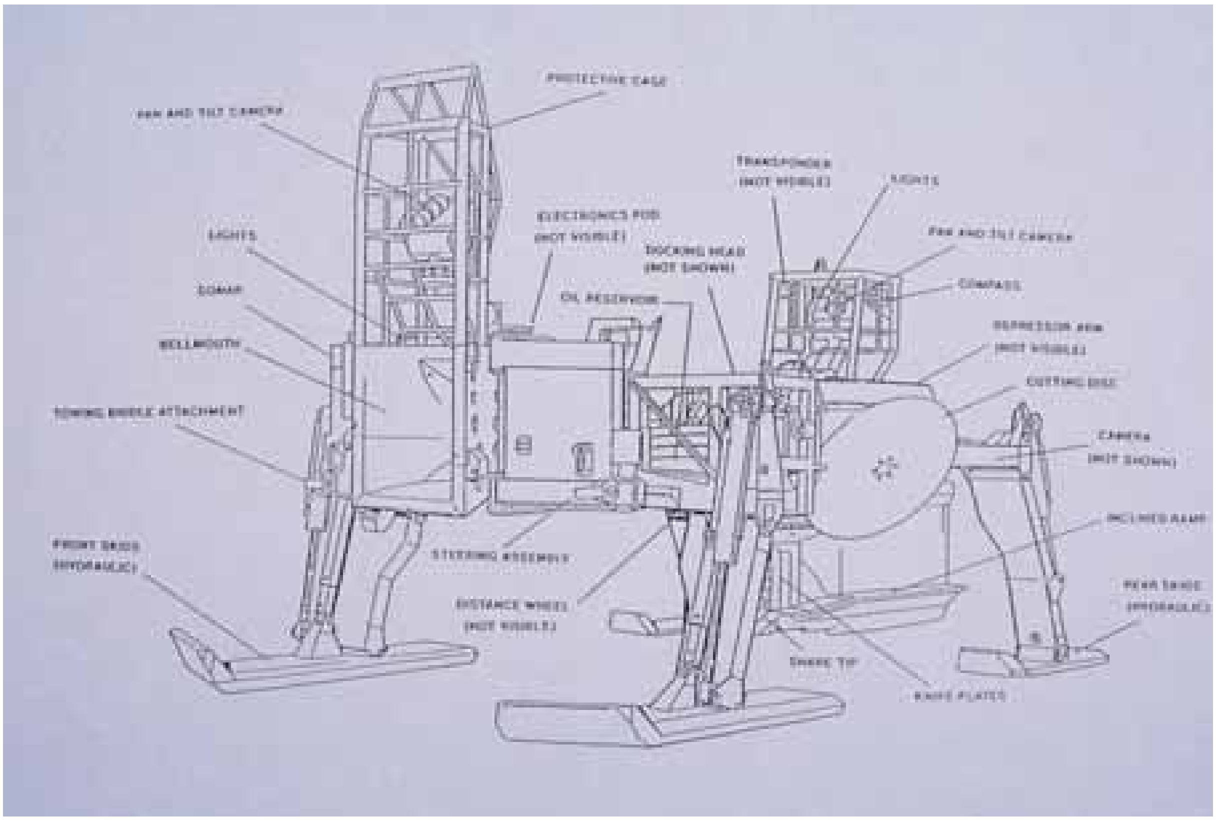


It is estimated there are now approximately 30 conventional narrow share and approximately 25 advanced cable ploughs (advanced, rock ripping and vibrating share) currently in service around the world.

Conventional narrow share cable ploughs

This type of cable burial plough is a passive tool towed from a host vessel. The plough share cuts a wedge of soil which is then lifted by the action of the plough cutting through the seabed. The cable is then fed through the pathway in the plough and the wedge of soil placed as cover over the cable. The cable laying operation involves cable being laid from the host vessel (usually over the stern of the vessel) with a managed catenary down to the bellmouth entry in the cable plough. The simultaneous lay and burial of the cable is then achieved as the cable vessel makes forward progress and the cable plough buries the cable as described above. Depth of burial is controlled by varying the deployed position of the hydraulically controlled skids and the plough is fully instrumented with cameras and sensors to monitor the passage of the cable through the plough and to also measure pitch and roll, depth of burial, distance travelled by the plough and residual tension in the installed cable. **Figure 3.11** shows a typical narrow share plough with the range of sensors and components illustrated.

Figure 3.11: Typical Narrow Share Cable Plough Illustrating Sensors and Plough Components



These types of plough can typically achieve a depth of burial of up to 1.0m in a wide range of seabed conditions and have been successfully used on telecom, power cable and UK offshore wind farm projects.

A selection of commonly used narrow share cable ploughs including details of the manufacturers and owners is listed in **Table 3.6**.

Table 3.6: Selection of Commonly Used Narrow Share Cable Ploughs

PLOUGH	CONVENTIONAL NARROW SHARE CABLE PLOUGHS		
Type	Maximum Burial Depth	Operator	Manufacturer
Cable ploughs (several ploughs deployed worldwide)	1.0m to 1.5m	Global Marine Systems	SMD Hydrovision Ltd
Sea Stallion Cable Plough	2.0m	Bohlen & Doyen	The Engineering Business Ltd
Sea Stallion Cable Plough	2.0m	Originally Cns Ltd	The Engineering Business Ltd
Sea Plows (several ploughs deployed worldwide)	1.5m	Tyco Submarine Systems	SMD Hydrovision Ltd

Figure 3.12 shows a cable plough being deployed from a purpose built launch and recovery system installed on the deck of the host vessel. **Figure 3.13** shows a conventional narrow share cable plough burying an offshore wind farm power cable away from the shoreline at North Hoyle. This figure clearly illustrates that only a minimum disturbance occurs on the beach or seabed during a cable burial operation using this type of plough. The plough share is deployed to a maximum depth of penetration of approximately 2.0m. The 'disturbed' mounds of sand adjacent to the cut trench are approximately 300mm to 400mm high. **Figure 3.14** shows the same cable plough burying the North Hoyle Offshore Wind Farm export cable up the beach with the offshore wind farm in the distance.

Figure 3.12: Cable Plough Launch and Recovery from a Host Vessel

(Photo courtesy of The Engineering Business Ltd)

Figure 3.13: Conventional Narrow Share Cable Plough Burying a North Hoyle Offshore Wind Farm Export Cable

Figure 3.14: Sea Stallion 4 Cable Plough Burying North Hoyle Export Cables up the Beach

(Photo courtesy of The Engineering Business Ltd)

Advanced cable ploughs

The category of Advanced Cable Ploughs covers the new generation of cable ploughs which have been designed to achieve increased burial depth for subsea cables of up to depths of 3.0m. **Table 3.7** below lists a number of Advanced Cable Plough types.

One type of Advanced Cable Plough system utilises a number of water jets fitted within the plough share to fluidise material at the leading edge of the share which in return reduces the required tow force and allows the plough share to penetrate deeper into the seabed. These new multi-depth ploughs have the ability to bury cables up to 3.0m deep. The water jets are most effective in sands, gravels and weaker clay conditions and have limited use in harder seabed conditions.

An alternative Advanced Cable Plough type is the Sea Stallion cable plough. This large cable plough can bury cables up to 3.0m deep by using a plough share with a unique geometry to allow this deeper cable burial. **Figure 3.15** shows a Sea Stallion cable plough on the quayside with the double cutting plough shoe design and **Figure 3.16** shows the same plough about to commence burial operations from the beach.

Table 3.7: Advanced Cable Plough Systems.

PLOUGH	ADVANCED CABLE PLOUGHS		
Type	Maximum Burial Depth	Operator	Manufacturer
MD3 – jet assisted plough	3.0m	CTC Marine Projects	SMD Hydrovision Ltd
Advanced cable plough – deep burial plough	Up to 3.7m	CTC Marine Projects	SMD Hydrovision Ltd
Hi – Ploughs – standard share or injector share	2.0m standard share 3.25m injector share	Global Marine	SMD Hydrovision Ltd
Advanced Sea Stallion	Up to 3.0m	Various	The Engineering Business Ltd
Sea Plan 8	Up to 1.5m	Tyco Submarine Systems Ltd	Perry Slingsby

Figure 3.15: Sea Stallion Cable Plough on Quayside

(Photo courtesy of The Engineering Business Ltd)

Figure 3.16: Sea Stallion Cable Plough Commencing Burial from the Beach

(Photo courtesy of The Engineering Business Ltd)

Another type of Advanced Cable Plough is the modular cable plough, the concept for which was originally conceived in the 1980s. The principle of the modular plough is to have a plough system with an interchangeable plough share which allows the operator to either fit a narrow share for cable burial or to fit a modular V-type share for the burial of flowlines or small flexible pipelines.

This type of plough has not proved popular and most operators have opted to design and build a plough system specifically tailored to the market they wish their plough system to operate in. An example of a modular plough is detailed in **Table 3.8** below. It is believed that this plough system has only been used in cable burial mode; however, this has not been confirmed.

Table 3.8: Modular Cable Ploughs

PLOUGH	MODULAR CABLE PLOUGHS		
Type	Maximum Burial Depth	Operator	Manufacturer
Modular plough system (cables or pipes)	1.2m	CTC Marine Projects	SMD Hydrovision Ltd

Rock ripping ploughs

The Rock Ripping Ploughs were developed in response to requirements from the subsea telecommunications market to provide a capability to protect cables in areas where telecom cables passed over seabeds which consisted of outcropping rock, or where the seabed strata was exceptionally hard and outwith the capabilities of a conventional narrow share plough. This requirement was primarily driven by fishermen trawling in seabed areas where such seabed conditions exist. Historically the fishermen would have avoided such areas owing to the risk of snagging gear. However, the need to find new fishing grounds has now forced the fishermen to work in these more difficult areas and in deeper waters.

Historically when a cable had to be buried in rock the traditional approach would have been to use a rock wheel cutter. These tools can cut an efficient trench, but tend to make relatively slow progress depending on the nature of the rock. Furthermore, the wear rate on the cutting teeth can be substantial. Therefore, the rock ripping plough was developed to meet this new challenge.

A Rock Ripping Plough has an additional, folding, rock penetrating tooth which is fitted to the leading edge of the plough share. The rock penetrating tooth significantly increases the ability of the rock ripping plough to penetrate and cut trenches in very hard ground seabed conditions. The overall performance of the plough is not generally affected in any way when the plough is cutting the trench in rock ripping mode.

Table 3.9 lists a number of rock ripping ploughs which are currently available in the marketplace. **Figure 3.17** shows a rock ripping plough; the rock penetrating tooth is clearly visible on the leading edge of the plough.

Table 3.9: Rock Ripping Ploughs

PLOUGH	ROCK RIPPING PLOUGHS		
Type	Maximum Burial Depth	Operator	Manufacturer
Rock Plough 1	1.0m rock 3.0m soft soils	CTC Marine Projects	SMD Hydrovision Ltd
Rock Plough 2	1.0m rock 3.0m soft soils	CTC Marine Projects	SMD Hydrovision Ltd
ISU Plough (for offshore umbilicals)	1.0 to 1.2m	CTC Marine Projects	SMD Hydrovision Ltd

Figure 3.17: Rock Ripping Plough

(Photo Courtesy of CTC Marine Projects)

Vibrating share ploughs

A vibrating share plough consists of a narrow share (suitable for the burial of cable systems) which is then vibrated to ensure cutting progress through difficult seabed conditions such as chalk and gravel beds. The vibration action is usually achieved by a hydraulic actuator. Table 3.10 **lists examples of vibrating share ploughs.**

Table 3.10: Vibrating Share Ploughs

PLOUGH	VIBRATING SHARE PLOUGHS		
Type	Maximum Burial Depth	Operator	Manufacturer
ESV 12	Up to 2.2m	Travocean	Unknown
ESV 11/3 Shallow Water Only (Up to 3 cables simultaneously)	Up to 1.3m	Travocean	Unknown
ESV 07/3 Shallow Water Only (Up to 3 cables simultaneously)	Up to 1.1m	Travocean	Unknown

The Travocean ESV 12 vibrating plough was successfully deployed to bury the Tangerine telecom cable off the east Kent coast adjacent to Dumpton Gap. The subsea cable system was successfully buried to a consistent burial depth of 1.4m in a chalk seabed as confirmed by the cable owner.

3.8.3 TRACKED CABLE BURIAL MACHINES

There are a large number of tracked cable burial vehicles deployed around the world. These types of vehicles are generally divided into two sub-groups:

- Tracked Vehicles for Shallow Water Use (usually within the range of air divers); and
- Tracked Vehicles for Deep Water Use (in water depths up to 2500m).

Table 3.11 describes a range of tracked cable burial vehicles used worldwide.

Table 3.11: Tracked Cable Burial Machines

Type	Burial Systems Available	Maximum Burial Capability	Maximum depth of Operation	Operator
Eureka	Jetting system Mechanical wheel cutter Mechanical chain excavator	1.0m 1.2m 2.2m	1500m	Global Marine
Otter	Chain excavator for shallow water working	2.2m	Within diver operations	Global Marine
Spencer	Chain excavator for shallow water working	1.5m	Within diver operations	Global Marine
Nereus III	Two separate burial tools available	1.0m	2500m	Tyco Submarine Systems Ltd
Nereus IV	Two separate burial tools available	1.0m	2500m	Tyco Submarine Systems Ltd
CT2	Jet trenching system	Up to 2.0m in sands and low to medium strength clays	3000m	CTC Marine Projects Ltd
Trencher T2	Jetting system Mechanical chain excavator	1.6m 1.6m	Up to 1000m	CTC Marine Projects Ltd
Trencher T1	Jetting system Mechanical chain excavator	2.0m 1.2m	Up to 1000m	CTC Marine Projects Ltd
TM 03	Jetting system Mechanical wheel cutter Mechanical chain excavator	1.0m 1.3m 2.3m	Within diver operations	Travocean
TM 02	Jetting system Mechanical wheel cutter Mechanical chain excavator	1.0m 1.2m 2.0m	Within diver operations	Travocean
MED 1	Jetting system Mechanical chain excavator	1.0m 3.0m	120m	Travocean
MED 1	Mechanical wheel cutter	1.5m	500m	Travocean
LBT1	Jetting system Mechanical wheel cutter Mechanical chain excavator	3.0m 1.2m 1.6m	50m	Marine Projects Int.

Tracked cable burial vehicles are usually operated (but not exclusively) in post laid burial mode to bury subsea cables which have been previously laid on the seabed and are typically used for shorter sections of cable burial. However, some vehicles have been used successfully to bury up to 10km lengths of subsea cable. Tracked cable burial vehicles are launched from the host vessel and then locate the subsea cable system to be buried by using a combination of cable detection and underwater camera systems. The tracks then straddle the subsea cable and the cable is loaded into the cable burial tool which is fitted to the vehicle. As the vehicle makes forward progression the vehicle has the capability to automatically steer along the line of the cable with an auto track capability linked to the cable locator system fitted to the front of the vehicle.

Divers are often required to assist in the loading and unloading of cable into and out of the cable burial tool fitted to the tracked vehicles. However, some of the vehicles have automatic cable loading and unloading features with an auto eject capability in the event of a power system failure to the tracked vehicle during operation. Cable owners are often reluctant to use such systems and therefore the more complex burial tools tend to be limited to shallow water use where diver intervention is possible. In deeper waters (which are out of diver range) only the more simple burial tools such as a jetting tool consisting of two forks which are positioned either side of the cable, tend to be used.

There are three types of burial tools which are commonly fitted to tracked cable burial vehicles:

- Jetting systems (sometimes accompanied by a dedicated dredging system);
- Mechanical rock wheel cutters; and
- Mechanical chain excavator.

These three types of burial tool are described below.

Jetting systems

Numerous types of jetting tools have been developed, most of which are subject to various patent protections, with operators usually favouring their own particular system.

A jetting system works by fluidising the seabed using a combination of high-flow, low pressure and low flow high pressure water jets to cut into sands, gravels and low to medium strength clays. Progress in clays is dictated by the available power budget to the tracked cable burial vehicle and the level of cohesion in the clay. In some cases a dredging system is employed to suck out the fluidised material to leave an open trench into which the cable then falls to the bottom through its self-weight. The jetting tools can also be fitted with a downwards forcing depressor which, together with the self-weight of the cable, helps to force the cable downwards in the fluidised trench. The effectiveness of any depressor system will be limited by the minimum bend radius and stiffness of the cable being buried and also by the on-bottom weight of the tracked cable vehicle itself to provide a downwards force onto the cable. This type of burial operation does give rise to sediments being suspended in the water adjacent to the burial operation and it can take a number of hours for such sediments to settle and for full visibility to return in the water column.

Mechanical rock wheel cutters

Mechanical rock wheel cutters can also be fitted to tracked cable burial vehicles and, as the name suggests, are used to cut narrow trenches into hard or rocky seabeds typically operating in the 1.5m trench depth range. The rock wheel cutter consists of a rotating wheel disc and is fitted with a number of replaceable rock cutting teeth. Progress is slow (100m/hr to 500m/hr) using these vehicles and, in extreme cases, progress of only tens of metres can be made in a full day of trenching operations. It is often the case that the vehicle has to be recovered for the cutting teeth to be replaced as they abrade quickly in the rock material thus losing their effectiveness in cutting mode. Owing to the very aggressive nature of the cutting tool, the cable is carefully guided through the tracked cable burial vehicle through an enclosed cable pathway over the top of the rock wheel cutter before being guided to the base of the cut trench. Diver intervention is usually required in any cable loading and unloading process. **Figure 3.18** shows a shallow water tracked cable burial machine which is fitted with a rock wheel cutter, but has the flexibility to interchange to a mechanical chain excavator if required.

Figure 3.18: Shallow Water Tracked Cable Burial Machine Fitted with a Rock Wheel Cutter

(Photo courtesy of The Engineering Business Ltd)

Mechanical chain excavators

Mechanical chain excavators are typically used in circumstances where the seabed material is beyond the capability of a jetting system or where deeper burial is required. Mechanical chain excavators typically operate in the 2.5m to 3.0m trench depth range as opposed to the 1.0m to 1.5m depth range that the mechanical rock wheel cutters operate in. The mechanical chain excavator tool usually consists of a number of cutting teeth similar to those used on the mechanical rock wheel cutter and a further number of mechanical scoops which are used to transport the cut material away from the trench.

As with the mechanical wheel cutter, all the teeth on the mechanical chain excavator are replaceable and interchangeable depending on the seabed conditions. An auger is sometimes in place at the upper level of the mechanical chain excavator. The auger helps to move away the cut trench material and prevent it falling back into the trench or from clogging the cutting chain. The augers are usually short, and only move the cut seabed material approximately 500mm away from each side of the trench. Again, because of the very aggressive nature of the cutting tool, the cable will be guided in an enclosed pathway around the top of the cutting tool to safeguard against any potential damage before it is placed into the base of the cut trench. Therefore, as for the wheel cutter, cable loading and unloading is a diver assisted operation.

Simultaneous lay and burial vehicles

In 2003, a new type of tracked cable burial vehicle was introduced to the offshore wind farm cable market, with the capability to lay and bury cables simultaneously. Manufactured by SMD Hydrodivision Ltd, the LBT1 was supplied to Marine Projects International Ltd and was first used on the North Hoyle Offshore Wind Farm for the burial of the inter-turbine array cables. **Figure 3.19** below shows the LBT1 being deployed over the side of the host vessel with a full reel of cable to install a section of cable between two of the North Hoyle offshore turbine generators. The LBT1 was fitted with both a forward chain excavator system for working with hard soils and a jetting tool mounted to the rear of the vehicle for the burial of the subsea cable.

Figure 3.19: LBT1 being deployed at the North Hoyle Offshore Wind Farm Site

Previous **Table 3.11** lists a selection of Tracked Cable Burial Machines, noting the various burial systems available for each machine together with corresponding details of burial capability.

3.8.4 FREE SWIMMING CABLE BURIAL MACHINES

A Free Swimming Burial ROV uses thrusters for propulsion and manoeuvrability and is equipped with a work package or work skid for intervention tasks or cable burial operations. All of the ROVs in use today are unmanned; however some of the early free swimming vehicles were manned. These vehicles are now consigned to museum exhibits.

The early free swimming burial machines were manned autonomous vehicles with very limited power budgets for burial operations. The early Pieces vehicles, as they were called, were generally deployed on repair and maintenance duties and would spend extended periods trying to shallow bury exposed sections of subsea telecoms cable into the seabed. However, after a near fatal incident on an early CANTAT cable which ultimately resulted in a successful full scale rescue of a stranded Pieces vehicle, the industry looked to remotely controlled vehicles for the next generation of cable intervention.

The first generation Free Swimming Burial ROVs were dedicated for repair and maintenance activities to assist in the repair of damaged sections of cable and to then attempt re-burial of the final repair splice of cable. The Free Swimming Burial ROVs used jetting systems to attempt the cable burial, but with low power budgets they only had limited success in sandy seabeds. SCARAB 1 and SCARAB 2 were the first vehicles of this type. Both of the vehicles were equipped with subsea power packs, control and telemetry functions via a control umbilical and had depth capabilities of 1000m. As subsea ploughs were introduced for the burial of subsea telecoms cables, the Free Swimming Burial ROVs developed into more sophisticated ROVs capable of a range of subsea intervention tasks with larger power budgets for cable burial. This next generation of Free Swimming Burial ROVs had cable burial tools with low and high pressure jetting tools and dredge units to allow the vehicles to work in sandy, clay and gravel seabeds. The SCARAB 4 vehicle which came into service in 1990, was fitted with a state of art rotating cylinder jetting tool with a series of high pressure jets capable of working into 400KPa clays.

Free Swimming Burial ROVs have generally stayed in the niche market area of cable repair and maintenance. However, these vehicles have seen significant technological development with jetting tools now capable of deeper burial using “jetting swords” which sit either side of the cable to be buried, and with depth ratings down to 2500 and 3000m.

Table 3.12 provides a listing of a number of free swimming cable burial vehicles which are used worldwide.

Some of the current Free Swimming Burial ROVs can interface to a tracked work package. This provides the Free Swimming Burial ROV the opportunity to have a stable work platform for burial operations and to revert to free swimming mode when inspection and intervention tasks are required as well as more manoeuvrability, especially in the deep water operations. **Figures 3.20** and **3.21** show the CM ROV3 cable burial vehicle. This vehicle can operate either in free swimming mode or can have a modular tracked unit fitted (as shown in the Figures). **Figure 3.21** shows the jetting lances in the fully deployed condition.

Some Free Swimming Burial ROVs now have power budgets of over 300kW and are equipped with manipulators for handling tasks, together with cable cutters, cable grippers and burial tools fitted to both the forward and rear sections of the ROV. In addition jetting lances, which are fitted to the end of a manipulator arm, allow for localised burial.

Dredging units fitted to Free Swimming Burial ROVs have a particular use when working far offshore in deeper waters, where seabeds can be encountered which consist of shell beds held together by fine sands. These seabeds are particularly difficult to trench using jetting systems, as the energy from the water jets deflects off the hard shell surfaces. This can be countered by using a combination of dredging and jetting as the dredging sucks in the sand and shells and breaks up the layer composition.

Another generation of dredging only units have occasionally been used for cable burial work at inshore locations. These dredging units are large suction machines which are generally used to excavate large holes in the seabed and are more commonly used for seabed levelling and dredging activities. Owing to the imprecise nature of their mode of operation, scarcity of use, and because they have a significant environmental impact, they are considered unlikely to be used for the burial of offshore wind farm cables. They have not, therefore, been included in the scope of review of this study.

Figure 3.20: CM ROV3

(Photo Courtesy of CTC Marine Projects)

Figure 3.21: CT2 Launch

(Photo courtesy of CTC Marine Projects)

Table 3.12: Free Swimming Cable Burial Machines

FREE SWIMMING CABLE BURIAL MACHINES					
Type	Burial Systems Available	Maximum Burial Capability	Maximum depth of Operation	Operator	Manufacturer
Atlas 1	Jetting System	Up to 1.0m in sands and low to medium strength clays	2000m	Global Marine	Perry Slingsby Systems
Atlas 2	Jetting System	Up to 1.0m in sands and low to medium strength clays	2000m	Global Marine	Perry Slingsby Systems
Excalibur	Jetting System	Up to 3.0m in sands and low to medium strength clays	2000m	Global Marine	Perry Slingsby Systems
Scorpion C/N Burial Sled	Jetting System	Up to 1.0m in sands and low to medium strength clays	3000m	Acergy – formerly Stolt Offshore	Perry Slingsby Systems
Various Work Class ROVs with Burial Sleds	Jetting System	Up to 1.0m in sands and low to medium strength clays		Saipem / Sonsub	Sonsub
Various Work Class ROVs with Burial Sleds	Jetting System	Up to 1.0m in sands and low to medium strength clays		Canyon Offshore	-
CT 1	Jetting System	Up to 3.0m in sands and low to medium strength clays	2500m	CTC Marine Projects Ltd	-
CMROV 1	Jetting System	Up to 1.0m in soft soils only	2500m	CTC Marine Projects Ltd	SMD Hydrovision Ltd
CMROV 2	Jetting System	Up to 1.0m in soft soils only	2500m	CTC Marine Projects Ltd	SMD Hydrovision Ltd
CMROV 3	Jetting system	Up to 1.5m in sands and low to medium strength clays	1500m	CTC Marine Projects Ltd	SMD Hydrovision Ltd
CMROV 4	Jetting system	Up to 1.5m in sands and low to medium strength clays	1500m	CTC Marine Projects Ltd	SMD Hydrovision Ltd
SCARAB III	Jetting System	Up to 1.0m in soft soils only	1000m – burial 2000m – inspection	ACMA Group	Oceaneering Ltd
Scarab IV	Jetting System	Up to 1.0m in sands and clays	1000m – burial 2000m – inspection	ACMA Group	Perry Slingsby Systems
Triton ST200	Jetting System	Up to 1.0m in sands and low strength clays	2500m	Tyco Submarine Ltd	Perry Slingsby Systems

3.8.5 BURIAL SLEDS

Most burial sleds are developed for the burial of the shore end section of cable systems and work in shallow water. As well as being used for open water shore end cable installation, these machines are often used for river crossing and estuary cable work.

Most of the systems are relatively simple in their technology and consist of a basic frame structure to provide a pathway for the cable and a simple hydraulic function to allow for a jetting tool to be deployed to the required depth of cable burial. In most instances the water pumps for the jetting tools are provided from the host vessel with pipework direct to the burial sled. These low cost shallow water burial tools inevitably require diver intervention for cable loading and unloading.

Burial sleds are also used in shallow water areas where the seabed or intertidal zone consists of very soft muds or where seabeds will not provide any bearing support to a tracked cable burial vehicle or a conventional subsea plough. The burial sled is likely to be a lot lighter than these types of burial machines, particularly if the burial systems utilise surface powered jetting systems which negates heavy subsea pumps and motors. It can be possible to make these burial sleds almost neutrally buoyant by the attachment of temporary buoyancy and diver lift bags. Hence, the lightweight configuration allows the burial sleds to work in soft seabeds which would be out of the range of other burial machines.

A selection of typical burial sleds which are currently used worldwide are listed in **Table 3.13**. The same table also includes details of injector systems. Injectors are large specialised jetting tools which are typically used in harbours and anchoring areas where deep burial is required (up to 10m). These units are powered from the surface and use massive pumps and power packs to deliver a very potent force into the seabed to achieve the depth of burial required.

Table 3.13: Burial Sleds

BURIAL SLEDS				
Type	Burial Systems Available	Maximum Burial Capability	Operator	Manufacturer
Bantam	Jetting System	2.2m	Global Marine Systems Ltd	ETA Ltd
Injector	Deep Water Jetting Tool – Specialised Application	Between 2.0m and 10.0m	Global Marine Systems Ltd	Unknown
Panzer	Jetting System	Between 2.0m and 5.0m	Global Marine Systems Ltd	Unknown
Sabre	Surface Powered Jetting Inductor Tool	2.0m	Global Marine Systems Ltd	Unknown
TJV 06	Jetting System	2.0m	Travocean	Unknown
TJV 05	Jetting System	Up to 4.0m	Travocean	Unknown
TJV 04	Jetting System	Up to 2.0m	Travocean	Unknown
TM7	Jetting System	Up to 3.0m	Land and Marine	Unknown

3.8.6 ALTERNATIVE CABLE PROTECTION METHODOLOGIES

When cable protection cannot be achieved by cable burial, or for operational reasons cable burial is not the preferred method for cable protection, there are a number of other alternative cable protection methodologies available to ensure subsea cables are protected from hostile seabed intervention.

The alternative cable protection methodologies which are reviewed in this section are employed on a worldwide basis and are suitable for all offshore wind farm development projects.

Typical examples where alternative cable protection methodologies would be utilised are as follows:

- Sections of cable close to J-tubes where the cable burial machine commences burial at a transition point away from the J-tube (typically 10m to 20m in distance);
- Areas along the cable route where the subsea cables cross existing cables or pipelines;
- Areas of surface laid cable which has resulted from the need to recover a subsea cable plough due to weather or other operational reasons;
- Where burial has been difficult to achieve and sections of cable have been surface laid in the original cable burial operation;
- Where for operational reasons it has not been practical to mobilise a cable burial machine; and
- Environmentally sensitive coastal and sea cliff areas where directional drilling is employed.

Each alternative cable protection methodology will have its relative merits and detractions and the selection of the most appropriate form of cable protection will be dictated by the requirements at a particular location.

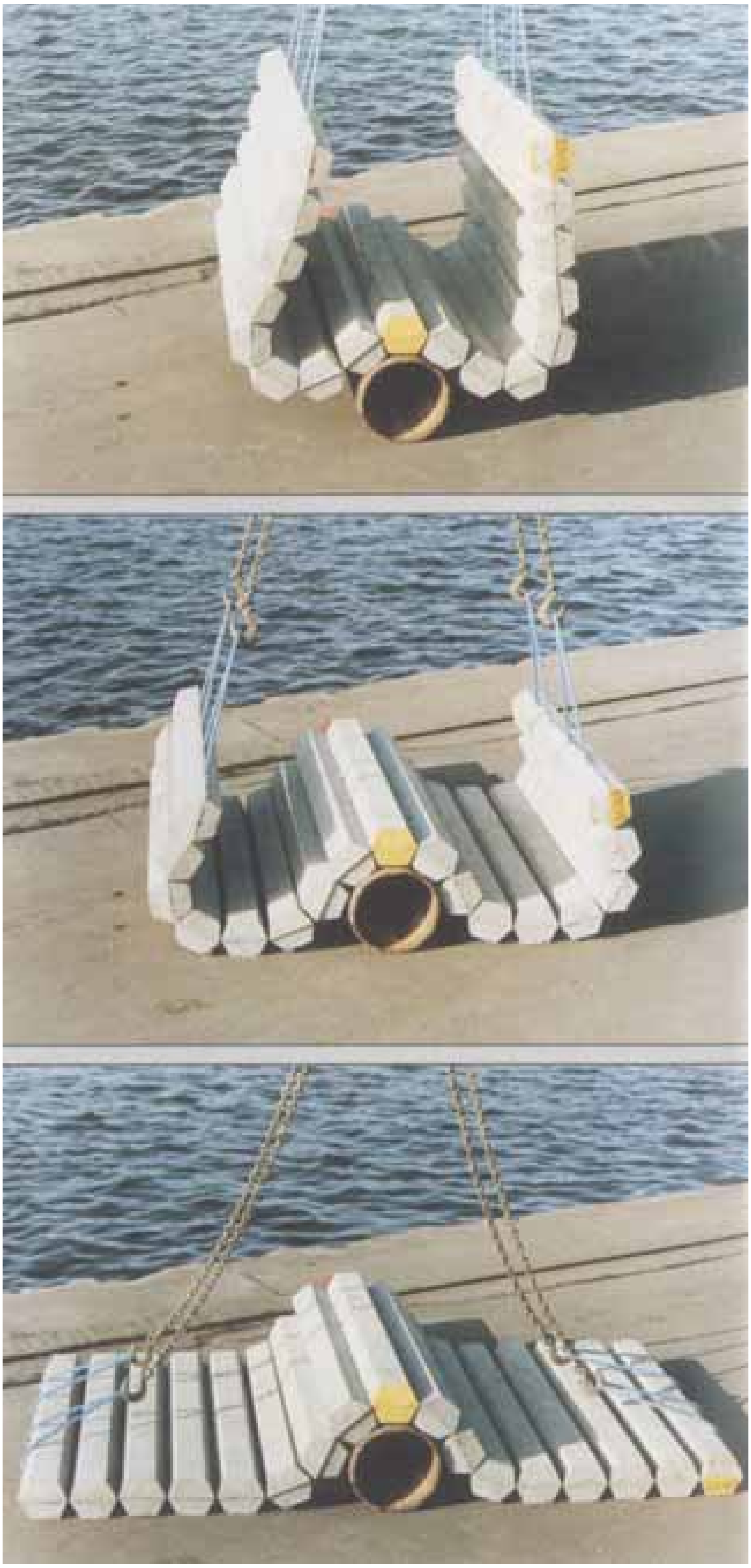
Concrete mattresses

Concrete mattresses are widely used on power cable and pipeline installations both as a means of primary cable protection and also for crossings over other existing subsea cables and pipelines. Concrete mattresses are prefabricated and consist of a number of concrete block sections connected by polypropylene rope. They are usually approved by other stakeholders, particularly fishermen who consider concrete mattresses to be potentially less damaging to their fishing gear than rock dumping. **Figure 3.22** shows a concrete mattress being lifted and **Figure 3.23** shows how a concrete mattress is deployed over a cable or pipeline.

Figure 3.22: Concrete Mattress being Lifted by a Lifting Frame

(Photo courtesy of FoundOcean Ltd)

Figure 3.23: Concrete Mattress being Deployed Over a Pipe Section



(Photos courtesy of FoundOcean Ltd)

The installation of concrete mattresses requires diver intervention to assist in their accurate placement. However, for safety reasons most mattresses are deployed with automatic release systems connected to the rigging, with divers either out of the water or well clear when each mattress is released. It is normal practice for a number of concrete mattresses to be transported to the work site on a host vessel with its own vessel crane which is used to individually deploy the mattresses. **Figure 3.24** shows the deployment of a concrete mattress.

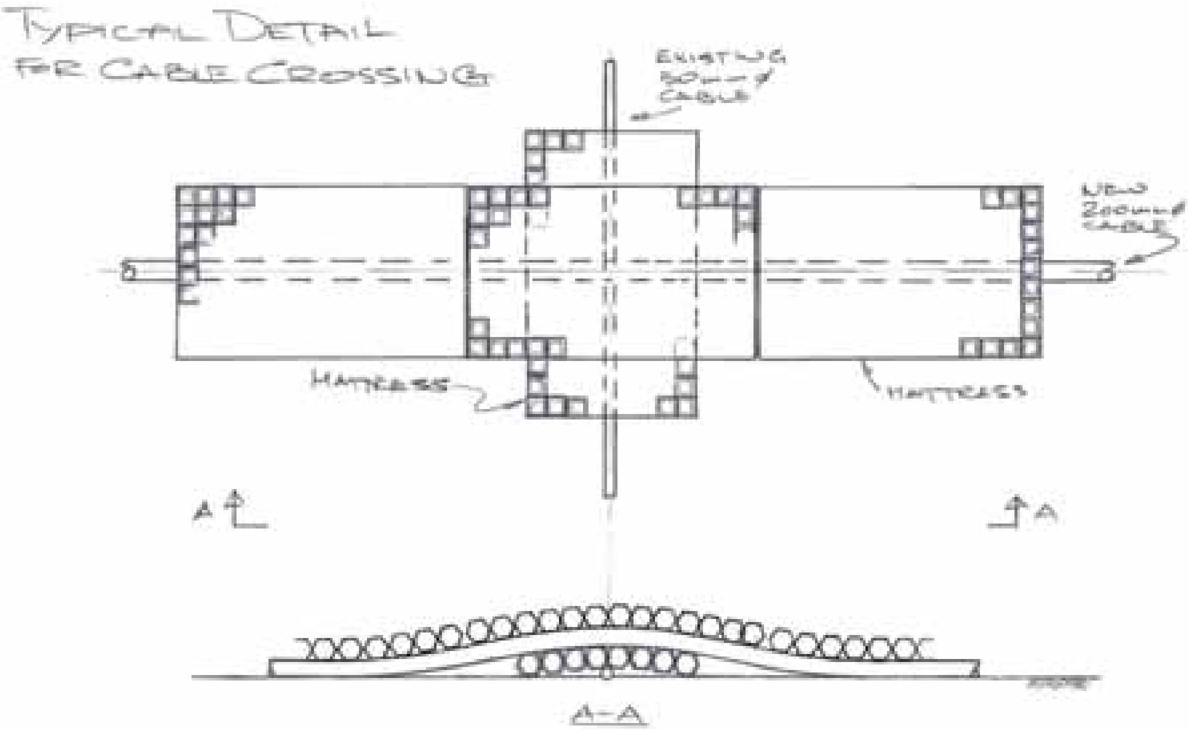
Figure 3.24: Concrete Mattress being deployed by Crane from a Host Vessel

(Photo courtesy of FoundOcean Ltd)

Concrete mattresses can each weigh up to 10 tonnes and a typical mattress would measure 5m x 3m x 300mm thickness. However, smaller and lighter mattresses are also available. The size, weight and density of the concrete used will be dictated by the stability calculations which have to be undertaken in advance of the mattress deployment. Such calculations will take into account any potential scour effects around the periphery of the mattresses.

Where concrete mattresses are used for cable or pipeline crossings, the procedure would involve the placement of concrete mattresses over the existing pipeline with the new cable then laid on top of these mattresses with a further layer of mattresses then added over the new cable to create a sandwich effect. This approach ensures satisfactory separation between the new cable and existing cable or pipeline whilst also ensuring a robust cable protection solution for the crossing arrangement. This procedure is illustrated in **Figure 3.25**.

Figure 3.25: Typical Detail for the Cable Crossing Arrangement using Concrete Mattresses to Provide Separation and Cover



Rock dumping

Rock dumping is an established methodology for protecting subsea cables both along their installed lengths and also at crossings with existing subsea cables or pipelines.

Many of the major offshore rock dumping contractors such as Van Oord, claim the technique is very resistant to both trawling and anchoring activities. However, rock dumping is not generally favoured by fishermen who claim it sets up a potential snagging point for their fishing gear. Furthermore, certain groups see the introduction of substrates which are foreign to the locality as falling into the category of undesirable. However, there is a counter review from other groups who view the introduction of a new rock reef as a potential new habitat for fish and other underwater species to colonise.

In shallower waters rock dumping is usually achieved either by the use of side tipping vessels which deposit their cargo in a somewhat crude method that often results in the need for larger volumes of rock to achieve the primary protection method or by using a grab device which is illustrated in **Figure 3.26**.

Figure 3.26: Placement of Rock for Scour Protection

Grout bags or sand bags

Grout or sand bags can be regarded as a smaller scale version of the mattressing process. They are usually installed by divers to stabilise or fix in place a cable or a pipeline over short distances.

Grout bags can either be deployed as pre-filled bags or for larger applications empty fabric bags are taken to the seabed and a diver coordinates the filling of the grout bag using a grout mix and pumping spread from the host vessel above. **Figure 3.27** shows a Grout Bag (in an onshore trial) which has been placed over a pipe section and filled with grout.

Figure 3.27: Grout Bag over a Pipe Section and Filled with Grout

Frond mattresses

Frond mattresses can potentially increase protective cover over a surface laid section of cable by stimulating the deposition of sediments which are suspended and transported in the water column. When the sediments connect with the frond mattresses, they are forced to settle; this eventually forms a new sand bank. Before a frond mattress is selected for a particular application it would be essential to assess the appropriateness of the technique for the local conditions and it may be necessary to deploy a frond mattress at the site in advance of the cable protection project to ensure that the procedure would be successful. **Figure 3.28** illustrates a frond mattress.

Figure 3.28: Frond Mattress Protection

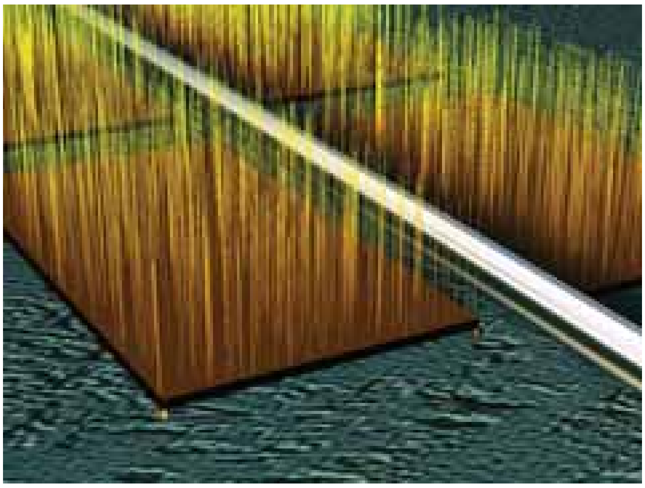
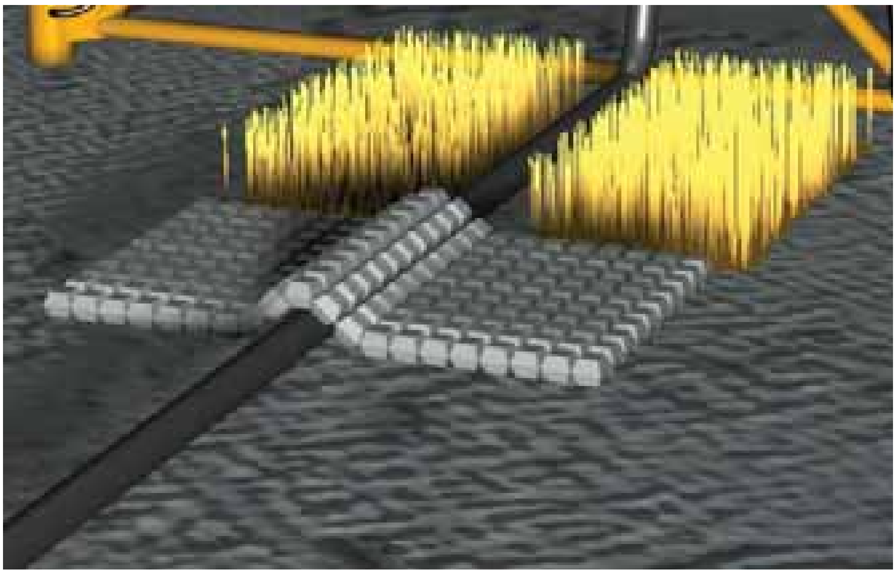


Figure 3.29 illustrates how a frond mattress and a concrete mattress could be used in conjunction to protect cables and pipelines close to an offshore structure.

Figure 3.29: Protection using a Frond Mattress in conjunction with a Concrete Mattress



Fronds are popular with environmental organisations as there is a perception that the indigenous substrate is being reinstated. However, experience has shown that situations such as storms, which create high energy situations on the seabed, have resulted in deposited materials around the fronds being stripped out.

The installation procedure for the frond mattresses would be identical to that explained above for concrete mattresses.

Uraduct

Uraduct is manufactured using high performance polyurethane elastomer. The system comprises two cylindrical half shells which overlap and interlock to form close fitting protection around the core product such as cable, umbilical or flexible/rigid flowline. For ease of handling, the half shells are manufactured in lengths of up to 2.0 metres with flexing characteristics to suit the required minimum bend radius of the product or ancillary shipboard lay equipment. The half shells are secured in place using corrosion resistant banding located in recessed grooves to ensure a smooth external profile. A range of sizes is available to support product outside diameters ranging from 15mm to 450mm and beyond.

Uraduct comes in varying sizes and stiffnesses to resist different levels of impact and is of particular use at cable crossing points or in areas close to structures, such as offshore wind turbine support structures or offshore oil and gas installations, where the risk from dropped objects is high. Uraduct is not commonly used along longer sections of cable which has been inadvertently surface laid on the seabed as it does not offer any further protection from trawling gear or anchors and only increases the target size.

Articulated metal shell connectors

Articulated metal shell connectors are typically used to provide cable sections with added mass and abrasion resistance in high energy environments such as a cable shore landings, which pass over rock outcrops and where other forms of cable burial are not possible. The articulated sections would be applied by surface divers in half sections which are then locked or bolted together to form a continuous pipe section.

Directional drilling

Directional drilling is employed by cable installation contractors when the topography of a landfall site makes it difficult to achieve a conventional landfall by trenching, or where there are environmental interest features that need to be avoided such as saltmarsh or chalk cliff. Directional drilling provides a very useful alternative, as it allows the cable installation to bypass the critical areas and only causes localised disruption at the drill site which can be reinstated when the directional drilling equipment leaves the site.

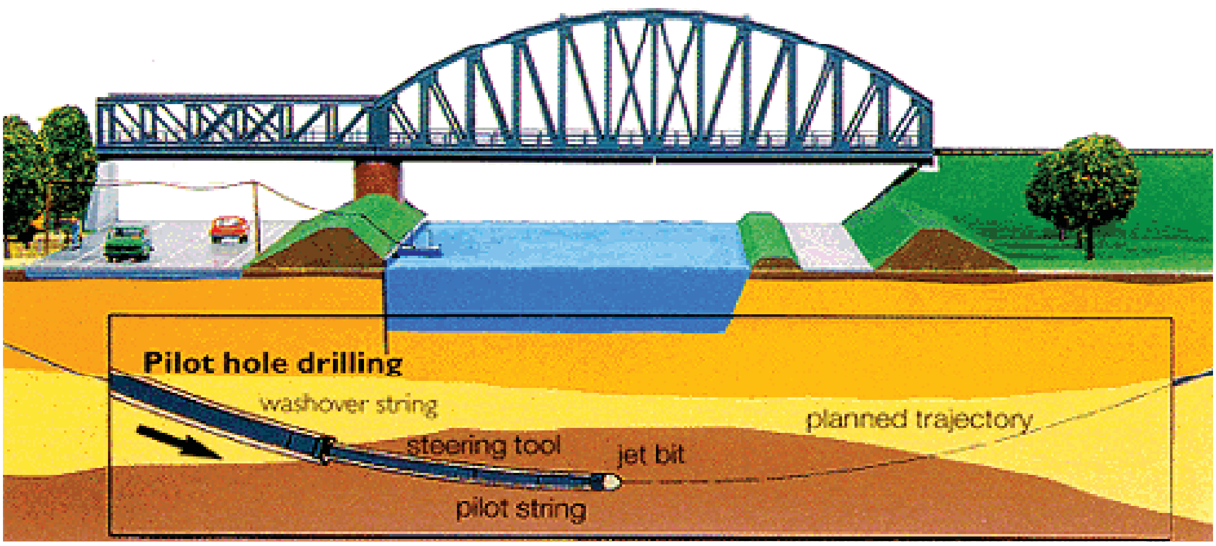
Figure 3.30 shows a typical directional drilling procedure. This procedure has been extracted from the LMR Drilling website (http://www.lmrdrilling.co.uk/intro.html). The directional drilling process can be undertaken in four separate phases and is described in detail below.

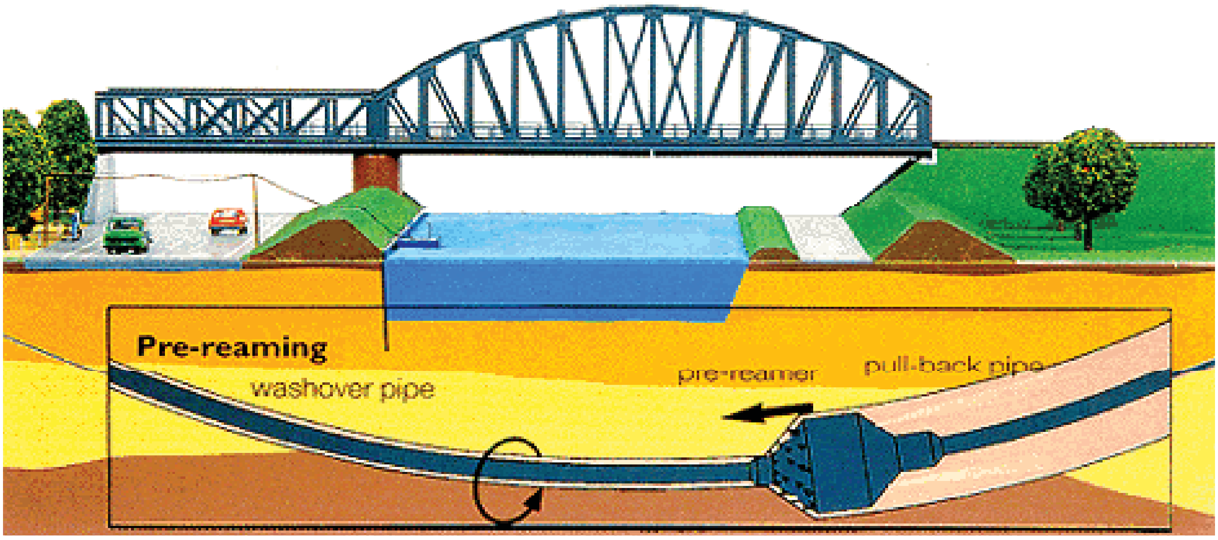
Drilling the profile. A small diameter pilot hole is drilled under directional control to a predetermined path using a mud-motor or jet bit on the end of the pilot string. The pilot string is drilled up to 80 metres in length, then the washover pipe is advanced in rotary mode until it is approximately 30 metres behind the drill bit. Alternate pilot string and drilling operations take place until the exit point is reached. Then the smaller pilot string is removed.

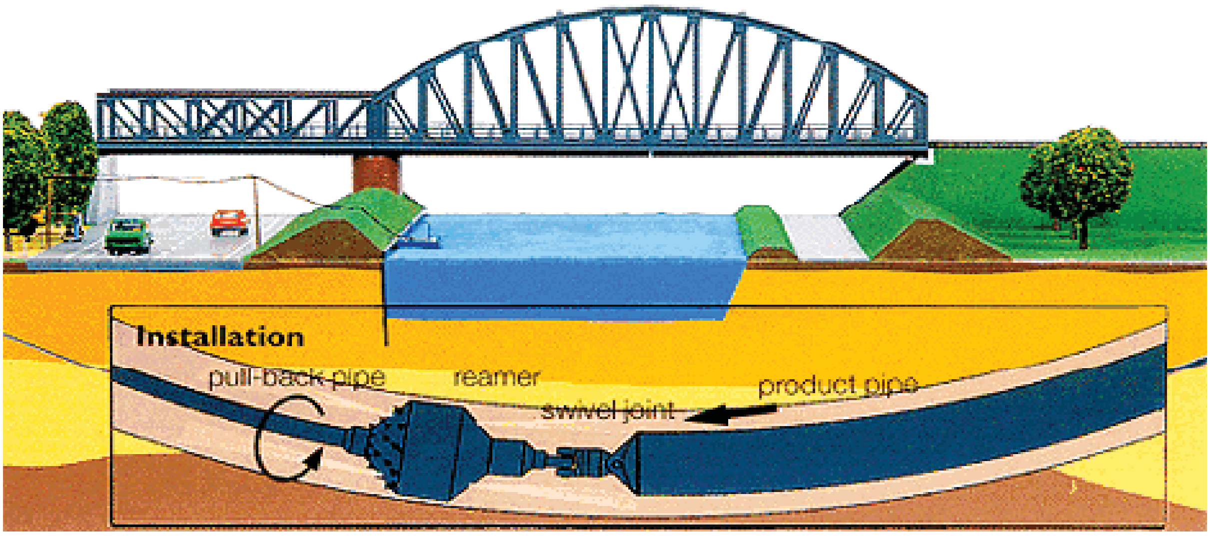
Enlarging the hole. Pre-reaming operations are carried out to enlarge the drilled hole to a size suitable for accepting the product pipe. Pull-back pipe is added behind the reamer. Depending upon the pipe diameter to be installed several pre-reaming operations may be necessary, each progressively enlarging the hole.

Installing the pipe. The pull-back pipe is connected to a 'cleaning' reamer which in turn connects to a swivel joint, (to prevent pipe rotation) that is attached to the pipeline towhead. The drill rig is then used to pull the product pipe into the preformed hole. The drilling fluid consisting of water and clay minerals will remain in the annulus and protect the pipe.

Figure 3.30: Typical Directional Drilling Procedure (http://www.lmrdrilling.co.uk/intro.html)







Site set up

The directional drilling rig is set up on an appropriate landward site and the directional drill is commenced from the land site position to the target point on the shoreline. The target point on the shore would be the end point of the directional drill and the entry point for the subsea cable into the conduit which would be inserted into the drilled hole. For most directional drill sites where a duct is being installed to receive cables from an offshore wind farm, the footprint of the land site would typically be 30m x 30m in area.

Drilling procedure

The procedure basically consists of drilling out to the target position and then pulling a duct pipe back through the drilled hole.

A small diameter pilot hole is drilled under directional control along a predetermined path using a mud-motor or jet bit on the end of the pilot string. The pilot string is drilled up to 80 metres in length, before the washover pipe is advanced in rotary mode until it is approximately 30 metres behind the drill bit. Alternate pilot string and drilling operations take place until the exit point is reached. The smaller pilot string is then removed. If necessary, pre-reaming operations are carried out with pull back pipe added behind the reamer to enlarge the drilled hole to a size suitable for accepting the duct pipe.

A pull-back pipe is connected to a 'cleaning' reamer which in turn connects to a swivel joint, (to prevent pipe rotation) that is attached to a pipeline towhead. The drill rig is then used to pull the duct pipe into the pre-drilled hole. Drilling fluid is used to lubricate the process which consists of water and clay minerals which will remain in the annulus and protect the pipe.

Cable pulling and jointing

After the drilling procedure has installed a duct for the cable path, the cable can be pulled up through the duct and connected in a joint transition pit.

For an offshore wind farm, the export cables would be laid up to the exit point of the duct on the beach and connected to the pulling line which would have been pre-installed through the duct created by the directional drilling. The line would then be used to pull the cable through the duct and a mobile winch unit is required to provide the pull force. When the cable end reaches the joint transition pit it is strain connected (to safeguard the future integrity of the cable joint) to a fixed point in the joint transition pit and the cable joint is made between the subsea cable and the land section of cable.

Site restoration

Following the completion of the drilling and cable pulling operations the land site would be restored and the joint transition pit would be secured with locks on the entry point to the pit with a security fence around the joint transition pit. Access to the joint transition pit is retained for the operational life of an offshore wind farm to secure a maintenance capability on the joint.

3.8.7 CABLE BURIAL IN MOBILE SEABEDS

The burial of subsea cables in areas where the seabed sediments are mobile has always posed a significant technical challenge to the cable installation industry to ensure that the cables remain fully protected for their design operational life.

If a subsea cable is buried along the longitudinal line of a mobile seabed area, such as a sandwave area, there is a high probability that sections of the cable may become exposed as a consequence of moving seabed sediments. Experience gained from the post installation surveys of subsea telecommunications cables has shown that sections of cable which may have been left surface laid during the initial installation have subsequently been re-buried by the movement of sandwaves, whilst at the same time previously buried sections of cable have been exposed.

In order to mitigate the effects of mobile sediments, deeper cable burial is often specified. This solution may work where the amplitude of the sandwaves are relatively low (typical 1m to 1.5m). However in areas where the amplitudes are much higher, deeper burial will not be possible on a practical basis. Furthermore, if deeper burial is attempted in these areas there would be a potential for a significant impact on the local environment.

To successfully mitigate the effects of mobile sediment seabeds, the only effective method is to undertake accurate and detailed surveys and to carefully plan the cable route to avoid any potential problems. The survey data should provide detailed bathymetric, geophysical and geotechnical information and the results of this survey should then be reviewed against historical chart data to ascertain any evidence of the mobility of the seabed in the area where the cables are planned to be buried.

With all survey and historical data to hand, a detailed cable route risk assessment can be completed. This will identify the optimum route for the cables and may well involve a complete route diversion to avoid mobile sediments such as sandbanks etc. The subsea cables can also be routed to follow the troughs of any major sandwaves or sandbanks such that any movement of sands would result in mobile sediments being deposited over the cables as opposed to exposing them. However, future accessibility of the cables for any potential repair or maintenance activities needs to be considered if such a policy is adopted.

3.8.8 CROSSING NAVIGATION CHANNELS

When the planned cable routing for the export cables requires a crossing of either an existing navigable channel or a proposed route for a navigable channel, it is necessary to install the cables to a suitable reference elevation to protect the cables from any future planned dredging operations along the line of the channel. There are two options which are commonly employed.

Option 1 – the pre-excavation method

The pre-excavation method requires an initial pre-excavation across the navigable channel before the export cables are installed. Export cables would then be buried using a subsea cable plough (or possibly a trenching vehicle) which will pass over the recently pre-excavated channel, during the cable lay procedure. It is anticipated that the cable crossing corridor across the channel would be up to 50m wide per cable and this section of the channel would be the only area subject to local excavation.

Excavation would either be achieved by use of conventional grab dredging equipment or by using specialised remotely controlled underwater excavation machines which are used for localised excavation. **Figure 3.31** (Option 1) shows the profile of the anticipated locally excavated section. In the example provided, the local excavation would have the objective of lowering the seabed level from reference Elevation +8.5m down to reference Elevation -10.5m.

Following the completion of the local excavation, a subsea cable plough or trenching vehicle would then traverse across the locally excavated section cutting the 1m depth of trench and simultaneously burying the cable to this target depth during the cable lay procedure. This will then ensure a target cable installation to reference Elevation -11.5m.

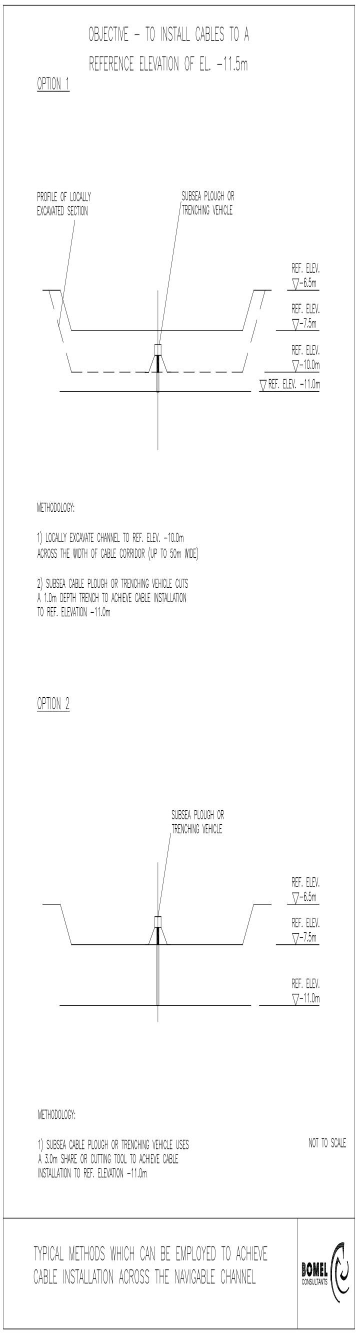
Option 2 – deep burial with plough or trenching machine

In order to avoid any pre-excavation across the navigable channel it may be possible to utilise a subsea plough or trenching vehicle fitted with either a deep burial plough share or cutting tool. The burial machine would be deployed to the full penetration depth of 3m when the plough or trenching unit traverses across the navigable channel. The same burial machine would then revert to the standard target depth of burial for the remainder of the export cable route.

Figure 3.31 (Option 2) shows the concept of deeper burial either using a subsea plough or the trenching vehicle.

The likelihood of success of this methodology would be dependent upon the local geotechnical conditions which exist at the point of the crossing of the navigable channel. These conditions would be verified by local site investigation prior to any installation activities commencing.

Figure 3.31: Methods to Achieve Cable Installation to Reference Elevation -11.5m across the Navigable Channel



3.8.9 BLASTING THROUGH ROCK

Blasting through rock has not been included in this review as an alternative cable protection methodology as it would be discounted on the grounds of high cost and significant impact to the environment. Where rock was encountered at a cable landing zone, horizontal directional drilling would be the preferred cable protection method. Further offshore, either a rock ripping plough, rock wheel cutter or a vibratory share plough would be used.

3.9 Cable Protection for Offshore Wind Farm Developments

This section of the report focuses specifically on the various cable protection methods which are relevant to the offshore wind farm industry. This section also includes feedback from cable installation works which have been completed on a number of UK Round 1 offshore wind farms.

Cable burial will be the primary cable protection methodology for the export cables which connect the wind farm to the shore and for the inter-array cables which connect the offshore WTGs to each other and inter-arrays. **Section 3.9.1** reviews the cable burial methodologies which were presented in **Section 3.8** and notes which of these techniques are most relevant for offshore wind farms. The type of cable burial machine which is used on any offshore wind farm project will always be determined by the seabed conditions which exist at the site, the choice of contractor who is selected to undertake the installation work and the availability of appropriate cable burial machines.

All of the alternative cable protection methodologies which were described in **Section 3.8.6** could potentially be employed on offshore wind farm subsea cables.

3.9.1 CABLE BURIAL OPTIONS FOR OFFSHORE WIND FARMS

Within **Section 3.8**, four separate types of cable burial machine were identified, namely:

- Cable burial ploughs;
- Tracked cable burial machines;
- Free swimming ROVs with cable burial capability; and
- Burial sleds.

Table 3.14 provides a summary of each of the above in terms of their relevance and potential application for the burial of offshore wind farm subsea cables.

Table 3.15 provides further guidance for each burial device (with the optional configurations of varying burial tools on such devices) on what performance each option is likely to achieve in various seabed sediments. It must be stressed that this qualitative approach is somewhat subjective as within each defined burial device category there will be varying performances linked to the power capability of any given device.

Table 3.14: Particular Relevance for Cable Burial Machines for Offshore Wind Farms

Cable Burial Machine	Burial Machine Options	Relevance for Offshore Wind Farms
Cable Burial Ploughs	Cable ploughs are available in varying types: ● Conventional narrow share cable ploughs ● Advanced cable ploughs ● Modular cable ploughs ● Rock ripping ploughs ● Vibrating share ploughs	All types of cable burial ploughs could be employed for the burial of cables on offshore wind farms. The type of plough employed will be determined by the nature of the seabed conditions. It is more likely that the cable ploughs will be used on the export cable routes as the lengths of cable are more suited to the burial method.
Tracked Cable Burial Machines	Tracked cable burial machines can be equipped with the following burial tools: ● Jetting systems ● Rock wheel cutters ● Chain excavators ● Dredging systems	Tracked cable burial machines could be used for the burial of the export cables, but are more likely to be employed for the burial of the inter-array cables for offshore wind farms. The type of tracked cable burial machine will be determined by the nature of the seabed conditions. Those fitted with jetting systems only will be limited to work in sandy and soft clay seabeds whilst those with mechanical cutting tools will have an extended range of use.
Free Swimming ROVs with Cable Burial Capability	Free swimming ROVs can be equipped with the following burial tools: ● Jetting systems ● Dredging systems	It is unlikely that free swimming ROVs equipped with a cable burial capability would be widely used for the burial of subsea cables on offshore wind farms. These machines are more commonly used in deeper water applications and when an intervention task such as a repair is required.
Burial Sleds	Burial sleds can be equipped with the following burial tools: ● Jetting systems ● Rock wheel cutters ● Chain excavators ● Dredging systems	Burial sleds are typically used for shallow water work and usually require diver assistance for the loading and unloading of cable. They may be utilised for the shore section of wind farm export cables but are unlikely to be used extensively for all cable systems for offshore wind farms as they tend to be less productive and responsive than their tracked cable burial machine counterparts.

Table 3.15: Guidance on the performance of burial devices (with burial device options) in various seabed sediments

Cable Burial Devices	Burial Device Options	Sediment Type					
		Sands	Silts	Gravel	Weak Clays	Stiff Clays	Rock
Cable Burial Ploughs	Conventional narrow share cable ploughs	✓	✓	✓	✓	✓	✗
	Advanced cable ploughs	✓	✓	✓	✓	✓	✗
	Modular cable ploughs	✓	✓	✓	✓	✓	✗
	Rock ripping ploughs	✓	✓	✓	✓	✓	✓
	Vibrating share ploughs	✓	✓	✓	✓	✓	✓
Tracked Cable Burial Devices	Jetting systems	✓	✓	?	✓	✗	✗
	Rock wheel cutters	P	P	P	✓	✓	✓
	Chain excavators	P	P	✓	✓	✓	✗
	Dredging systems	✓	?	?	✗	✗	✗
Free Swimming ROVs with Cable Burial Capability	Jetting systems	✓	✓	?	✓	✗	✗
	Dredging systems	✓	?	?	✗	✗	✗
Burial Sleds	Jetting systems	✓	✓	?	✓	✗	✗
	Rock wheel cutters	P	P	P	✓	✓	✓
	Chain excavators	P	P	✓	✓	✓	✗
	Dredging systems	✓	?	?	✗	✗	✗

KEY

✓	=	Should be capable of burial.
?	=	Performance will be related to the type of sediment and the power delivery to the burial device.
P	=	Performance possible in the sediment type but not an ideal application.
✗	=	Unlikely to be capable of burial.

Cable burial for offshore wind farms is usually undertaken using a barge which is specifically mobilised with cable handling and burial equipment. The same barge will also be equipped with a number of heavy duty tow winches which are capable of deploying a six or eight point anchor system to provide stability during cable burial operations. An anchor handling vessel is independently used to lift and place anchors in order to allow the cable installation barge to appropriately reposition itself as the burial works progress.

In circumstances where the cable installation barge is the host vessel for cable burial operation using a towed subsea plough, the anchors are deployed in such a manner which allows the barge to tow the plough whilst hauling on the deployed anchor array until such time as the slack is taken up on the anchor wires and the anchors have to be repositioned. The frequency of change of anchor positions will be dependent on a number of factors such as water depth, predicted tow forces and the size of barge etc. However, as a typical guide on a number of wind farm projects undertaken to date, a burial length of between 100m and 200m has typically been achieved on a single set of anchor deployments before the anchors have to be repositioned. The deployment of anchors must be carefully monitored and controlled whilst in the vicinity of other cable or pipeline systems as would typically occur at a pipeline or cable crossing location to avoid any potential damage to such existing infrastructure.

3.9.2 CABLE CORRIDORS FOR EXPORT CABLES

It is standard practice for the export cables from an offshore wind farm to be consented to be installed within a cable corridor. The cable corridor may typically be 500m to 600m wide of the centreline of the planned cable route and provides the wind farm developer and cable installation contractor a degree of flexibility to cope with the following:

- Avoidance of any localised obstructions such as wrecks etc. which do not appear on Admiralty Charts but are discovered in later surveys specific to the project;
- Localised areas of difficult ground conditions where burial may prove difficult. For example small rock outcrops, boulder formations or glacial till outcrops; and
- Routing of cables within the corridor limits to follow the troughs of sandwaves in areas where mobile seabeds are known to exist.

3.9.3 CABLE INSTALLATION ON OFFSHORE WIND FARMS TO DATE

This section of the report contains cable installation information for offshore wind farms which have been installed to date. It should be noted that only limited information was available for a number of sites listed in **Table 3.16**. Supplementary information has been obtained from additional news items and data published on websites and with reference to articles which have appeared in the technical press. Therefore, the assembled data is a collection of market information from a wide variety of sources.

Table 3.16: Cable Installation Experience and Feedback on Recently Installed Offshore Wind Farms

Wind Farm	Cable Route	Soil Conditions	Burial Depth and Method	Feedback Information (where available)
Arklow Bank	Export Cables	Superficial sediments overlying harder sediments which are believed to possibly be glacial till.	A subsea cable plough was used to bury the export cables.	It is understood that surveys undertaken post installation indicated localised exposures of cables. This was possibly caused by scouring of the superficial sediments adjacent to the bank. It is also understood that the export cable suffered a fault resulting from an anchor contact with a repair being completed within one week. Further cable protection methods are under consideration.
Nysted (Denmark)	Export Cables and Inter-Array Cables	It is believed there are a variety of seabed conditions across the site.	A variety of installation techniques were employed. Jetting was used in areas of looser substrates which included sands, silts and clays with shear stress less than 75kPa. Pre-trenching and backfilling was used to cut through areas of harder substrate with back-hoe excavators working from a shallow water jack-up barge.	It is understood that the cable installation and burial were successfully completed. However, the burial operations took a considerable period of time owing to poor weather. The offshore spread does not appear to be particularly weather resistant potentially which explains the apparently protracted operations.
Horns Rev	Inter-Array Cables	-	-	It is understood that the installation contractor encountered difficulties whilst installing and burying the inter-array cables. It is thought that the wave climate proved problematic during the installation operations and it is believed that divers were subsequently employed to bury the cables which were left exposed, particularly close to the offshore structures.

Wind Farm	Cable Route	Soil Conditions	Burial Depth and Method	Feedback Information (where available)
North Hoyle	Export Cables	Close to the wind farm there were stiff clays associated with glacial till. However, the vast majority of the route consisted of sands and gravels.	A Sea Stallion subsea cable plough with a 2m burial depth capability was employed to achieve a target burial depth of 1.5m.	The installation work proceeded well without any problems. One of cables was installed from the shore to the wind farm and the other cable installed from the wind farm to the shore. Both cables crossed the BHP owned pipeline to the Hamilton offshore facility. Concrete mattresses were used to separate and protect the cables at the crossing and diver intervention was required to bury the sections of cable from the edge of the mattresses to the termination points of ploughing operations.
	Inter-Array Cables	The array on the east side of the wind farm had stiff clays associated with glacial till. The remainder of the site consisted of sands and gravels.	The LBT1 trencher was used which simultaneously laid and buried the inter-array sections of cable to a target burial depth of 1m.	The LBT1 is equipped with a forward mechanical cutting tool which sits in front of the main jetting unit for cable burial. It achieved good burial across the majority of the site apart from when working in the stiff clays on the eastern array where burial was only possible in the softer sediments. The LBT1 also has to overrun the cable line to allow the final cable end to be pulled in the J-tube. This typically leaves a 50m section of cable unburied close to the second WTG structure. Diver techniques were used to bury these sections of cable and this resulted in the burial works being carried over into a second season following the main installation of the offshore wind farm.

Wind Farm	Cable Route	Soil Conditions	Burial Depth and Method	Feedback Information (where available)
Scroby Sands	Export Cables	Mostly sands along the export cable route.	Burial was undertaken using a Sea Stallion plough which had been modified to achieve a target depth of burial of 3m.	It is understood that all three export cables were generally buried to the target depth of burial of 3m and this deep burial requirement was a permit requirement based on EMF and its effect on migratory fish as well as concerns with mobile sands. The second export cable had to be cut during the installation due to adverse weather, an offshore joint was subsequently introduced and the repair splice buried with post lay burial techniques.
	Inter-Array Cables	Mostly sands along the inter-array cable route.	Burial was undertaken using a Sea Stallion plough which had been modified to achieve a target depth of burial of 3m.	It is understood that some inter-array cables have become exposed as a consequence of scour around the base of the offshore structures. It is also believed that remedial rock dumping has been undertaken but the results of this subsequent intervention are unknown.
Kentish Flats	Export Cables	-	The export cables were buried using the Global Marine owned Hi-Plough.	The Hi-Plough was fitted with jetting equipment to reduce tow forces during installation. However, the jetting system was not utilised, partly owing to concerns with respect to suspended sediments affecting local shell fish beds and fish spawning grounds. Sediment load downstream of plough operations was monitored and the limits imposed by CEFAS for increase in sediment load over background levels were not breached at any time during operations.
	Inter-Array Cables	-	The inter-array cables were buried using the Global Marine Otter tracked vehicle in jetting mode.	Difficulties in burial operation were encountered where the cable installation had crossed spud depressions from the main installation vessel – Mayflower Resolution. Generally the work appears to have been successfully completed without any major incidents.

Wind Farm	Cable Route	Soil Conditions	Burial Depth and Method	Feedback Information (where available)
Barrow Wind Farm	Export Cables	Gravels and glacial tills.	Subsea cable plough.	A subsea cable plough was used to bury both the export cables. During the installation of one of the cables an operational incident occurred in which the plough overran and damaged the cable which resulted in the need for an offshore joint.

3.10 Burial Assessment and General Survey Techniques

Burial assessment survey (BAS) techniques are commonly employed by the subsea telecommunications industry. A BAS survey is conducted along the proposed corridor for the installation of the subsea cable to provide an advance indication of the likely seabed conditions which will be encountered during cable burial operations. The survey will also give further confirmation of the seabed topography.

The BAS survey will be complementary to the other surveys which are commonly employed along the potential planned cable route. These surveys would comprise:

- Geophysical survey – to establish the bathymetry and seabed profile and also identify any potential hazards along the proposed cable route.
- Geotechnical survey – this will usually consist of vibrocores and cone penetration tests (CPT) along the cable route to establish the viability of cable burial. Boreholes are not usually undertaken as they are expensive and the cable installer is only interested in data for the top 2m to 3m of seabed and the CPT and vibrocore data adequately provides this data.

The BAS survey is usually undertaken using a burial assessment survey tool which is normally a scaled down simplified version of a narrow share cable plough. The BAS tool is pulled along the route of the proposed cable well in advance of the scheduled cable installation work as part of the pre-survey operations. The BAS tool provides real time data obtained for the penetration of the tool into the seabed. This includes the towing resistance of the tool, pitch and roll data, plus sonar and visual data if camera systems are fitted to the tool.

In certain cases the burial assessment tool can be a simple grappling hook, although the feedback results are not as precise as those obtained from the plough-like BAS tool. The data is still meaningful in that it provides an indication of the potential difficulties in cutting a trench into the seabed. All BAS tools have the added advantage of clearing the route of any unchartered debris such as disused or out of service cables or discarded anchor chain or wire. This creates scars on the seabed, the persistence of which will depend on the local seabed conditions. In coarse sands and gravels the grappling hooks will penetrate to a depth of up to 1m and infilling of the resulting scar will occur almost instantaneously (EMU Ltd, 2004). In coarser grounds, the grappling scars will be more persistent; cobbles will be displaced and overturned.

The data from the burial assessment survey is then used to generate a burial protection index (BPI) for the complete cable route. The BPI takes into account all of the potential hazards to the cable system and assesses the results from all survey data, including the BAS survey. The BPI is then used to design the type of armouring along the cable route, i.e. rock armour, double armour or single armour and to derive a burial depth which will take into account the safety of the cable system whilst ensuring an environmentally friendly and cost effective installation.

By assessing the BPI correctly for the complete route of the cable, projects can expect routes with a varying burial depth requirement. This may result in burial depths varying from 0.5m to 2.0m along the route. The subsea telecommunications industry (and the cable installation contractors working within this industry) have established that it is far better to only bury cables to the minimum depth required rather than comply with a global target burial for the complete system length. A significant number of the cable installation contractors who work in the offshore wind farm industry have experience with the subsea telecommunications industry and they are lobbying to have a transfer of technology so that the lessons learnt can be applied for offshore wind farms in UK waters. The argument which states why try to embed a cable down to 3.0m if the cable is safe and has been buried with an acceptable burial method to 1.0m is compelling and deserving of serious consideration.

There is a real possibility that BAS surveys may become part of the survey regime for offshore wind farms. Therefore, the environmental impacts of a BAS survey may need to be considered as part of future consenting requirements. However, as the BAS tool will generally be a scaled down version of the primary burial tool intended for the actual burial works, there are no different environmental effects other than those already described for the primary burial tools. The only difference is that the BAS tool will make a first pass along the route in advance of the primary burial tool completing the installation of the subsea cable.

3.11 Decommissioning

The Energy Act has not yet provided any clear guidance on the legislation related to the decommissioning of offshore wind farms. However, it is almost certain that all of the offshore structures would have to be removed to the seabed (partial removal). The nacelle and towers would be removed in reverse operation to construction using a heavy life vessel. Cables would be disconnected after being isolated offshore and pulled out of the J-tubes.

It is probable that the subsea cables would be left buried and notified as being disused or out of service. The reason being that to de-bury the installed subsea cables is likely to result in a significant disturbance to the seabed. If cables are only buried to a shallow depth in sandy seabed, an under-runner can be used to de-bury the cable. This device is put on the cable and as the name suggests 'under runs' the cable while being towed from a line from a host vessel. This procedure, however will not work for deeper buried cables as is commonly associated with offshore wind farms (1.0m and deeper), especially when the cables are effectively buried in clays, gravels, chalk etc. Therefore, de-burial would involve the use of significant subsea plant (as yet not commercially available to the market on a significant scale) using aggressive methods such as cutting large open trenches to access the buried cables.

Certain sections of cable would be removed for a decommissioned offshore wind farm. This would include both the beach section of cable down to the low water point and the sections of cables close to the offshore WTGs before full depth of burial is achieved away from the J-tubes on the structures. It is difficult to predict if cables would be fully removed at any disused cable or pipeline crossing. The crossing point is likely to consist of concrete mattresses or similar. Over the course of time this construction is likely to have formed an artificial reef; to remove the crossing construction would therefore have a negative impact on the subsea environment local to the crossing point.

4 Physical change

4.1 Introduction

The purpose of this section is to describe and, as far as is possible, quantify the fate of sediment disturbed when the cable burial techniques described in **Section 3** are employed in a range of varying seabed conditions. It addresses the physical nature of the change but not the potential effect on parameters which is covered in **Section 5.**

The key parameters that will affect the volume of seabed sediment disturbed, brought into suspension, dispersed in the surrounding sea area and finally re-deposited on the seabed during cable burial operations are:

- The cable technique being used; and
- The site conditions i.e. seabed type, tidal and wave conditions.

This appreciation of the extent of the physical disturbance resulting from cable burial operations enables the environmental impacts discussed in **Section 5** to be placed in context.

The main parts of this section cover:

- **Section 4.2** outlines the site conditions that can influence the type of equipment necessary for cable burial.
- **Section 4.3** discusses the level of sediment disturbance that is likely to occur when cable burial is undertaken with the range of techniques discussed in Section 3 and the ground conditions defined in **Section 4.2**.
- **Section 4.5** discusses the dispersal and re-deposition or settlement of sediment brought into suspension. This section also covers methods available to quantify the dispersal and settlement and discusses recent experience from the UK offshore wind farm industry.

4.2 Site Conditions

4.2.1 SEABED CONDITIONS

The geology and geomorphological characteristics of the seabed will determine the type of sediment disturbed during the cable burial operations and will also have a significant influence on the type of equipment used for these operations. A good understanding of seabed conditions is, therefore, required for engineering planning and to assess the environmental impacts of the burial operations.

The ground conditions that will be encountered during cable burial may comprise a range of material sizes from fine to coarse sediments and rock. To aid understanding and provide consistency, soil and rock types discussed throughout the report are defined in **Table 4.1**. This is based on the soil classification produced by the Permanent International Association of Navigation Congresses (PIANC) and reproduced in BS 6349, Part 5.

Table 4.1: Classification of ground conditions

Type	Particle Size and Characteristics
Clays	Cohesive Less than 0.002mm Exhibits strong cohesion and plasticity Can vary from Very Soft (shear strength less than 20kN/m2) to Hard (shear strength greater than 150kN/m2)
Silts	Can range in size from 0.002mm (fine) to 0.06mm (coarse) Some cohesive strength, non plastic or low plasticity
Sands	Can range in size from 0.06mm (fine) to 2mm (coarse) Cohesionless Can vary in strength between loose, dense and cemented
Gravels	Can range in size from 2mm (fine) to 60mm (coarse) Cohesionless Strength generally loose but possible to find cemented gravels
Boulders/cobbles	Can range in size from 60mm to 200mm (coarse) Cohesionless Strength loose
Rock	Sedimentary (including Chalk), Igneous, Metamorphic Can vary from Very Weak (Compressive strength ,<1.25MN/m2) to Extremely Strong (>200MN/m2) Structured or unstructured/structureless (See Section 4.3)

4.2.2 TIDES

An understanding of the tidal conditions at the site is essential to assess the fate of sediment brought into suspension during cable burial operations. Tidal flows will transport suspended sediment away from the cable route. The time the sediment will remain in suspension is largely determined by the particle size, with coarse sediments (sand and gravels) re-depositing on the seabed relatively quickly and finer sediments (silts, clays and chalk particles) remaining in suspension for a greater length of time. The extent of the seabed over which the sediment is re-deposited is largely determined by the strength of the tidal currents. The stronger the tidal currents, the greater the excursion of a suspended sediment particle and, therefore, the extent of the seabed that will be subject to re-deposition. However, with sediment dispersed over a larger footprint than on more moderate tidal flows, the depth of deposited sediment is likely to be less.

4.2.3 WAVES

Wave conditions may affect the fate of suspended sediment. Their influence is, however, likely to be secondary to the tidal conditions as water depths along the majority of the cable route are likely to be such that tidal processes are the primary forces driving sediment movement. Wave data will primarily be required for the planning of the offshore cable installation works rather than to assess the fate of disturbed sediment.

4.3 Level of Sediment Disturbance

The level to which the seabed is disturbed is primarily related to the nature of the ground and the type of tool selected to bury the cable. The type of device used to support the tool is likely to have a secondary influence.

This section discusses the application of the cable burial tools described in **Section 3** in the range of ground conditions described in **Section 4.2**. The following cable burial tools have been considered:

- Ploughs: Simple; Advanced Jetting; Deep Burial; Rock Ripping; Vibrating
- Jetting: Fluidisation; Erosion
- Dredging
- Rock Wheel Cutter
- Mechanical Chain Excavator

The section covers the likely effect of these systems in terms of the level of disturbance to the seabed. **Section 4.3.5** attempts to quantify this disturbance by ranking the effects of the cable burial systems and provides limited advice on the calculation of the volume of sediment disturbed and brought into suspension.

4.3.1 PLOUGHING

Cable ploughs (**Section 3.8.2**) are generally used in sand, silt, all types of clay and weak rock such as structureless chalk, which generally consists of sand to cobble-sized fragments in a matrix of silt. They can also be used in harder rock if the plough is fitted with a rock penetrating tooth, or in chalk and gravel beds if a vibrating plough share is used.

The controlled operation by which cable ploughs work, “displacing” the sediment into which the cable is lowered, followed by the natural backfilling of the trench ensures that soil disturbance is kept to a minimum, and also minimises mixing between soil particles and the surrounding water. The type of soil most susceptible to mixing with water during ploughing is silt, because silt possesses no internal cohesion and the particles are small enough to be eroded by gentle water turbulence. Silt may remain in suspension for days giving the current chance to transport the sediment some distance away from the trench.

Structureless chalk, as for silty soils, is also susceptible to mixing and dispersion in the surrounding sea water during ploughing.

4.3.2 JETTING SYSTEMS

Jetting systems are one of the most commonly employed cable burial tools used by tracked vehicles (**Section 3.8.3**), ROVs (**Section 3.8.4**), and burial sleds (**Section 3.8.5**). The mechanisms employed by jetting systems for developing a trench will largely depend on the soil type.

Cohesionless soils

In cohesionless soils, the soil can be liquefied or fluidised with jets at relatively low pressures (i.e. low jet exit velocities). Liquefaction or fluidisation occurs when the pore water pressures in the soil become equal to the total overburden stresses, reducing the effective stresses to zero. In both cases, the soil particles and water behave very much like a dense fluid. However, there is a distinct difference in the two conditions. In liquefaction, the volume and bulk density is more or less constant (Ishihara, 1993). In fluidisation, the water content is increased and the soil structure is completely broken down to give a material of lower density. An increase in the jet flow rate at low jet pressures simply causes an increase in the volume of the liquefied/fluidised soil (N.B. an increase in flow rate at constant pressure can only be achieved by increasing the total nozzle area). If the jet pressure/velocity is increased, the velocity of the fluid flowing over the surface of the soil will increase until eventually the soil particles are lifted off and transported away from the soil mass as suspended sediment. This is the process of erosion or scour.

A trench in cohesionless soil is thus created by a process of erosion/scour. Jetting systems are sometimes used in combination with a dredging system to increase the rate of removal of soil (see **Section 4.3.3**). The problem with liquefaction in cohesionless soil is that the trench walls collapse and flow back into the trench. This means that a lot of soil has to be removed before there is a significant increase in trench depth. The final trench shape in cohesionless soils tends to have very gentle sloping sides (Lincoln, 1985). It may require several passes before a trench is created with sufficient depth.

Due to the difficulty in forming a trench in cohesionless soils, some jetting systems do not even attempt to create one. The “fluidisation train” used for burying offshore pipelines in cohesionless soils is one such example (Boom, 1976). The train works by fluidising the soil beneath a pipe so that the pipe can sink under the combined weight of itself and the train. Water is injected into the soil around the pipe at relatively low pressure, which is just enough to cause fluidisation but not necessarily erosion.

The likely effects will depend on which mechanisms take place. If a trench is formed by erosion, a substantial amount of material may be transported away from the trench area as suspended sediment. The extent to which the sediment will be spread is dependent on the current velocity and the particle size. For example, coarse sand and gravel will settle out on the seabed very close the trench, especially in a slack current. In contrast, silt and fine sand will remain in suspension longer, and could be transported for a significant distance in a strong current.

If the jetting system only fluidises the soil to allow the cable to sink through it, the impact will be negligible, since there will be no sediment displacement.

Cohesive soils

Liquefaction/fluidisation is a principal mechanism in the breaking up of cohesionless soils during water jetting because the pore pressures in the soil mass are able to respond relatively quickly to the increase in water pressures caused by the jets. In contrast, in cohesive soils (clays), the response is relatively slow, by which time the soil has been broken up by a different mechanism.

In cohesive soils, the general erosive potential is much reduced due to the cohesive bonds between particles (Dunn, 1959; Flaxman, 1963). However, localised erosion and scour enables the jets to begin to form cuts in the solid material. Each jet tends to cut its own slot based on the various directions of the jets. The rate at which this cutting process takes place depends on the soil strength and the jet velocity/pressure at the cutting face (Lincoln, 1985). However, in very soft clays the jets may erode soil in a similar mechanism to that for sand. As the jetting proceeds, the high water pressures in the cut slots rapidly cause hydraulic fractures to develop (Hubbert & Willis, 1957; Jaworski *et al.*, 1981; Murdoch, 1993). These develop along planes of weakness and have a tendency to propagate perpendicular to the direction of minimum principal stress. Propagation may therefore be expected in both vertical and horizontal directions according to the depth of the jet slot. It is probable that most propagation will be in the vertical plane causing cracking and failure of the forward face.

In stiff or hard clays, certain jetting systems utilise a number of high pressure jets which are used to cut sections of the clay face. These are combined with lower pressure jets on the same jetting tool to then 'break up' the fractured clay face.

As the jetting system advances, the inward pointing jets, particularly at the base, will further break up the already broken lumps of soil and finalise the cutting of a complete trench, provided the progress is sufficiently slow. If an attempt is made to advance the system too quickly, the jetting tool will come into contact or near contact with the soil face and the tow force will significantly increase.

Normally, a dredging system needs to be used in combination with the jetting system in firm to hard clays, otherwise it is very difficult to remove the cut material away to form a trench. However, even when a dredging system is also used, some weakened material and lumps of disturbed soil will remain on the bottom of the trench to receive the pipe or cable as it is lowered into the trench by the forward movement of the burial device. The depth of pipe or cable sinkage will depend on the size, number and remoulded shear strength of the soil lumps.

Although the trench will be wider than the jet tubes, due to outward pointing jets, this will be limited by the smaller separation normally required between the jetting system and the cutting face in cohesive soils. In many instances where a high power jetting system has been deployed in a hard soil seabed the trench width will be close to the spacing of the jet tubes. The trench sides will stand vertically for all but the very softest clays, although it will be broken and irregular due to the jet slotting action and the effects of hydraulic fracture.

In very soft to soft clays, much of the soil will be eroded and mixed with the surrounding seawater. Clay sized particles will remain in suspension much longer than sand or silt sized particles, and could be transported long distances by the prevailing current. However, this means that when the sediment is eventually re-deposited on the seabed, the thickness of deposition will be very small.

In firm to hard clays, most of the soil will be broken into sizeable lumps before it can be completely eroded. The lumps would need to be removed by a dredging system in order to form a trench. Even in strong currents, the heavy weight of the lumps will ensure that they are deposited close to the trench. This means that the thickness of deposition may be large, but the extent only very limited and localised adjacent to the trench.

Weak rocks (including chalk)

Only jetting systems which have a very high power delivery will have any impact on weak and fractured rock seabed. It is very rare for a subsea jetting system to be deployed to attempt to cut trenches into a rocky seabed.

The mechanisms for forming a trench with a jetting system in weak rocks will be a combination of those that take place in cohesive and cohesionless soils. In structured rock, the mechanisms will be very similar to those in hard cohesive soil, with fluidisation being non-existent, erosion very localised, and rock break-up being dominated by hydraulic fracturing. In unstructured rock that easily breaks down into small hard fragments, both erosion and hydraulic fracture will dominate, with fluidisation contributing where the fragments are small.

The mechanisms for chalk will depend on the grade and density of the material. Structureless Grade D chalk will probably behave like a cohesionless material with the silt matrix becoming easily suspended in water by the processes of erosion. Since structureless chalk typically has a large range of particle sizes (from silt-size to cobble-size), it may not be possible to fluidise the material sufficiently to enable a cable to sink without losing a substantial proportion of the finer material to erosion. Structured Grade A chalk would behave like a hard clay, with hydraulic fracture occurring very easily along existing fracture joints. However, it would be difficult to break the chalk into smaller blocks than already exist *in situ*, especially in medium to high density chalks. A dredging system used in combination with the jetting system would have difficulties in removing large rock fragments to create a trench.

In most weak rocks including structured medium to high density chalk, other trenching systems will be more suitable, such as a plough with rock penetrating tooth or a rock wheel cutter.

In structured weak rocks, the material would be mainly fractured/cut into sizeable blocks before much of the material could be eroded or fluidised. In this case, any trench would have to be formed by a dredging system, which would lift the blocks and deposit them adjacent to the trench. In structured soft, fine-grained rocks, such as chalk, there will also be some disintegration of the rock into its constituent components, and this material could become suspended in the surrounding water and transported by the current some distance from the trench. However, as mentioned earlier, jetting is highly unlikely to be used for trenching in structured rocks.

In structureless rocks, the material would be broken down into a wide range of particle sizes from clay or silt-size up to boulder-size. The clay to fine sand-size particles will become easily suspended in the water and transported long distances by the current. The larger sizes, that could only be removed using a dredging system, would be deposited close to the trench. As such, the impact will be a combination of the impacts for cohesionless and cohesive soils.

4.3.3 DREDGING SYSTEMS

Dredging systems used on tracked cable burial machines (**Section 3.8.3**), ROVs (**Section 3.8.4**) and burial sleds (**Section 3.8.5**) can be used for a range of soil types including sand, silt and certain clays. However, the larger the particle size, the harder it is to move material in a slurry suspension. Dredging systems remove soil to create a trench by a process of suction. The suction tubes are sometimes referred to as eductors. The educted soil is normally “blown” into the surrounding sea to the sides of the trench, where it is also transported as suspended sediment by the current until it settles out on the seabed. Dredging systems work best when the soil is in a slurry state. For this reason they are normally used in combination with a jetting system that is used to fluidise the soil prior to dredging.

Dredging systems can remove the soil material and deposit it on a barge or, more conveniently, disperse the sediment into the sea away from the trench. The dispersal distance and thickness of deposition will depend on the particle size and current speed, in the same way as for eroded materials. The impact that the dispersed sediment makes on the local aquatic environment will depend on how well adapted the marine life is to this type of sediment deposition.

4.3.4 ROCK WHEEL CUTTERS AND CHAIN EXCAVATORS

In hard clays and rock, mechanical chain excavators or rock wheel cutters (**Section 3.8.3**) are often used to create a cable trench. In these materials, a narrow slot is formed into which the cable is lowered. The action of cutting the rock or hard clay causes the material to be broken down into its constituent components, such as sand for sandstone, and silt for siltstone, limestone or chalk. In order to form an open slot the loose material has to be removed. This material naturally mixes with and becomes suspended in the surrounding seawater. Due to the protection provided by the hard ground, the slot does not need to be very deep, typically only 0.5-1.0m.

Chain excavators are also sometimes used in sands and gravels. The movement of the chain fluidises the granular soil in the vicinity of the cutter, forming a low resistance "slot" for the cable to be pushed through. In this case, because the soil is being fluidised without an open slot being formed, the disturbed material can and does largely remain contained within the ground. Thus, the amount of sediment becoming dispersed is minimal.

The effect of using chain excavators or rock wheel cutters in hard clay or rock is to disperse clay to sand sized particles into the surrounding seawater. However, the mass of the suspended sediment will be limited by the size of the cut slot. This suspended sediment will be transported away from the trench to some distance dependent on the particle size and current velocity.

4.3.5 QUANTIFICATION OF DISTURBANCE

Ranking disturbance

An attempt has been made to rank the level of seabed disturbance resulting from cable burial operations discussed above. The results of this exercise are presented in **Tables 4.2** and **4.3** where a ranking from 1 to 10 has been adopted with 1 indicating a low level of disturbance and 10 a high level of disturbance. Inevitably the tables present a simplification of a complex process but, nevertheless, provide a broad indication of the level of disturbance that is likely to occur when cabling burial operations take place in a range of seabed types. It is also worth noting that other seabed interventions such as offshore dredging or certain forms of aggressive fishing which filter the upper layer of seabed would have significantly higher rankings (see **Table 4.4**).

Table 4.2: Level of sediment disturbance arising from use of plough types in different ground conditions

Plough Type	Ground Conditions					
	Sand	Silts	Gravels	Clay	Unstructured Rock – Matrix Material	Weak Rock (Chalk)
Conventional Narrow Blade	1	1	1	1	N/A	N/A
Advanced with Jetting	2	3	2	2	2	N/A
Deep Burial	1	1	1	1	1	N/A
Rock Ripping	1	1	1	1	1	4
Vibrating	1	2	1	1	2	6

Level of disturbance 1 = Low, 10 = High, N/A = Not applicable

Table 4.3: Level of sediment disturbance arising from use of other burial tools in different ground conditions

Tool		Ground Conditions						
		Sand	Silts	Gravels	Clay	Unstructured Rock	Chalk	Structured Rock
Jetting	Fluidisation	2	2	N/A	N/A	N/A	N/A	N/A
	Erosion	3	4	3	3	N/A	N/A	N/A
Dredging		4	6	4	N/A	N/A	N/A	N/A
Rock Wheel		3	4	3	3	3	8	4
Mechanical Chain Excavators		3	4	3	3	3	N/A	N/A

Level of disturbance 1 = Low, 10 = High, N/A = Not applicable

Quantification

There is very limited research and advice on the quantification of the volume of material that is disturbed and brought into suspension by cable burial operations. In the absence of detailed information conservative assumptions will need to be made for the following parameters:

- Volume of material disturbed;
- Rate of sediment release into the water column; and
- Vertical distribution of suspended material throughout the water column.

An estimate of the rate at which sediment is disturbed can be made based on the size of the slot or trench created by the tool. For cutting tools the rate of sediment disturbed can be calculated based:

Depth of Deployment of Tool x Tool Width x Rate of Progress

A similar approach may be adopted for a plough but it should be appreciated that these tools displace rather than remove sediment from the seabed.

As an example, a wheel cutter tool 250mm wide forming a 1000mm deep trench at a rate of 250m/hour will cut 62m^3/hr. Reviewing evidence from land trials of these tools and also reviewing subsea video a reasonable estimate of only 10 to 15% of cut material will backfill into the trench with the remainder deposited at the sides of the cut trench or removed as suspended material.

In the absence of more specific information, it is reasonable to assume all fine sediment (clays, silts and sands) disturbed during the cable burial operations would be brought into suspension. The distribution of this sediment throughout the water column will depend upon the size of the particles and level of disturbance caused by the cable burial system. Although coarser sediments are also likely to be brought into suspension this material will quickly settle back to the seabed and is unlikely to be dispersed by tidal currents.

4.4 Seabed Disturbance by Other Activities

When considering the potential impact of cable installation as a whole, it is necessary to put these into context with other influencing factors including natural perturbations such as storm activity and other seabed users such as oil and gas installations and aggregate extraction, both of which cause disturbance to the seabed. The main impact associated with cable installation relates to the physical disturbance of seabed and the subsequent creation of a sediment plume. These impacts are however localised in nature and are, in general, one-off, short-term effects, with the seabed usually returning to its original state. When compared with the area affected by other activities, the spatial extent of cable installation is very small. **Table 4.4** provides an indication of the extent of physical disturbance caused by other seabed uses in the UK continental shelf. At certain sites the cumulative and in-combination effects with other activities and projects will need to be considered during the assessment process in order to determine the overall effect on existing environmental parameters.

Table 4.4: Examples of physical disturbance of the seabed by seabed uses

Activity	Spatial Extent / Unit Area	Reference/Source
Deep water		
UK Offshore pipelines	5084km length of pipeline installed; giving total length of 5847km (assuming a 15% contingency for interlink pipelines)	Ongoing research by Bomel Ltd. on behalf of HSE
UK Oil and gas installations	240 offshore platforms 180,000 m^2 (assuming average plan area of 30 m x 25 m x 240 offshore platforms)	Ongoing research by Bomel Ltd on behalf of HSE
Shallow water		
UK Aggregate extraction (for 2005)	134 km^2 (area actually dredged) 1257km^2 (licensed) 21.2 m tonnes	Crown Estate (2005)
UK Dredging disposal (for 2004)	310 km^2 (licensed) 30.1 m tonnes (wet tonnage disposed)	Cefas (pers. comm.)

4.5 Dispersal and Re-Deposition of Sediment

4.5.1 METHODS

Once the sediment has been lifted into suspension it will disperse under the action of the tidal flows. The strength of these currents and the dispersion and settling characteristics of the suspended sediment will determine the footprint over which the sediment will be deposited.

Sands and gravels disturbed during the cable burial operations will settle back to the seabed very rapidly and the footprint is unlikely to extend any great distance from the cable route. Silts, clay and chalk particles will remain in suspension for a greater period of time and will be dispersed over a much greater distance, depending upon the strength of the tidal currents. However, the depth of deposition over such a large area is likely to be small.

Relatively simple dispersion and deposition calculations can be undertaken to assess the magnitude of the problem based on tidal flow data presented in the form of "tidal diamonds" on published Admiralty charts or measurements from the site. Alternatively more sophisticated methods may be adopted using sediment dispersion models to track the movement of sediment particles. Such models require tidal flow inputs from hydrodynamic models.

When calculating the predicted physical changes it is important that the changes are put into context with natural and other anthropogenic changes that occur. The effect of the physical change on receptors within the footprint of change will be dependent on a number of factors including the ambient levels of suspended sediment and the degree of variation throughout the year, for example during storm events. If the natural levels of suspended sediment and the seasonal variation are high then the degree of impact is likely to be less. There is considerable variation in the natural and anthropogenic induced levels of suspended sediment around the UK coast. Suspended sediment concentration varies around the UK from 1-327 mg/l around the English coast and 1-227 mg/l around the Welsh Coast but annual mean values are typically 1-110 mg/l (Parr *et al.*, 1998; Cole *et al.*, 1999). Other areas, particularly near estuaries will have higher concentrations. In the study area of the proposed Sheringham Shoal Offshore Wind Farm off the north Norfolk coast (Scira, 2006), concentrations varied from 10mg/l to 30mg/l and between 30mg/l (in summer) to 60mg/l (in winter) for the study area for Thanet offshore wind farm, off the east Kent coast (Royal Haskoning, 2005). The variability in the ambient levels of suspended sediment and the seasonal variation that can be experienced mean that it is not possible to state what the potential effect of cabling could be on certain receptors.

In addition an area of seabed subject to disturbance already will be less affected by subsequent changes. In order to put the potential effects into context it should be considered against a number of other activities that occur within the marine environment, where studies have been completed to investigate potential and actual effects, e.g. aggregate extraction and fishing activity. Aggregate activity is a well controlled and monitored activity where levels of suspended sediment have been measured. There are a number of potential sources of increased suspended sediment concentrations including the release of material at the cutter or drag-head, overspill during hopper loading and sieving (which may be necessary in order to obtain an optimum sediment load). Of these potential sources the material suspended at the drag-head is the most likely to be similar to the material suspended during ploughing for cabling activities. Measurement of the plume generated by the movement of the drag-head alone have shown that the volume of sediment introduced into the water column is barely detectable and is in the order of 1% of the material introduced by screening and overflowing (Hitchcock *et al.,* 1998, John *et al.*, 2000). The scale of effect will obviously vary dependent on the sediment size and the relative amounts of overspilling/sieving undertaken but does provide a reasonable indication of the relative scale of effect when compared to aggregate extraction. It must also be borne in mind the temporary nature of the effect which is limited to one event (per cable) over a short time scale along with the immediate start of recovery of the seabed following disturbance.

The low levels of sediment that are mobilised during cable laying mean that there will be only low levels of deposition around the cable route. The finer material will generally remain in suspension for longer but will settle and remobilise on each tide with no measurable material left in place. Coarser sediments are expected to settle within a few metres of the cable route and following disturbance are likely to recover rapidly, given similar communities in the vicinity.

Case studies are provided below which illustrate some of the predicted physical changes resulting from cable laying activities. The resulting direct and indirect effects that could occur on the environmental characteristics are discussed in **Section 5**. **Section 5** also puts the potential environmental effects into context with other activities within the marine environment.

4.5.2 RECENT EXPERIENCE

Introduction

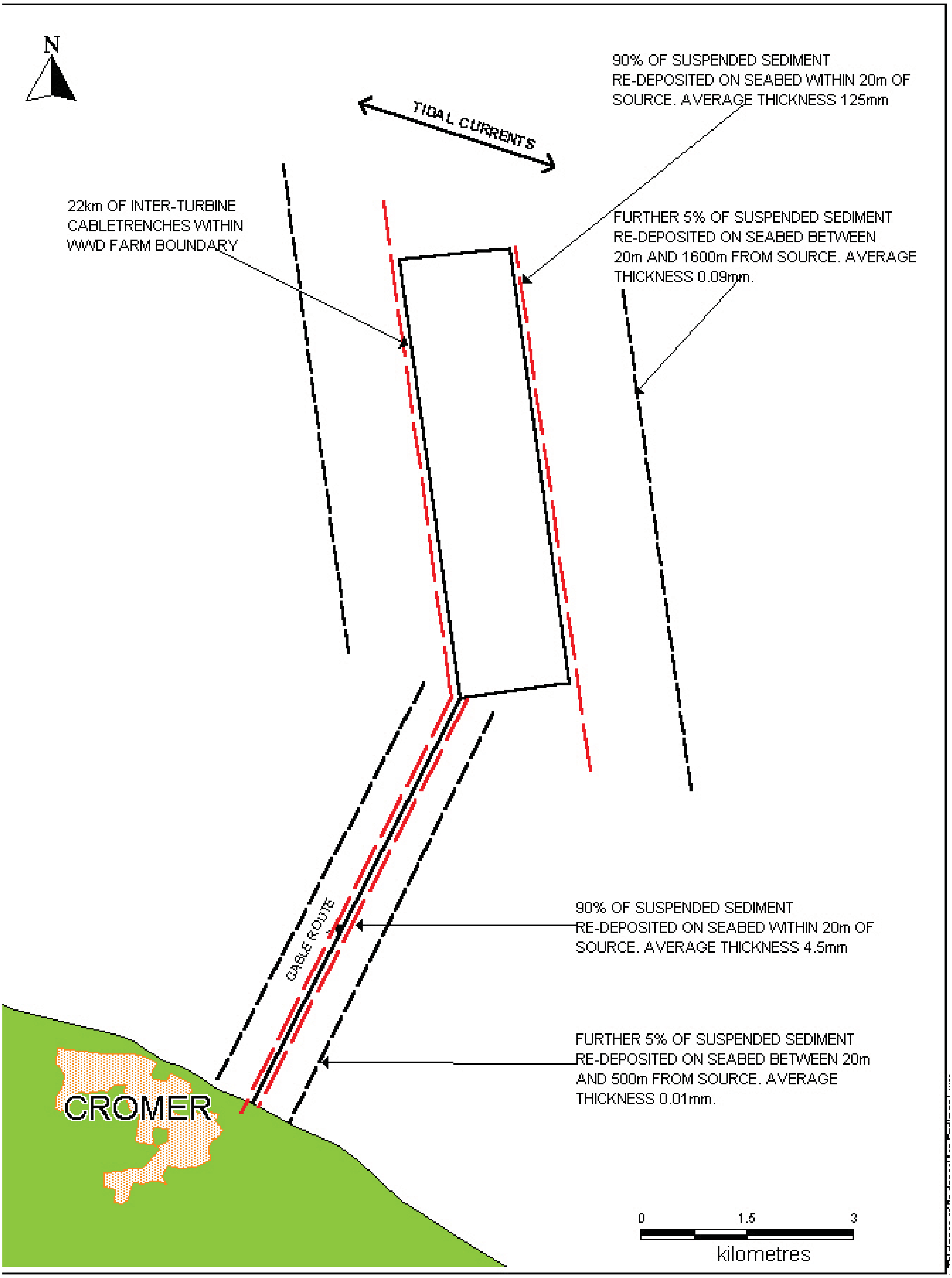
This section covers recent experience and case studies identified during the literature and data search completed for the study. As part of this search discussions were held with ABP Marine Environmental Research Ltd who, with Cefas and HR Wallingford, are undertaking RAG Sedimentation Theme Study SED01 – Review of Round 1 Sediment Process Monitoring Data – Lessons Learnt. The discussions were to ensure that any relevant data collected under SED01 was made available to this study.

Norfolk (Cromer) Offshore Wind Farm

As part of the environmental impact assessment for the Norfolk (Cromer) Offshore Wind Farm (Norfolk Offshore Wind, 2002) Royal Haskoning undertook an assessment of the fate of sediment released during ploughing operations in superficial silts, sands and gravels and the underlying boulder clay and chalk. An assessment of the relative proportions of the fine and coarse sediments was made based on seabed samples and the depths to consolidated materials. Advice was provided by Engineering Technology Applications Ltd. on the volume of material displaced during ploughing and, conservatively, it was assumed all this material was brought into suspension. An allowance was also made for the volume of sediment disturbed by the plough skids.

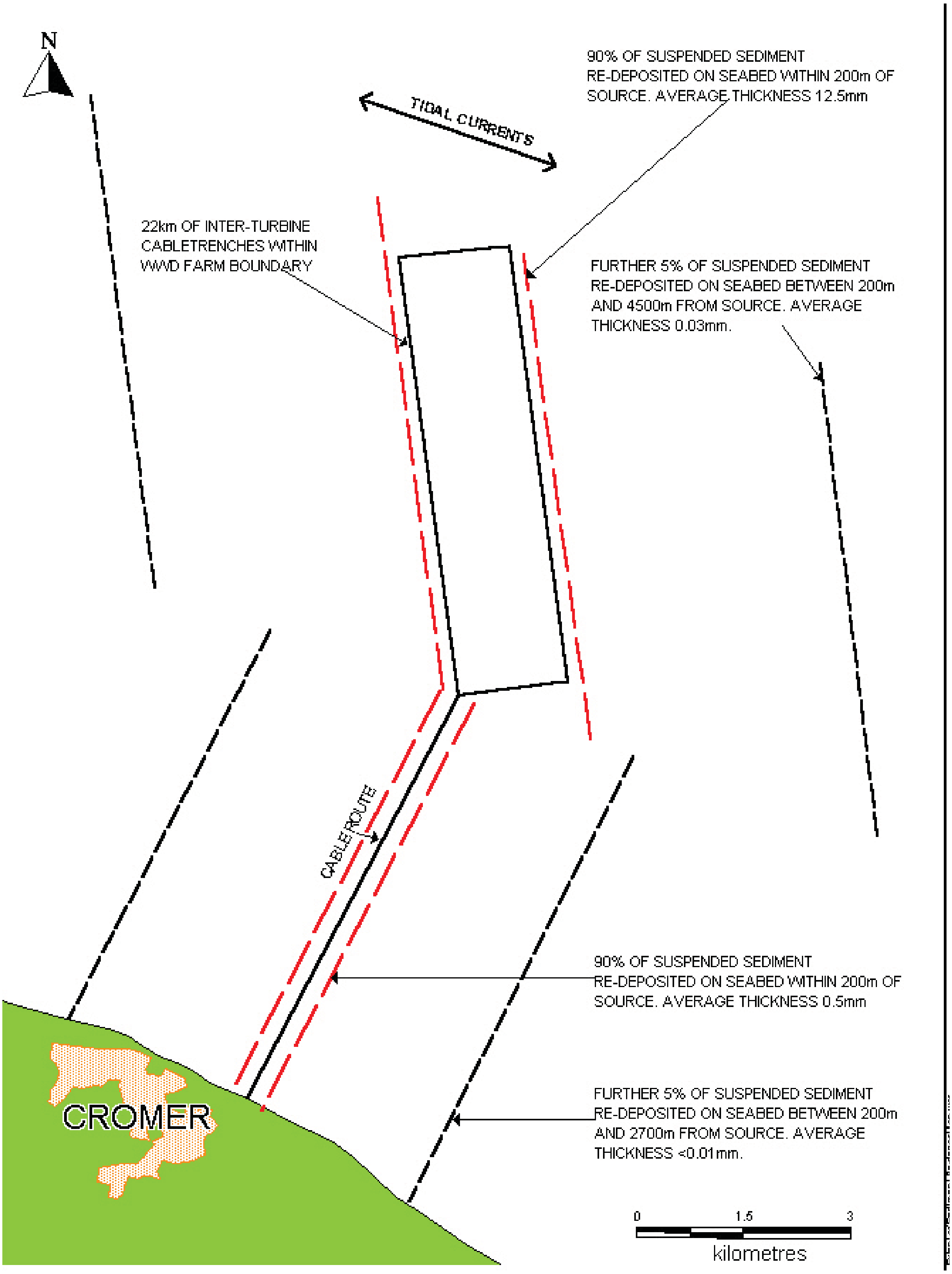
The re-deposition of the coarse sediment was assessed by considering settling velocities of the particles, tidal current speeds and the height of the release point. The calculations indicated that the footprint for the re-deposition of the coarse sediment was sensitive to both the tidal conditions (i.e. spring or neap) and the time of release within the tidal cycle. The results indicated that the largest deposition footprint but smallest depositional depth (200m either side of the cable with a deposition depth of a few millimetres) would occur with release at a mid spring tide. In contrast, the smallest footprint but greatest depth (20m either side of the cable with depth of approximately 10mm) occurred with release at high water neap (see **Figures 4.1** and **4.2**). For fine sediments it was considered that particles would disperse throughout the water column and background suspended sediments concentrations would only be raised by a few percent.

Figure 4.1: Maximum Thickness of Sediment Re-Deposition



(Norfolk Offshore Wind, 2002)

Figure 4.2: Maximum Extent of Sediment Re-Deposition



(Norfolk Offshore Wind, 2002)

Sheringham Shoal Offshore Wind Farm

A broadly similar approach was adopted by HR Wallingford, for the assessment of ploughing operations for the Sheringham Shoal Offshore Wind Farm. However, within the study a more sophisticated approach was adopted for the dispersion of fine sediment using the dispersion model SEDPLUME-RW. The model used the hydrodynamic output from a TELEMAC-2D flow model and the assumption of a logarithmic velocity profile through the water column to track the 3-dimensional movement of fine sediment particles (mobile surface layer comprising sandy gravel with less than 4% fines). The results indicated that dispersion of sediment was rapid with concentrations dropping to less than 1mg/l above background within a single flood or ebb excursion. It was noted that dispersion occurred at a slower rate on a neap tide than a spring tide because of the lower rate of turbulent diffusion with footprints 4km and 9km either side of the cable route. The scenarios included ploughing through chalk, ploughing through a silt/clay/sand mix and trenching through chalk.

For ploughing chalk during a neap tide, the dispersion footprint extends for around 9km in each direction, with concentrations dropping to levels of less than 1mg/l (above background) within a single flood or ebb excursion. For the spring tide simulation the higher turbulence causes the chalk concentrations to drop below 1mg/l (above background) within 4km of the cable route.

The results for fines arising from other bed types with high percentages of fines, the neap tide footprint extends less than 2km, while the spring tide footprint is very small. As before the neap tide footprint is larger due to the lower rate of turbulent diffusion. The extent of the footprint on both tides is less than that of chalk due to the lower amount of material available per metre length of cable and the settling of silt during periods of slacker flows (chalk is assumed to have zero settling). This result is applicable to much of the inter-turbine cabling within the wind farm site where there are no exposures of chalk.

The volume of material released by trenching through chalk is much higher, and therefore the extent and persistence of concentrations above 1mg/l is much greater. The predicted plume extends more than 10km in either direction at a level of up to 20mg/l (above background) on a neap tide. The model predicts a gradual drift of the plume towards the shore over the six tides, but that the plume has dispersed to less than 1mg/l concentration before the end of the model run.

The footprint of silt deposition was found to extend over a wide area, but at an undetectable rate. Even under slack water conditions, the maximum rate of deposition over the six tide simulation was less than 0.5mm in the areas of greatest deposition, and in most of the footprint area the rate was far less. This result is anticipated as the deposited fines will be re-suspended on each tide, with no measurable material left in place.

Dispersion and deposition of coarser sediment was not modelled as sand will only be carried a few metres from the point of disturbance. The sediment distribution of the unconsolidated surface layer in large parts of the area affected by the cabling is predominantly gravely sand with a small amount of silt.

The high sand/gravel content of the in situ sediment, together with the relatively small disturbance arising from cable ploughing or trenching to 1m depth, suggests that for most of the cable route the majority of any disturbed sediment will fall immediately to the bed in the immediate location of the cable. Because of the minimal disturbance, fine sand is almost all likely to remain within the bottom 1m -2m of the water column (even this is probably conservative) and typical settling velocities of around 10mm/s will ensure that the sand settles within half an hour (or less) or becomes part of the ambient near bed transport. Medium or coarse sand will settle within minutes. The vast majority of the disturbed sediment will initially resettle within 20m of the cable, with almost no sand being carried more than 100m from the cable except as part of the natural background transport.

The presence of surface sand/gravel along much of the cable route restricts the extent of fine sediment dispersion, and the modelled results are only applicable to those limited areas where chalk or other competent beds are exposed or have only a very thin surface layer of mobile sand. The plotted model results are therefore conservative for a 1m depth of burial, but still show that suspended sediment will be quickly dispersed. In the areas where the export cables are proposed to be buried up to 3m (shoals / sand waves) the cable is installed in (mobile) sands only, with no disturbance of the underlying chalk or other beds.

London Array Offshore Wind Farm

An assessment of the cabling operations for the London Array Offshore Wind Farm has been undertaken by ABP Mer (RPS, 2005). The work assumed that jetting techniques would be adopted and burial depths would be between 1 and 3m. An assessment of the surface sediments was based on a comprehensive grab sampling exercise supported by seismic and side-scan surveys. It was found that the inter-array and export routes were predominately covered with fine sands. In parallel with the assessment of seabed conditions, suspended sediment data was collated. This included data from the Southern North Sea Sediment Transport Study, archive data held at CEFAS and measurements taken specifically for the project.

Limited modelling was undertaken to quantify the impacts of the cabling operations. An assessment was completed based on the likely type and volume of sediment that would be disturbed, an assessment of the fall velocity of the disturbed sediment and the ambient tidal flows that would carry suspended sediment.

The assessment concluded that the fine sand disturbed during the cabling could typically be carried a distance of 1170m in the 30 minute period it would remain in suspension (based on peak flows). At other tidal conditions settlement would occur more rapidly and the distance fine sand would be carried would be significantly reduced. It was concluded that with the rapid dispersion of the sediment it was unlikely that concentrations would be measurable above the ambient conditions. Coarser sediments disturbed during the cabling operations would fall out of suspension in far shorter distances.

The conclusions from the study were supported with reference to monitoring at Nysted and Kentish Flats Offshore Wind Farms.

Nysted Offshore Wind Farm

During the construction of the Nysted Offshore Wind Farm in Denmark, strict requirements were imposed on the release of sediment from sea bed operations including the installation of the array cable. To ensure compliance with the requirements monitoring was undertaken and subsequently reported upon by Seacon (2005).

The wind farm is located in the Femer Belt separating Germany and Denmark and is approximately 2km from the coast in water depths between 6 and 9.5m. The surface sediments within the wind farm area are generally medium sands with very low silt/clay content. The thickness of the overlying sands varied between 0.5 and 3m, underlain with clay deposits.

Cable laying operations were undertaken using jetting where the substrates permitted and using pre-trenching and backfilling where hard substrates were encountered. The trenching operations were undertaken using a back hoe dredger rather than the more specialist systems described earlier in this section. Measurements of turbidity were taken continuously during the cabling operations and daily mean and maximum values determined. The jetting operations resulted in significantly less turbidity than the pre-trenching and backfilling operations with mean and maximum values at 200m from the various operations of:

Trenching	Mean = 14 mg/l Max = 75 mg/l
Backfilling	Mean = 5mg/l Max = 35mg/l
Jetting	Mean = 2mg/l Max = 18mg/l

These values compare with the restrictions set by the Danish Energy Agency of 15 mg/l as a mean value and 45 mg/l as a maximum value.

Seacon concluded that the higher rates of sediment release from the pre-trenching and backfilling was a result of the larger volume of sea bed strata disturbed during these operations and the fact that the material disturbed during trenching was lifted to the surface for inspection. This meant that the sediment was carried through the full water column before being placed alongside the trench. Although the trenching was undertaken using non-specialist equipment, a comparison of the monitoring results for the trenching and jetting operations at Nysted support the disturbance levels set in **Table 4.3** above.

Kentish Flats Offshore Wind Farm

For Kentish Flats, EMU Ltd undertook turbidity monitoring during the cable installation in fulfilment of the FEPA licence conditions (EMU Ltd., 2005). Background data was collected from October 2004 to the beginning of February 2005. During the cable burial operations site measurements were taken 500m down-tide of the three export cables which were laid using ploughs. The results of the monitoring showed:

- Marginal, short-term increases in background levels (approximately a 9% increase to the modal concentrations); and
- Peak concentrations occasionally reaching 140mg/l (equivalent to peaks in the natural concentrations driven by the tidal cycle).

These site observations support the broad conclusions from the modelling undertaken for the Cromer, Sheringham and London Array wind farms and suggest that the environmental effects of cabling methods are likely to be short-term and localised.

Cable Burial Operations at Lewis Bay, Nantucket Sound

In 2003 Applied Science Associates Inc undertook modelling simulations to estimate water column sediment concentration and sediment deposition resulting from the proposed embedment of submarine electricity cables in Lewis Bay, Nantucket Sound (Galagan *et al.*, 2003). SSFATE model simulations were completed to quantify these impacts for cables buried to a depth of 6ft in sand-sized marine sediments. It was assumed that a jetting device would be used to create a trapezoidal trench measuring 6ft across at the top, 2ft across at the bottom and 8ft deep. It was also assumed that 30% of the total sediment fluidised within the trench would be evenly distributed vertically throughout the overlying water column with the remaining 70% remaining within the limits of the trench. The maximum flood and ebb tide currents of 0.6ft/s with a water depth of 3.5ft was adopted within the modelling.

The modelling results indicate that sediment was re-deposited on the seabed within 200ft of the trench with a maximum depositional depth of around 25mm immediately adjacent to the cable route. The modelling also indicated that suspended sediment concentrations would reach a maximum value of 120 mg/l along the cable route and reduce to less than 20 mg/l within 1000ft of the cable route.

It is interesting to note that the results of the above modelling exercise completed in the USA are broadly in agreement with the modelling and site measurements discussed above for a number of wind farms in the UK.

4.5.3 CONCLUSIONS AND FURTHER RESEARCH

The findings from the studies undertaken for a number of UK offshore wind farms indicate that the disturbance to seabed sediments during cable burial operations are likely to be short term and relatively localised, particularly if ploughing techniques are employed. It is unlikely that cumulative or in-combination impacts will present significant problems because of the short term nature of the burial operations.

As noted earlier there is limited research and advice on the quantification of material arising from cable burial operations, particularly if jetting, dredging or cutting/excavating methods are adopted. This lack of base information on the release of sediment into suspension limits the benefits that could arise from the use of more sophisticated modelling techniques to establish the fate of released sediment. It is, therefore, suggested that this is an area where further research would be of value. It is appreciated that monitoring requirements included in FEPA licences for UK Round 1 and 2 offshore wind farms will provide valuable data for the quantification of the impacts of cable burial operations.

4.6 Mitigation Measures

The previous sections have discussed the influence of cable burial operations on sediment disturbance. In practice the main areas where mitigation measures can be adopted to reduce this disturbance are during the selection of the cable route and cable burial method. Both the route and burial methods adopted will be a balance between the engineering issues associated with the route corridor (see **Section 3.10** on the Burial Assessment Surveys) and the key environmental issues associated with the site. The range of environmental issues likely to be encountered is discussed in **Section 5**.

An appropriate level of site investigation (see **Section 4.2.1**) is an essential to ensure that the optimum route and burial methods are selected for the cable. The level of data gathered should be sufficient to provide confidence in the selected route and burial method and allow the assessment of the potential environmental impacts. It is at this stage that mitigation (e.g. re-routing) may be considered should the environmental impacts be significant. The completion of an appropriate level of site investigation in the early stages of the project will reduce the risks of delays during the consenting process and the risk of major changes in the later stages of a project. It will also allow a more strategic approach to be adopted for cable route planning and avoid the need for reactive or "firefighting" measures to deal with environmental and engineering issues.

Once the cable route and burial technique have been selected there are limited measures that can be adopted to reduce sediment disturbance. The precise timing of the works (e.g. over a spring or neap tide) and the speed at which the burial proceeds may have some influence over the sediment disturbance, however, these parameters are largely determined by operational constraints and it will generally not be possible to make significant changes in an attempt to reduce sediment disturbance.

5 Potential impacts and mitigation measures

5.1 Introduction

This section addresses the potential environmental impacts that could be experienced during cable installation activities, together with possible mitigation measures that can be used to minimise the magnitude and significance of effects. Although the length of the corridor for cable installation impacts can be long, the footprint of impact is narrow, generally restricted to 2-3m width, with certain methods of installation requiring the use of anchors (see **Section 3.9.1**).

The main impact associated with cable installation relates to the disturbance of sediment (**Section 4.3**) and the subsequent creation of a sediment plume. The disturbance is restricted to the area described above and the generation of a plume and subsequent settlement is localised, with the area affected dependent on geological and hydrodynamic characteristics. Although the scale of effect will be site specific it is important that the impact should be put into context with natural perturbations resulting from storm activity and other activities occurring in the vicinity including fisheries, aggregate extraction, and other sediment plume generating activities.

Impacts and mitigation measures are described and discussed for:

- Subtidal ecology;
- Intertidal habitats;
- Natural fish resource;
- Fisheries;
- Marine mammals;
- Ornithology;
- Shipping and navigation;
- Seascape and visual character; and
- Marine and coastal archaeology.

Discussion of impacts is divided into two categories:

- Potentially significant impacts – which are considered relevant to the installation of cables and could result in significant environmental effects; and where relevant
- Other impacts – which may be considered to be impacts by stakeholders but, are unlikely to cause significant effects.

Mitigation measures to avoid, reduce or minimise environmental effects have been cited along with a discussion on their effective implementation, where known. During the planning phases of a proposed offshore wind farm many of the potential impacts are reduced through good environmental management practices, including the avoidance of known sensitive sites or areas with high proportion of fines, chalk areas, sensitive areas for fish spawning, etc. These can occur where there is enough knowledge of the baseline environmental conditions. However, in other areas it is important that a degree of flexibility is present to enable certain mitigation measures to be applied, for example, seasonal restrictions and micro-siting of cable routes.

5.2 Subtidal Ecology

5.2.2 INTRODUCTION

Subtidal habitats likely to be encountered by cable routes include the following:

- bedrock and boulders;
- reefs;
- chalk;
- gravel and shingle beds;
- sand and mud (silts and clays) banks;
- maerl beds;
- seagrass beds; and
- biogenic reefs such as horse mussel beds *(Modiolus modiolus)*, and *Sabellaria spinulosa* (Ross worm) reefs (Johnston et al., 2002).

Potentially significant effects include:

- Seabed disturbance; and
- Increase in suspended sediment concentrations and subsequent settlement.

Other effects include:

- Potential contaminant release;
- Electro magnetic effects;
- Heating effects; and
- Cable coating effects.

5.2.2 POTENTIALLY SIGNIFICANT EFFECTS

Seabed disturbance

Some weeks prior to the installation of the cables, a cable burial assessment survey can be carried out (see previous **Section 3.10**). Disturbance to the seabed, leading to an alteration of habitat and associated species will occur during the burial assessment survey and during cable burial operations. Such impacts are likely to be limited to an area 2-3m either side of the cable, depending upon the size of the installation device used. In general, the range of installation devices available would have similar impact footprints, especially those that are tracked or have skids in contact with the seabed. Recovery of the seabed is, to some degree, dependent on the substrate that is left following installation.

Certain techniques will aid recovery by infilling the trench following cable placement. In respect to this potential impact, the action of a narrow blade conventional plough is expected to fulfil this criterion more than any other method of installation. With a narrow blade conventional plough, a wedge of soil is lifted, the cable placed at the base of the trench and then the displaced soil wedge is allowed to backfill naturally. Any other excavation method will disturb the sediment and not allow layers of sediment to be reinstated in the same sequence in their natural state. For example, mechanical cutter or jetting systems have aggressive cutting mechanisms which are used to cut open trenches.

Certain installation devices require the use of a vessel that utilises an anchor array to stabilise the cable laying vessel which would slightly increase the area of disturbance (see **Section 3.9.1**). As the vessel needs to move as the cable is laid, anchors are repositioned, increasing the area of potential impact.

Where cable crossing (see **Section 3.8.6**) is necessary there would be a requirement for the placement of cable protection measures such as concrete mattresses, which would cover a larger area, in the order of 150m^2 for each cable crossing. The exact area would depend on the specified requirements from the existing cable owner.

Installation of cables close to turbine foundations using either ploughs or remotely controlled tracked vehicles will always result in a short section of cable close to the J-tube exit points not being buried as a consequence of limitations in the cable burial procedure. A common solution for these short lengths of exposed cable (typically 10m to 15m) is to use either over covering concrete, frond mattresses or rock dumping. Rock dumping can be problematic, especially in and around sensitive habitats, as careful placement would be required in order to avoid unnecessary damage to habitats and species. Burial under the dumped rock would involve a permanent loss of habitat where the placement occurs. These rocks, similarly to all surfaces in contact with the sea, would be readily colonised by a range of fouling species, and may act to cause localised increases in biodiversity. However, artificial increases in biodiversity through the introduction of an essentially 'alien' substrate cannot be considered as a beneficial impact. As previously mentioned, another alternative is to use concrete or frond mattresses as a protective measure for cables. Frond mattresses will encourage the accumulation of sediment and, in an area that comprises soft sediments this is likely to be preferable as it is more in keeping with the natural environment.

Mobile species, in the vicinity of the cable route and inter-array area, may avoid the footprint of the impact. Sessile species, however, would be damaged or killed during excavation through direct contact with the installation device, burial and dislodgement. The significance of the impact would depend on a number of factors including:

- The nature and geology of the seabed where the cable is to be laid. The geology needs to be ascertained to at least the depth of cabling to ensure that where sediments overlay bedrock within the depth of cabling activity, the effect of cabling through all habitat types is assessed;
- The nature of the assemblage of species within the footprint of the works (e.g. species abundance, richness and diversity in the study area, and the value of this assemblage in the context of the wider seabed area within which the cabling operation is to occur); and
- The sensitivity, importance and recoverability of the species/communities including any seasonal variation e.g. spawning activity and over-wintering species.

In terms of the recovery of the seabed following disturbance, studies have shown that initial recolonisation takes place rapidly following a disturbance event with certain species returning almost immediately to the disturbed site. The length of time taken for recovery will be dependent on a number of characteristics including the nature of the seabed, the community types present, the duration and footprint of the proposed activity and the degree of disturbance already experienced at the site. There are a number of activities that can cause disturbance including severe storms, bottom fishing and aggregate extraction. Studies have shown that in shallow water and estuarine environments where disturbance is more frequent and opportunistic species are more likely to dominate the community structure, recovery occurs rapidly whereas in deeper water undisturbed areas the recovery to a more stable community could take many years. The degree of existing disturbance is therefore of importance in assessing this effect and in deeper water environments the impact of other activities, such as fishing, should be taken into consideration.

Rates of recovery of invertebrate communities appear to be associated with the rate of recovery of the seabed sediment characteristics. Experiments undertaken to record recovery given different intensities of disturbance revealed that when sediment was removed to a depth of 10cm recovery of the faunal component occurred within 64 days of the disturbance. However, when sediment was removed to 20cm depth, recovery was not complete until after 107 days but had occurred within 208 days of the disturbance. Thus recovery at more intensely disturbed sites took nearly twice as long. Nevertheless, the higher intensity disturbance did not have a significantly greater effect on the community than was found in the less intense disturbance (Dernie *et al.*, 2003). This implies that cabling could take longer still for recovery due to the depths of disturbance. However, cabling activity replaces the sediment, albeit in a different structure, and the majority of the communities are within the top 10-20cm of the sediment indicating that recovery may be influenced strongly when disturbance intensity changes between these depths but may not differ too much once disturbance occurs below this depth.

Studies have been undertaken in a number of habitat types in order to record recolonisation rates following dredging activity. The results of these studies are summarised in Newell *et al.*, 1998, and show variation in recovery times of between 3 weeks for freshwater semi liquid mud and 12 years (and >7 years) for sand-gravels (and coral reefs). Studies have shown that adult migration has been observed as the major mode of recolonisation (Savidge & Taghon, 1988; Thrush *et al.*, 1991). These recovery rates should however be put in context with the nature and extent of the disturbance compared to cable installation. Due to the localised nature of the cabling activity whereby the area affected is generally restricted to 2-3m width of substrate, the overall effect on the benthic ecology is not likely to be significant if the habitat distribution throughout the wider area is homogenous. However, if there are specific areas, directly in the path of the cable, where the habitats are not widely distributed and/or particularly sensitive to disturbance, then these will need to be avoided. One such example includes cable installation through areas of biogenic reef comprising of *Sabellaria spinulosa*, the reef building honeycomb worm. The reefs formed by the worm provide valuable habitat for many associated species and would be destroyed by cabling activity, albeit in very localised areas. They are also listed as a priority habitat under the EU Habitats Directive and specialised surveys are required in order to define the boundaries of the reef. Although these species have a high recoverability, their nature conservation importance means that any direct loss that damages the integrity of the reef structures or adversely affects their development would be considered as being of significance.

In summary, potential effects from disturbance on seabed habitats are 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 wedge is lifted by a ramp on the plough share, the cable is placed at the bottom of the trench and the wedge of soil then allowed to naturally backfill onto the cable. 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.

Suspended sediment

Impacts resulting from cabling include the release of sediment into suspension (see **Section 4.3**). This can have a number of effects on the benthic species inhabiting areas adjacent to the cabling activity. The significance of the impact will be dependent on the type of sediment, the hydrodynamic conditions and the sensitivity of the species affected in addition to the type of installation method.

The potential change in significance as a result of the type of sediment and hydrodynamic conditions is outlined in **Section 4.3.5** and summarised in **Tables 4.2** and **4.3.**

Increases in suspended sediment can affect filtering mechanisms of certain species, such as specific types of worm and brittle stars, through the clogging of gills or damage to feeding structures. Suspended sediment can also attach to fish eggs causing abnormalities or death. The sensitivity of the receptor is an important consideration when determining the significance of this effect. This includes its tolerance to a given effect, but also to its potential for recovery from such an effect (discussed in sub-section above). Its tolerance will be similar in all areas of the UK but will also depend to some extent on its adaptability to its ambient conditions. If a species has adapted to survive in a wide variety of conditions (such as in estuaries where suspended sediment concentrations (SSC) may be measured in grammes per litre), it is more likely to survive a small increase in SSC than a species which is exposed to a lower variation in SSC throughout the year. Information on the sensitivity (tolerance) of species should be obtained from published literature and consultation with relevant experts. Information can be found on the Marine Life Information Network (MarLIN) website (http://www.marlin.ac.uk) and the UK Marine SAC Programme website (http://www.ukmarinesac.org.uk/marine-communities.htm) that provide detailed information on the sensitivity/intolerance of many key features of the marine environment. However, it should be noted that the knowledge base for determining sensitivity of species is limited and research is needed to increase the confidence in such predictions. Many of the species in the marine environment are likely to have some degree of tolerance to increases in suspended sediment in order for them to adapt to natural perturbations and are therefore likely to survive localised short term effects.

A prolonged increase in suspended sediment concentrations can affect the penetration of light through the water column affecting the photosynthetic activity of macroalgae, phytoplankton and eel grass. This is unlikely, however, during the installation of cables, as suspended sediment is only a very localised short term effect.

As the material settles out of suspension, it can cause smothering to sensitive species and can change certain habitat characteristics. Studies outlined in **Section 4.5.2** show the potential for settlement in site specific situations and generally conclude that the extent of the settlement will depend on the factors outlined above but, in general, the effect is expected to be short term and localised with one example showing settlement ranging from 20m up to a maximum of 200m either side of the cable, dependent on the state of the tide (Norfolk Offshore Wind, 2002).

5.2.3 OTHER EFFECTS

Potential contamination due to sediment disturbance

Consideration must also be given to the potential for contaminant remobilisation during cable installation activities due to disturbance of contaminated sediments. It is, however, less likely that high levels of contamination would be encountered away from the coast, unless the cable passes close to a historic or active disposal site. The screening/scoping process will identify if the cable route is likely to encounter potentially contaminated sites; in which case it would normally be a requirement to undertake sediment analysis prior to decision making relating to this aspect.

Electro magnetic field generation

Submarine power cables can generate electro magnetic fields (EMF) in the surrounding seabed and water. The potential impact of EMF on fisheries is discussed in **Section 5.4.**

It is currently unknown which invertebrate species could be affected but magnetic sensitivity has been demonstrated for the following: Decapoda (*Crangon crangon*), Isopoda (*Idotea baltica*) and Amphipoda (*Talorchestia martensii* and *Talitrus saltator*) (Greater Gabbard Offshore Winds Ltd., 2005). In all cases, magnetic sensitivity is understood to be associated with orientation and direction finding ability such that the animal may become disorientated; depending on the magnitude and persistence of the confounding magnetic field the impact could be a trivial temporary change in swimming direction or a more serious impact on migration (Greater Gabbard Offshore Winds Ltd., 2005).

Although there has been no targeted monitoring specifically to investigate whether distributions of crustaceans and molluscs have been affected by the presence of submarine power cables and associated magnetic fields, monitoring to meet other specific objectives relating to offshore wind farms has not revealed any evidence to show such an effect. There are therefore uncertainties regarding the significance of this potential impact. However, it is not expected that the impact would be of significance, since the species that could be affected are known to be mobile and, as such, are able to avoid impacted areas. Generally the habitats that they inhabit are widespread and the effects of magnetic fields are usually highly localised around the cable.

Potential heating effects

The effect of radiated heat from cables buried in the seabed has been considered by the Connecticut Siting Council (CSC, 2001) as part of the 'Cross Sound Cable Interconnector' project, a high voltage DC buried cable system between New England and Long Island New York. The CSC estimated a rise in temperature at the seabed immediately above the buried cable of 0.19^{o}C and an associated increase in seawater temperature of 0.000006^{o}C.

The potential rise in temperature is therefore considered to be impossible to detect against natural fluctuations in the surrounding sediments.

Cable coating effects

The leaching of chemicals and substances from cable coatings and cable sheaths are likely to have a minimal impact on the surrounding environment. Burial of the cable will further reduce possible environmental effects. Research conducted on the environmental impact of a submarine cable used to transmit hydrophonic data to shore from an acoustic hydrophone array in Monterey Bay, California reported no apparent effect on infaunal abundance (Kogan *et al.*, 2003). Where the cable had become exposed, colonisation had occurred by encrusting species such as anemones, echinoderms and sponges (**Figure 5.1**), with fish congregating near the cable in places.

At present, no specific regulations or standards exist for submarine cable coatings with respect to environment impacts arising from their constituents

(UKCPC and Nexans Norway A/S, pers. comm.). However, cable manufacturers may be certified to ISO 14001 'Environmental System Management Certification' and as part of this certification, manufacturers are required to demonstrate effective ways to minimise environmental risks.

Figure 5.1: Submarine cable 3.2 cm wide colonised by *Metridium farcimen* anemones

(Kogan et al., 2003)

5.2.4 MITIGATION MEASURES

Where cable installation activities are proposed within sensitive locations and the significance of the impact is considered to be high it may be possible to mitigate the effect by altering the cable route or micro-siting of the cables to avoid localised areas. Micro-siting of the cables was a measure that was recommended in the ES for Thanet offshore wind farm in order to avoid dense aggregations of the reef-building worm *Sabellaria spinulosa* (Thanet Offshore Wind, 2005).

Baseline information on the distribution of sensitive habitats and species within the construction area can be effectively used to plan the positioning of anchor arrays. In this way, exclusion zones for anchoring can be established if necessary. Disturbance due to anchors can be further reduced by using tenders to lift the anchors rather than dragging them across the seabed.

Where there are species that are particularly sensitive to increases in suspended sediment occurring close to positions of cable burial, it is recommended that the technique that would result in the lowest release of sediment is utilised whenever this is possible.

It is important when installing cables through hard substrate that does not naturally infill following cable burial, such as bedrock, gravel, hard clays, that, when possible, techniques are used to back fill the material to ensure that a berm is not left. Backfilling the trench will ensure that species recovery occurs quicker and that obstacles are not left on the seabed. Utilising installation devices that possess depressors, designed to infill plough furrows, can effectively mitigate the impact and reduce the need for manual backfilling to occur.

5.3 Intertidal Habitats

5.3.1 INTRODUCTION

The main intertidal and shoreline habitats and communities likely to be encountered during export cable installation include:

- cliffs;
- estuaries;
- saltmarsh;
- bedrock and boulders;
- gravel and shingle shores;
- sand and mudflats;
- seagrass beds, and;
- biogenic (living) reefs such as mussel beds (*Mytilus edulis*) and the reef building worm, *Sabellaria alveolata* reefs.

Estuaries, saltmarshes, sand and mudflats have a high ecological value, often being important as feeding, roosting and nesting areas for waders and wildfowl. Chalk platforms and boulder shores are examples of important geological features and typically support a wide variety of algae and marine invertebrates, which are distributed in distinct zones related to tolerance to exposure and desiccation. Seagrass beds and biogenic reefs provide a habitat for a wide range of associated species and can increase habitat heterogeneity and biodiversity in otherwise impoverished areas. Many of these habitats will have designated status.

Potentially significant effects in the intertidal zone include:

- Seabed disturbance;
- Sediment mobilisation (including potential release of contaminants); and
- Settlement of material.

5.3.2 POTENTIALLY SIGNIFICANT EFFECTS

Seabed disturbance

Construction activities leading to disturbance will include provision of access for equipment and any specific preparations that may be necessary, such as the placement and excavation of anchors to assist the cable installation barge; construction of jointing chambers, removal of structures such as concrete facings on sea walls, breach of sea defence structures and excavation of trenches to the jointing chamber.

Disruption to intertidal habitats will occur within the construction corridor. The magnitude of direct disturbance is likely to be similar for all installation techniques (i.e. width of trench created) but will vary with width of the shore (see **Section 5.2.2**). The significance of the impact will largely depend on the environmental sensitivity of the area affected and is based on the following parameters:

- Habitat type and overall distribution within the localised area and wider environment;
- Recoverability of habitat and species;
- Importance of the habitat/species (i.e. protected status);
- Use of the area for feeding and/or roosting birds (see also **Section 5.7**); and
- Use of the area for fish spawning, nursery and/or feeding grounds (see also **Section 5.4**).

Intertidal habitats that are more sensitive to the impacts of cable burial are generally those that have established in more sheltered conditions, where natural perturbations are lower and less frequent. Such habitats include saltmarsh, mudflats, muddy gravel, bedrock, biogenic reef and eel grass beds. These habitats, in general take longer to recover from disturbance compared to those which are more dynamic and/or frequently disturbed such as sand flats, shingle beaches and mixed sediment habitats. Such dynamic habitats are likely to support a different assemblage of species which are better adapted to and more tolerant of frequent, short term disturbance, such as occurs naturally and is associated with cable installation.

The sensitivity of the intertidal environment can also display distinct temporal patterns, associated with seasons. Examples include use of the site by wading waterbirds and wildfowl during the over-wintering period (see **Section 5.7**), or being of seasonal importance to important life stages of fish and shellfish species (see **Section 5.4**).

Sediment mobilisation

In addition to direct disturbance, there are also issues relating to sediment mobilisation across the intertidal area. Cable installation within the intertidal zone is very likely to be undertaken during periods of low tide, and as such the potential for resuspension of material is reduced. Some of the disturbed material will, however enter into suspension during the flood tide but the extent of this will depend on the sediment type and cohesiveness. Resuspension of sediment is not likely to be of concern where cabling occurs within cohesive or coarse sediments, but can be significant when cabling is undertaken in non-cohesive fine sediments or chalks. Potential effects of suspended sediment are detailed in **Section 5.2.2**.

Within fine sediments there are also issues to consider in relation to potential contaminant release. Contaminants, such as oils and heavy metals, generally attach to fine sediments but certain chemicals can persist in coarser sediments. Disturbance of sediment can release associated contaminants into the water column. If contaminants reach a certain level they can cause effects on certain species or can bioaccumulate through the food chain. However, the effects of contaminant release on the environment tend to be localised and would only be of concern near industrialised areas. Investigation of potentially contaminated sites that may lie within the cable route would be considered during the screening and scoping phase. If nearby sites are identified where there is evidence of historic contamination, sediment sampling will be necessary in order to determine the level of concentration within the sediment. Predictions can then be made as to whether the release of contaminants could have an adverse effect.

Settlement of material

Settlement of suspended material has the potential for smothering to occur that could cause the burial of important or sensitive species and habitats (see **Section 5.2.2**). Given that the installation generally occurs during low tide, it is only likely to be the fine sediments that have been disturbed, which may become suspended in the water column during the flood tide.

5.3.3 MITIGATION MEASURES

Access to a site requires careful planning to avoid any sensitive features, which can be marked to ensure effective avoidance by construction plant and staff. Such features include rare or notable plants for example on shingle banks or saltmarsh, the presence of biogenic reef areas and the presence of important sessile (non-mobile) communities or species. Vegetated shingle areas should be avoided, or a process of translocation agreed.

Horizontal directional drilling (within **Section 3.8.6**) is an appropriate form of mitigation to avoid damage, particularly in the intertidal and landfall areas where habitats may be more sensitive (e.g. chalk cliffs, saltmarsh, etc.). This methodology has been proposed for the Thanet offshore wind farm due to the *inter alia* geological features of the area and the presence of saltmarsh habitat (Thanet Offshore Wind, 2005).

In order to promote recovery within the intertidal zone, material displaced as a result of cable burial activities should be back filled. This reduces the potential for remobilisation of sediments and enables recovery of benthic organisms to occur within a much quicker timescale. Where sensitive habitats (e.g. vegetated shingle, saltmarsh, etc.) are present along a cable route it may be necessary to remove vegetation prior to installation and replant/enhance following installation. Stabilisation techniques may also be necessary in certain conditions.

Guidance is available relating to translocation and enhancement for saltmarsh habitat in the Environment Agency/Defra publication 'The Saltmarsh Management Manual' (Environment Agency, 2005) and the Chartered Institute of Water and Environmental Management (CIWEM)/Royal Society for the Protection of Birds (RSPB) document 'The saltmarsh creation handbook: a project managers guide to the creation of saltmarsh and intertidal mudflat' (RSPB, 2005a).

5.4 Natural Fish Resource

The installation and burial of export and inter-array cables has the potential to impact upon the natural fish resource (finfish and shellfish) in a number of ways including:

- Habitat disturbance;
- Noise and vibration;
- Smothering and contamination; and
- Electro magnetic field generation.

5.4.1 POTENTIALLY SIGNIFICANT EFFECTS

Habitat disturbance

The following fisheries habitat types have the potential to be affected by the cable installation process:

- Spawning grounds;
- Nursery grounds;
- Feeding grounds;
- Over-wintering areas for crustaceans;
- Migration routes; and
- Shellfish beds.

Disturbance caused by the presence of installation vessels and equipment (and associated noise) will displace fish within the water column from the vicinity of operations. This is seen as a localised and temporary displacement of fish, which in isolation is generally not a significant impact on natural fish resources.

Most species of marine fish spawn in the water column and so changes to the seabed through the placement of a cable do not have severe long-term implications. However, disruption to the spawning of species that do utilise the seabed, such as Atlantic herring (*Clupea harengus*), sandeels (*Ammodytes tobianus)* and dogfish, should be minimised through alternative routing or timing to avoid spawning areas or periods respectively.

In general, CEFAS recommend that construction on or in the seabed should be carried out outside of the spawning season for substrate spawners e.g. February to April for spring spawning herring. As this is an important operating window, it may be prudent to determine the extent of spawning areas within the cable-laying corridor. In the absence of data regarding the importance of sites for spawning, additional studies may be required to determine whether mature fish in spawning condition are present in the area during the spawning season and/or whether eggs and larval stages are present (see CEFAS, 2004).

Nursery grounds (areas favoured by juvenile fish) are also important habitats, although in many locations such habitats may be widespread. If the cable pathway crosses through an important nursery ground, then the relative importance of the site to that region should be assessed.

As most fish species are relatively opportunistic predators, particular feeding areas are not well defined. However, some species of fish may congregate in certain areas at particular times of the year to feed on particular prey species. The routing and laying of the cable should therefore minimise disruption to such sites wherever possible.

Habitat disturbance can be a more significant issue to benthic (associated with the seabed) mobile fish resources such as many shellfish species. This is particularly relevant for areas which are important for certain shellfish life stages where there is reduced mobility, namely crustacean over-wintering areas and settlement areas for juvenile shellfish. Settlement areas are discussed further in '*Smothering*' section below.

The true extent of seasonal migration by many fish and shellfish species is becoming better understood. Again the severity of impact from cable installation activities is likely to increase for species that migrate across the seabed, namely crustacean species such as lobster (*Hommarus gammarus*), spider crab (*Hyas araneus*) and edible crab (*Cancer pagarus*). Routing and timing of cable-laying operations to avoid disruption to this seasonal activity may be required. For example, for the Norfolk (Cromer) Round 1 Offshore Wind Farm, mitigation cited in the Environmental Statement recommended that the export cable, which covered an inshore area believed to be important for "pairing" (or mating) of edible crab, should be installed outside this period (July-September) (Norfolk

Offshore Wind, 2002). The presence of this local crab fishery, which is considered to be of local and national importance, led to a FEPA consent condition requiring a crab surveillance programme to be formulated (Cefas, pers. comm.).

Molluscan shellfish species, such as king scallop (*Pecten maximus*), mussel (*Mytilus edulis*), native oyster (*Ostrea edulis*) and cockle (*Cerastoderma edule*), do exhibit avoidance behaviour over very short distances, but are less mobile than crustacean species and likely to be directly impacted by trenching operations. For most shellfish beds any resulting mortality along the width of the cable route is generally not a significant loss in relation to the remaining population. For small, isolated beds, however, the physical damage and disturbance from cable-laying operations can be significant.

Mussels settling on the seabed attach to surrounding hard surfaces, including other adjacent mussels. This behaviour can alter the seabed substrate with the formation of biogenic reefs. These reefs can extend over significant areas of seabed creating a rich habitat for other species as well as suitable habitat for further mussel settlement. Such reefs are widespread, but generally found in large shallow inlets and bays in estuarine areas (Holt *et al.*, 1998; BMT Cordah, 2003). Ploughing through these reefs can in some instances destabilise the reef by leaving exposed edges prone to damage by wave and current action. While biogenic reefs formed by *Mytilus* are found to be more tolerant of disturbance than other types of biogenic reef such as *Sabellaria* reefs (Holt *et al.*, 1998) (see **Section 5.3**), these species-rich habitats should be avoided where possible.

Noise & vibration

The potential impact of noise and vibration on the natural fish resource within the affected area will be largely dependant upon the 'hearing' sensitivity of the fish species concerned. In this context three main types of fish are recognised:

- Hearing specialists: These species, including herring and sprat, 'hear' sound through the acoustico-lateralis system; a collective term for the inner ear and lateral line. Sound vibrations are also detected by a gas-filled swim bladder which is connected to the inner ear via a gas duct;
- Hearing specialists with mid range sensitivity: These species, including cod, mackerel and salmon, are hearing specialists but are deemed less sensitive to noise, due largely to the lack of a gas duct between the inner ear and the swim bladder; and
- Non-hearing specialists: Typical species include flatfish such as dabs, plaice and sole and elasmobranchs such as dogfish. These species are non hearing specialists and do not possess a swim bladder.

Noise associated with cable laying will therefore impact upon hearing specialists to a greater extent. The effect of underwater noise on fish can be categorised as (Nedwell *et al.*, 2003):

- Primary effects: These include immediate or delayed **fatal injury** of animals near to powerful sources, such as the blast from underwater explosives;
- Secondary effects: These include **injuries and deafness** which may have long term implications for survival; and
- Tertiary effects: These are most likely to be associated with cable laying and include **avoidance of the area** which could have significant effects in the vicinity of breeding grounds, migratory routes or schooling areas.

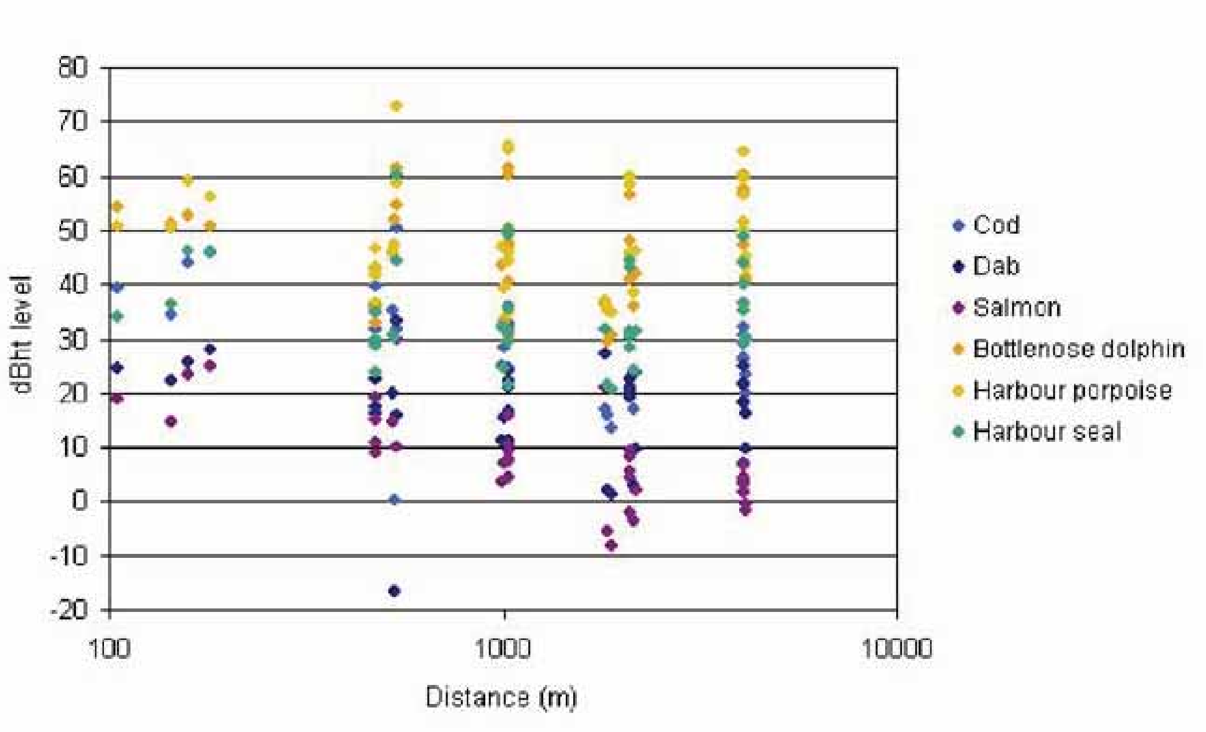
Nedwell *et al*. (2003, 2005) proposed a measure of sound that takes into account the differences between species in terms of hearing ability. This measurement is referred to as dB_{ht} (*Species*). The derivation of dB_{ht}(*species*) involves the measurement of sound passing through a filter that mimics the hearing ability of individual species and provides a species specific measurement of the likely level of perception of sound by the species. For a full description of the dB_{ht} (*Species*) measurement and the uncertainties involved in its application, the reader is directed to Nedwell *et al*. (2003, 2005). While the dB_{ht} (*Species*) approach is still being validated and reviewed, available information suggests that species of fish and marine mammals (see **Section 5.6.1**) will show a strong avoidance reaction to sound levels of 90 dB_{ht} and above. Strong avoidance by most individuals is likely to occur at 100 dB_{ht} with a mild avoidance reaction occurring in a minority of individuals at levels above 75 dB_{ht}. The effect of such impacts will be dependant upon a combination of factors including the type and magnitude of the noise along with the proximity of an organism to the source of the noise.

In the context of offshore wind farm construction, much of the work relating to the impact of noise upon species has focussed on the effect of pile driving, as this is by far the 'worst case scenario' in terms of the production of high intensity impulsive sound. Sound levels associated with cable installation have received considerably less attention and very little monitoring data is available.

Nedwell *et al*. (2003) have reported that cable trenching in sandy gravel at North Hoyle offshore wind farm produced noise at a source level of 178 dB re 1μPa @ 1m. However, when illustrating the dB_{ht} levels of the noise as a function of range, the following figure was produced.

Although based on some uncertainty, due to the high levels of variability in the noise produced, **Figure 5.2** clearly shows that, for each species the dB_{ht} level is below 90. In this situation, significant avoidance reactions amongst fish would not be expected to occur.

Figure 5.2: Cable burial noise (North Hoyle Offshore Wind Farm)



Source: After Nedwell *et al*., (2003)

The example in Nedwell *et al*. (2003) only covers one installation method in one type of substrate. It is possible that certain burial tools in certain seabed sediments may produce noise at a higher level than recorded at North Hoyle. Further information is required on the noise levels associated with other forms of cable installation before any clear guidance on the expected levels of associated disturbance to fish and/or mammals can be made. However, the early indications are that there is no significant impact from cable burial noise on fish species. In addition, no harmful events have been reported from the well established subsea telecommunications industry. For a more detailed assessment of the effects of man made noise on fish see Nedwell *et al*. (2003). For further information on noise effects on marine mammals see **Section 5.6.1.**

Turbidity

A reduction in light levels within the water column can create a number of adverse effects on fish and shellfish resources. Long term increases in turbidity will reduce the extent of the photic zone (the depth to which light can penetrate the water column) resulting in changes to flora and fauna. Cable laying operations result in temporary increases in suspended sediment which, while generally not sufficient to alter biotopes, will impact upon sensitive species or those reliant on certain levels of visibility.

Decreased visibility through increased concentrations of suspended sediments can affect predatory fish such as mackerel (*Scomber scombrus*) and turbot (*Psetta maxima*), which rely on vision to detect and locate prey, leading to decreased feeding efficiency. In addition many fish species such as herring rely on light levels to aid migration and shoaling behaviour. Low light levels caused by high levels of suspended sediment could impair the ability of species to shoal as part of migrations to spawning or feeding grounds. Studies described in **Section 4.4** indicate short term and localised increases in turbidity over a number of tidal cycles (for those cable installation methods investigated).

Smothering

The blanketing or smothering of benthic animals and plants, may cause stress, reduced rates of growth or reproduction and in the worse cases the effects may be fatal (Bray, Bates & Land 1997). The impact of smothering on fish and shellfish will be a function of the settling behaviour of sediment resulting from increased suspended sediment concentrations relative to background levels, the sensitivity of certain species and/or lifestages to those increases and their ability to move to other areas. The significance of this impact is dependent on many variables including hydrography, seasonality, sediment type, species and the technique used to bury the cable (see **Sections 4.2** and **4.3** for more details).

The main impact on fish is the irritation and clogging of gills. Juveniles are more susceptible to this as adult fish would normally be able to detect significantly elevated levels of suspended sediment and move away from the affected area (ABP Research, 1997).

Smothering can result in significant mortalities on shellfish beds as they are less mobile than fish species, with many having lifestages that are sensitive to variations in sediment particle size within the water. Respiratory and feeding apparatus may be clogged by the settlement of significant amounts of sediment that is mobilised by cable-laying operations. Filter feeders such as mussel, oyster and scallop are therefore among the most vulnerable to smothering effects.

Shellfish are particularly susceptible during spring when spatfall occurs (Posford Duvivier & Hill, 2001). If sensitive spawning or shellfish beds cannot be avoided entirely, seasonal avoidance may be required.

Water quality

Cable installation requires extensive use of shipboard and subsea equipment which in many cases is hydraulically driven. There is a consequent risk of spillage of hydraulic fluid from vessels. The spillage is, however, limited by the system design. Perhaps the greatest risk is a major leak from a burial ROV system when operating on the seabed. Such systems have typical reservoir capacity of 60-100 litres. Spillage risks can be minimised by good practice:

- Deck mounted hydraulic equipment should be fitted with saveall (cofferdam) surrounds to catch leakage and prevent discharge over the vessel side;
- Spare hydraulic oil should be securely stowed, preferably below decks;

- Oil levels should be monitored regularly to safeguard against undetected leakage;
- Hydraulic systems should be designed to limit discharge in the event of a system failure with use of no return valves where possible;
- ROV hydraulic systems should not be all fed from a single common reservoir, but have a number of separate reservoirs to limit any potential impact from a system failure; and
- Appropriate spillage control procedures and equipment should be available on board the operations vessels.

Other potential sources of pollution include lubricants used during horizontal directional drilling methods of cable installation. These are generally inert biodegradable substances such as bentonite which will disperse rapidly. Some localised and short term aesthetic impacts on the sea surface may be experienced.

Water quality (and pollution prevention) will also be an important consideration where cable installation takes place within or near a designated Shellfish Water. The EU Shellfish Water Directive (adopted in 1979) outlines the requirements for the quality of designated waters which support shellfish (defined as bivalve and gastropod molluscs) and aims to protect these shellfish populations from the harmful consequences resulting from the discharge of polluting substances into the sea. This Directive has been transcribed into UK legislation under the Surface Waters (Shellfish) (Classification) Regulations 1997 and The Surface Waters (Shellfish) Directions 1997. Cable laying in these areas should be avoided; where avoidance is not possible, close liaison with fishery operators and management authorities, including the Environment Agency is recommended.

Electro Magnetic Field (EMF)

The transport of electricity through an export and inter-array power cable has the potential to emit a localised electromagnetic field (EMF) which could potentially affect the sensory mechanisms of some species of marine fauna. The degree of impact and the subsequent effect on marine communities was investigated by The Centre for Marine and Coastal studies and Cranfield University in 2003 and 2005, funded through Collaborative Offshore Wind Research into the Environment (COWRIE). The COWRIE investigations found that the EMF emitted by industry standard AC offshore cables had a magnetic field component and an induced electric field component (COWRIE, 2003). These EMF components were both within the range of detection by EM-sensitive aquatic species, such as sharks and rays (Elasmobranchii).

It is generally acknowledged that elasombranchii will encounter multiple EMF components within the wind farm from the inter-turbine array and as a linear field from the export cables. From previous research it has been shown that iE-Fields can affect the behaviour of elasmobranchii when they reach a critical level. The main potential impact is the disruption of the sensory cues for feeding in benthic dwellers in and around the wind farm area. This is general for all species of benthic dwelling elasmobranchii that feed diurnally and nocturnally.

EMF could have two possible effects on the behaviour of elasmobranchii. Firstly, resident elasmobranchii could be deterred from feeding in and around the area within the wind farm footprint and where cables are buried. The second impact could be one of attraction of elasmobranchii to the footprint of the wind farm potentially causing an unnatural clustering effect in the area.

There are, therefore, potentially significant effects on fisheries interests but to date there has been no evidence to indicate the likelihood and/or magnitude of these. The research undertaken by COWRIE, under laboratory conditions only has been insufficient to determine the precise extent of detection for many marine species; the behavioural response within the zone of detection and therefore the likely impacts on fisheries resources due to EMF from sub-sea cables (COWRIE 2005).

For the Thanet Offshore Wind Farm site, English Nature stated that (given current levels of ecological understanding) there will not be a significant impact to the populations of elasmobranchii that are resident within the wind farm footprint and cable export route but English Nature's advice is provided in the light of current information that is available (English Nature, 2006).

Additional research work on electromagnetic field effects is due to be carried out under the auspices of COWRIE, which will entail "in the field" research. It is likely therefore that developers will be asked to commit to take on board the most up to date information on electromagnetic field effects, thereby making necessary and reasonable adaptations during the construction, operation and monitoring of wind farm developments.

5.4.2 MITIGATION MEASURES

In terms of the natural fish resource, general mitigation measures should seek to do the following:

- Avoid spawning and nursery habitats. Such information should be available from published sources or previous surveys. If this is not available then a series of dedicated surveys should be commissioned as part of the wider EIA, in discussions with Cefas;
- Avoid sensitive spawning times for substrate spawning species where possible (exact periods will be site specific and require evidence);
- Impacts from noise may be mitigated by timing construction to avoid sensitive feeding, spawning and nursery area/times of the year;

- Use techniques which minimise re-suspension of sediment in areas where biotopes sensitive to smothering are present and where sediment is found to have elevated levels of pollutants; and
- To minimise pollution risk the laying of the cable should be undertaken in accordance with an Environmental Management Plan and general environmental good practice on site (e.g. CIRIA Marine Construction Site Guide).

5.5 Commercial Fisheries

Impacts to commercial fisheries may result from effects to the targeted fisheries resource or due to alterations to fishing practices as a consequence of cable-laying operations. This section details the impacts of cables and cable installation relating to commercial fisheries over and above those identified in the natural fisheries section (**Section 5.4**).

Commercial fishing activity can be broadly divided into two approaches: mobile gear (where the nets or lines are towed by vessels) and static gear (where nets, lines or pots are left in the environment for a period of time)[1] (**Table 5.1**). The vessels used for these various methods may have some degree of specialism.

Table 5.1: Commercial fishing gear: mobile gear and static gear

Mobile Gear Vessels	Static Gear Vessels
Beam trawler	Drift netter
Seine netter	Gill netter
Trawlers (e.g. demersal, freezer, pair)	Long liner
Dredgers (e.g. scallops, cockles)	Potter/whelker
	Rod and line

Both mobile and static gear vessels have the potential to be impacted by cable installation. The main effects of cable laying on commercial fishing activity, of potential significance are:

- Restricted access to fishing grounds;
- Temporary fish stock displacement; and
- Snagging of fishing gear.

Each type of impact can lead to reduced returns and/or increased costs that result in reduced profitability for the sector. However, the actual significance of the effect would be highly site specific and dependant upon the duration of the installation process.

1 A variation on static netting gear can involve nets being set, but not anchored, enabling them to drift in the current: drift netting.

The greatest risk associated with fishing-cable interactions is to trawlers that may 'snag' a cable, which can pose a significant danger to the vessel and its crew, if not properly managed. Guidance for the fishing industry regarding submarine cables is presented in "Fishing and Submarine Cables Working Together" produced by the International Cable Protection Committee (ICPC) (Drew & Hopper, 1996) and free charts which ICPC issue to fishermen to plot the routes of submarine cables. This information is intended to help fishermen avoid snagging submarine cables and to provide information about what to do if a cable becomes caught in fishing gear.

5.5.1 POTENTIAL EFFECTS

Access to fishing grounds

Fishing vessels are prevented from fishing within the immediate area during cable laying and burial operations. As a result there may be short term restrictions to fishing grounds. In some areas, fishing vessels affected will be temporarily displaced to adjacent fishing grounds, which can lead to an increased risk of gear conflict and a temporary reduction in catches where fishermen are forced to fish unfamiliar or less favourable grounds.

During cable installation operations a safety zone surrounding work boats should be established; this can result in increased steaming times to fishing grounds and hence increased fuel costs and reduced fishing time or a longer working day. Again this is a short-term impact that may be difficult to quantify as fishing vessels will often target several fishing grounds and so should be able to fish alternative grounds to avoid short-term restrictions. The landing of the cable in constricted areas (e.g. narrow estuaries) can interfere more significantly with fishing vessel movements as vessels may be restricted in departing from or returning to port/berths.

As restrictions are likely to be short term, impacts are generally thought to be minimal. For example, the two export cables from the North Hoyle wind farm to the landing beach, a distance of 7.5 km, took approximately 4 to 5 days each to lay and bury (Bomel Ltd., pers. comm.). Furthermore, one of the landing routes under consideration for the North Hoyle project up the Rhyl estuary was abandoned in favour of alternative route, partly because of the disruption this would have caused to the local fishing fleet (Bomel Ltd., pers. comm.). Therefore, the likely impact on access to commercial fishing grounds is likely to be small given the wider impacts of the wind farm.

Fish stock displacement

During construction there will be a short term movement of fish away from the cable laying area due to *inter alia* noise, seabed habitat alteration and turbidity (see **Section 5.4**).

There are two mechanisms by which fish and shellfish may be displaced from the installation area. One is direct avoidance of the burial site in response to noise, the turbidity plume or both. This will be a local effect of short duration that will cease once the cable has been installed (see **Sections 4.3** and **4.4**). The other is in response to sea bed habitat alteration that may well downgrade the cable route as a feeding area. Due to the short duration of construction activity and the small width of habitat affected by cable laying, the likely impact on commercial fishing is expected to be small.

The temporary displacement of fish stocks through disturbance or habitat alteration is predicted in the Environmental Statements for the Horns Rev and the Nysted wind farms, Denmark. The short term nature of this impact has been corroborated by subsequent monitoring studies. The most recent monitoring report available from 2004 concludes for Nysted that:

> *"the direct and indirect impacts of the earthwork [conducted from September 2002 to February 2003] on eelgrass, macroalgae and invertebrates were limited in space and time and a full recovery of the populations close to the cable trench is expected in the near future."* (Elsam Engineering & ENERGI E2, 2005).

For Horns Rev, which forms part of Denmark's important commercial sandeel fishery, the 2004 monitoring report found that "There is no indication that the construction of the wind farm has had a marked effect on the sediment composition in the wind farm area. There was no indication of an increase in the content of silt/clay and very fine sand in the impact area from 2002 to 2004. Sandeels are very sensitive to changes in the content of these sediment sizes and will completely abandon the area if the weight fraction of the silt/clay content rises above 6%." Sediment movement resulting from cable laying was found to be insignificant in the relatively dynamic environment of the wind farm.

There is concern amongst the fishing industry of the potential impacts on fish stocks of EMF emitted by operating power cables (see **Section 5.4**). This is particularly important to small vessel operators as these vessels have a limited operating area from their home port and therefore may be unable to still target highly displaced resources. Monitoring of the earliest-established offshore wind farms, Horns Rev and Nysted, have to date found no significant impact of either the export cable or the inter-array cables on fish stock displacement. The creation of significant areas of hard substrate through placement of the turbines and associated rock armour has, however, led to a changed (moderately increased) epibenthic productivity (macroalgae and benthic invertebrates) that has attracted commercial fish species within the turbine array. There has been no reported reaction of these fish species to the presence of cables with localised emissions of EMF.

The permanent alteration of the seabed will be most pronounced with the use of rock dumping to protect cables when burial is not feasible and the installation of concrete mattresses at cable crossings. While this is seen as predominantly a negative impact for commercial fisheries, the introduction of hard substrate creates habitat diversity, which can benefit some commercial resources e.g. crustacean fisheries.

Mobilised sediment may settle on fishing gear (e.g. monofilament gill nets) and reduce their efficiency. The significance of this depends on background turbidity levels and given the dynamic hydrographic conditions of much of the UK coastline this is likely to be insignificant.

Snagging

The extent of the physical disturbance to the seabed along the cable route will depend on the prevailing geological conditions, which determine the cable installation techniques that can be used. For soft sediment, natural infilling or assisted infilling by the cable burial tool should ensure that no debris to potentially snag a fishing net is left on the seabed. However in rocky substrata or in clay, chunks of debris could potentially cause fishing nets to snag.

Snagging can also occur where stretches of cable are exposed for example over rocky substrata, spanning sand waves or at any location where cable is surface laid prior to any post lay burial operation. However, there should not be a problem for the latter point, as the fishermen should be respecting exclusions zones until all cable burial operations are complete. Shifting sediment can also expose previously buried sections of cable.

Seabed hazards resulting from the trenching of the cable route, including any exposed sections of the cable itself, can interfere with benthic fishing gear, particularly beam trawl, otter trawl and drift netting. Static gear also has the potential to become snagged on subsea cables. The small 1m long anchors used by inshore vessels to secure static gear are found to penetrate sand to a depth of around 0.2m (less in coarser sediments). These may drag in strong currents and become snagged on cable. The risk lies in attempting to recover the gear, which is often through the use of grappling hooks. The cable route assessment should however take on board all of these potential hazards and the design depth of burial for the cables should provide suitable mitigation against the measured risks.

Danger arises where vessels, unknowingly snagged on a cable attempt to heave the gear free from the seabed obstruction. This can lift the cable clear of the seabed, exposing more cable that causes a significant downward pull from the weight of cable.

The recovery of snagged gear is not recommended and fishing operations will be compensated by cable operators if provided with evidence of such instances. Such claims are only compensated providing that the fishermen have not operated within restricted fishing or anchorage zones.

5.5.2 MITIGATION MEASURES

The extent and risk 'associated' with interactions between cables and fishing vessels should be avoided or minimized through appropriate:

- Routing of cables and scheduling of cable laying operations;
- Cable laying technique to ensure sufficient cable burial and/or protection;
- Communication of cable laying activities and cable positions (via Notices to Mariners, Fishing News, Kingfisher Bulletins and Admiralty Charts); and
- Monitoring of the cable *in situ* to identify and address areas of impact and risk to fisheries.

The choice of cable route and cable laying techniques would be determined following an assessment of existing commercial fishing activities in the area and the sensitivities of the resources upon which they depend.

The use of best engineering practices would be employed e.g. ensuring 100% of the cable route had adequate protection with no exposed sections of cable wherever possible.

Using suitable local fishing vessels as guard vessels for cable laying operations provides useful alternative income to the fishing industry.

Monitoring of the cable route post installation (e.g. side scan sonar) and regular communication with fishermen should help minimise impacts and risk from construction operations. Communication with fishermen will be greatly facilitated with the use of a suitable fisheries liaison officer.

5.6 Marine Mammals

Marine mammals[2] have a wide ranging distribution and, as such, there are no marine mammals considered to be exclusively British. The cetaceans most commonly encountered and described as part of offshore wind farm projects are the harbour porpoise *Phocoena phocoena* and the bottlenose dolphin *Tursiops truncatus*. Harbour porpoise are by far the most abundant[3] (Hammond *et al.* 2002).

Two species of seal are resident in UK waters; the common seal *Phoca vitulina* and the grey seal *Halichoerus grypus*, with the grey seal being more numerous (English Nature, 2004).

The range of potential impacts upon marine mammals during cable installation (and, to a much greater extent, offshore wind farm construction) are of

2 In the context of this Technical Report, 'marine mammals' is the collective term for seals (pinipeds) and whales, dolphins and porpoise (cetaceans).

3 For details of other cetacean species occurring in northwest European waters see http://www.jncc.gov.uk/page-1554

particular significance, given that each of these animals is afforded a high level of individual protection under a suite of national and international legislation and signatory agreements[3] (Defra, 2005). As such, potential adverse impacts upon a single individual of a species of marine mammal must be considered as being of significance and, therefore, there is a requirement to apply practicable and financially feasible mitigation measures in order to be compliant with the legislation (in particular, the Habitats Directive).

5.6.1 POTENTIALLY SIGNIFICANT EFFECTS

Cable laying operations have the potential to impact upon marine mammals through:

- Collision with the vessel or support vessels;
- Noise and visual disturbance from the vessel and cable burial system;
- Contact with any fuels and chemicals[4] that may be accidentally released during the operation; and
- Interactions or entanglement with the cable or other lines between the vessel and the installation tool.

Collision risk

While there are no accurate records of the number of incidents of accidental collisions between marine mammals and shipping in UK waters (e.g. Hammond *et al.*, 2003), it is considered that a direct relationship exists between shipping intensity, vessel speed and the number and severity of collisions, certainly in the case of whales (Laist *et al.*, 2001). Certain assumptions can be made about the risk of collision with marine mammals (Sakhalin Energy Investment Company Limited, 2005; Laist *et al.*, 2001):

- All types and sizes of vessels can hit marine mammals;
- Vessels over 80m in length cause most severe or lethal injuries;
- Serious injuries to mammals rarely occur if struck by vessels travelling at speeds of less than 10 knots;
- Mammals struck by vessels are usually not seen prior to impact, or are seen too late to avoid impact; and
- The risk of collision increases in poor visibility.

Collisions between marine mammals and the cable burial vessel are considered to be unlikely. The cable burial vessel whilst working in the shallow water locations, is likely to only make very slow progress while laying and burying cable, with a burial rate of 1000m of installed cable per hour and therefore would

4 Such accidental releases are likely to be similar in extent, duration and significance as for other parameters and is not discussed in this section.

not be travelling at over 10 knots during installation operations, thus reducing the risk of fatal injury, should a collision occur.

Visual disturbance

Marine mammals may be disturbed by the presence of vessels and human activities, particularly in sensitive locations such as in close proximity to seal haul out sites and marine mammal foraging areas. Such disturbance, during sensitive periods (such as the breeding and pupping season of seals), may lead to significant impacts such as the abandonment of young and reduced reproductive success (Brown and Prior, 1997).

Underwater noise

There is increasing concern over the impacts of underwater noise as a result of anthropogenic activities upon marine life in general. This issue is of greater relevance to marine mammals, given both their physiological capacity for detecting and responding to sound, and the high levels of protection that they are afforded.

The sources and intensities of sound associated with offshore wind farm construction and the related impact on marine life has been investigated by Nedwell *et al.* (2003) and Nedwell & Howell (2004). Further useful information is provided in Jansy *et al.* (2005) and Madsen *et al*. (2006). The impact of noise on marine mammals can be divided into three levels:

- Those that cause fatal injury;
- Those that cause non-fatal injury such as deafness and other auditory damage such as temporary threshold shift (TTS); and
- Those that cause behavioural change (e.g. avoidance, cessation of feeding etc.).

Similarly to the impacts of underwater noise on fish, available information suggests that species of marine mammal will show a strong avoidance reaction to sound levels of 90 dB_{ht}(*species*) and above. It is, however, considered highly unlikely that cable installation would produce noise at a level that would cause a behavioural reaction in marine mammals. For a more detailed discussion of the dB_{ht}(*species*) measurement, an example of where the measurement has been applied to cable installation and the likely levels of effect on both marine mammals and fish, see **Section 5.4.2**.

Entanglement

The risk of marine mammals becoming entangled in a cable under low tension, or in any other lines used to connect the installation tool to the vessel, is considered to be extremely limited. Most seals and cetaceans would be expected to avoid areas of human activity and significant disturbance and, as such, would be unlikely to venture close enough to the cable burial vessel to become entangled. A review of relevant published literature and discussions with installation contractors has not identified any reports of marine mammals of any kind becoming entangled during cable burial operations.

5.6.2 MITIGATION MEASURES

Visual and other construction related disturbance, in relation to hauled out seals, can be effectively mitigated by avoiding cable installation operations in the vicinity of known haul out sites during sensitive periods, such as the breeding season (late June to early July for common seal and late July to early December for grey seals (although this varies with position around the UK). Wherever possible, seal haul out sites should be avoided during the planning of the cable route in order to completely remove the potential for disturbance to occur.

Further study is required to assess the noise levels produced by the range of available cable burial devices and tools in the types of seabed sediments encountered in UK waters. This can be achieved through real time monitoring of cable installation, such as at North Hoyle, or through specific experimentation and computer modelling. Only once sufficient, reliable data is available can the disturbance caused by cable installation be understood and effectively mitigated. As a precautionary measure, given the conservation significance of the species involved, it may be necessary, as a minimum, to employ Marine Mammal Observers on the installation vessel and to have a protocol in place to delay installation activities from occurring if marine mammals are detected within a predetermined distance from the installation vessel. Such a need would be identified through consultation with the relevant nature conservation body and the JNCC (JNCC, 2004).

5.7 Ornithology

Concerns and issues relating to birds, in the context of offshore wind farms are primarily concentrated on the wind turbine array. The installation of both the export and inter-array cabling is of significantly lower concern.

Potentially significant effects of cable installation on birds are limited. The main area of concern would be:

- Disturbance of normal behaviour in the intertidal; and
- Disturbance of normal behaviour at sea.

Other effects on birds would be limited to:

- Prey availability.

5.7.1 POTENTIALLY SIGNIFICANT EFFECTS

Disturbance of normal behaviour in the intertidal

In the intertidal zone, the impact of disturbance upon birds may be significant. The presence of construction plant and activity is likely to cause temporary disturbance to birds which would otherwise be foraging, loafing and roosting. The significance of the impact depends upon a number of factors, including the importance of the intertidal site to birds, the duration of intertidal works and the season in which the works are programmed. Such disturbance would be particularly significant if the intertidal area in question is designated as an SPA.

Disturbance of normal behaviour at sea

The installation of export cables involves activity in shallow coastal waters that can provide favourable foraging habitat for a wide range of seabird species, particularly in areas of shallow sandbanks. Noise levels and the presence of vessels and machinery associated with the installation process may impact on the use of the area by foraging birds, or those 'rafting' on the sea, through disturbance of normal behaviour. However, given the transient nature of cable installation, such disturbance will be highly limited, both spatially and temporally and would not be of major concern.

5.7.2 OTHER EFFECTS

Prey availability

Impacts on the seabed, and within the water column, that cause direct removal or displacement (i.e. due to noise) of fish and benthos, may indirectly impact birds through a reduction of prey availability in favoured foraging habitat.

Offshore, foraging seabirds target a range of different fish species, particularly in shallow coastal waters. If installation activity causes the movement of prey species out of the area, this is likely to result in a related displacement of bird species that would follow the prey. The impact of displacement would be limited in both extent and duration and not considered as being significant, unless the cable is to be installed in an area that supports an important prey resource that has a limited distribution in the wider study area and is associated with a sea area considered to be suitable for the designation of offshore SPAs[5].

Similarly, in the intertidal zone, there may be a short term decrease in prey abundance caused by the direct loss of flora and fauna in the footprint of the installation device. The significance of this impact would depend on the availability of similar prey within the intertidal, outside the installation footprint.

5 http://www.jncc.gov.uk/page-1414

5.7.3 MITIGATION MEASURES

For installation works in the intertidal zone, the approach to appropriate mitigation will be determined by the sensitivity of the habitat. If installation is to take place within an area of importance to birds, such as an SPA, it will be necessary to ensure that the measures proposed are sufficient to avoid an adverse effect on the integrity of the designated site. In such circumstances, it will be necessary to agree mitigation with the relevant nature conservation body as part of the EIA process.

In many cases the SPA will be designated for supporting over wintering assemblages of waders and waterfowl. Restrictions may be placed upon works occurring during the over wintering period (1st October to 15th April in any one year) or other sensitive times for specific species (e.g. breeding periods for Annex I birds, such as little tern).

Offshore, practical implementation of mitigation measures aimed at minimising impacts on birds is extremely difficult. In particularly sensitive areas, such as shallow sandbanks, avoiding key times of year in terms of peak numbers of birds feeding over known areas of the cable route would ensure that significant disturbance is avoided. However, such an approach is likely to be difficult to achieve, unless there is reliable and robust information on the locations and seasonality of important prey resources in the study area. Also, given the transitory and temporary nature of the installation, the effect upon birds, at sea is unlikely to be significant.

Examples of operational restrictions that have been placed on offshore wind farms through the FEPA licences in order to minimise the impacts on birds, include:

- Kentish Flats

  "The Licence Holder must ensure that if cable installation occurs between October and April inclusive (the over-wintering season for several wader species) the beach installation, including trenching and cable laying, avoids the sensitive period 2 hours either side of high water. The Licence Holder should also investigate putting in place acoustic shielding around all construction activities on the beach and at the adjacent construction compound in Hampton Pier car park to further minimise any potential disturbance."

- Barrow

"As there are internationally important numbers of common scoter in the vicinity of the wind farm, the Licence Holder must ensure that works are undertaken in the months of March to October (inclusive) so as to minimise disturbance to over-wintering birds. Any specific requirement for works outside these times shall only take place after written approval from the Licensing Authority (following consultation with CEFAS and English Nature). In so far as is practicable, the majority of the piling or drilling works shall only be undertaken during the months of April to June."

Where technically and economically feasible, effective mitigation could be applied through the final choice of the cable installation technique. For example, the use of horizontal directional drilling (as opposed to ploughing and trenching) would reduce the area of intertidal impacted and involves shorter periods of human presence in areas sensitive to disturbance.

5.8 Shipping and Navigation

A maritime traffic survey, navigation assessment and a Navigation Risk Assessment will be required for the offshore wind farm development, in accordance with the requirements of the Maritime and Coastguard Agency's (MCA) Marine Guidance Note MGN 275(M)[6]. Information from this work can be used to identify and evaluate potential impacts regarding the cable installation.

A Guidance Document is also available on the 'Assessment of the Impact of Offshore Wind Farms: Methodology for Assessing the Marine Navigational Safety Risk of Offshore Wind Farms' (DTI, 2005a). The purpose of the guidance document is to provide a template to be used by developers in preparing their navigational risk assessments, and to assist Government Departments in the assessment of these.

The key impact associated with cable installation activities will be:

- Increased risk of collision by existing navigational users in the cable installation area.

POTENTIALLY SIGNIFICANT EFFECTS

Collision risk

Due to the increase in the number of vessels and movement of the vessels involved in cable deployment and burial, there will be some temporary and minor disruption to navigation. There are a number of particular factors which

6 Proposed UK Offshore Renewable Energy Installations (OREI) – Guidance on Navigational Safety Issues

will affect collision risk for vessels undertaking cable installation (or maintenance) which can be summarised as follows:

- The navigation (i.e. direction and manoeuvrability) of cable installation vessels is restricted by the cable and any burial equipment operated from the vessel. Laying speed is slow (anywhere between 100m/hr to 1000m/hr), and the heading of the cable installation vessel may well be set to minimise environmental forces from wind and current. The cable installation vessel is likely to be operating subsea equipment, and may be moored by anchors which will be deployed some hundreds of metres from the vessel. All these factors may not be anticipated by passing navigational traffic. Although Notice to Mariners are issued via the Marine Coastguard Agency they do not always get received by all intended recipients. For example, during the installation of power cables across the Solent in the late 1990's a power boat race came very close to the mooring wires of the main cable installation barge (Bomel Ltd., pers. comm.);
- Cable installation vessels will always display cable laying signals to warn passing traffic. Similarly, radio navigation warnings will be requested and broadcast in addition to advance notification of works in a notice to Mariners and Kingfisher bulletins and Kingfisher Information charts; and
- Cable layers are typically supported by various vessels including anchor handlers, dive support vessels, ROV vessels and personnel launches. The activity of such vessels should be under the control of the operations superintendent of the main installation vessel to ensure coordination.

The effects on shipping and navigation will be described within the project's navigation risk report, and possible risk mitigation measures suggested. As part of the project's required Navigational Risk Assessment, the DTI (now BERR) guidance (2005a) advocates implementation of a proposed Marine Navigational Safety Goal which should be managed through the life of the offshore installation. This includes a list of measures that serve to reduce risk to that which is "as low as reasonably practical" and that ensures "relevant good practice risk controls are in place".

The development of Emergency Response Plans for each site is also recommended as part of the guidance such that the lines of responsibility and reporting are clear and predefined, to minimise any potential risks to human life and the environment (DTI, 2005a).

5.8.2 MITIGATION MEASURES

Vessels associated with cable installation works may lead to some temporary minor disruption to regular traffic and navigation; however the degree of these effects will be site specific and can be minimised through planning and liaison with appropriate regulators and other sea users. Best practice mitigation measures (as also cited above) relevant to construction and maintenance activity include:

- Circulation of information to vessel operations prior to operations;
- General notices via Navtex, Notices to Mariners and Admiralty Charts;
- Workshops to discuss navigational issues during construction;
- Use of guard vessels during construction;
- Monitoring of shipping during construction;
- Development of Emergency Response Plans; and
- Measures to advocated by BERR's proposed Marine Navigational Safety Goal.

Other guidance for ship collision avoidance also exists (UKOOA, 2003) and good practice guidelines should be followed whenever it is intended to anchor or locate a vessel within two kilometres of cables, pipelines and other subsea installations (UKOOA, 2002).

It should be noted that Safety Zones as defined under the Energy Act 2004, which serve to protect safety of life around offshore installations, only apply to the offshore wind farm structures and not the associated vessels. Exclusion areas around installation vessels cannot therefore be enforced under these provisions. Guidance in ICPC (1996), cautions fishermen to keep at least one nautical mile away from a cable laying vessel and that fishing gear should never be operated astern of such a vessel for risk of engaging with a plough which will typically be operating three times the water depth away from the stern of the main cable installation vessel.

5.9 Seascape and Visual Character

BERR has produced guidance on the assessment of seascape and visual impacts of offshore wind farms (DTI, 2005b) This guidance makes recommendations on how to assess and deal with the seascape and visual impact assessment element of an EIA for an offshore wind farm development.

Seascape and visual impacts related to the cable installation activities and not considered to be potentially significant, will be limited to:

- Presence of the cable installation vessel and support vessels;
- Associated activity including plant and people present in the intertidal area; and
- Possible sea surface aesthetic effects from any sediment plume generated as part of the installation, particularly where chalk is disturbed.

5.9.1 POTENTIAL EFFECTS

Cable installation activities will have a physical impact on the environment (see **Section 4**) and may, therefore, alter its visual appearance. The key issues of concern are the effects upon unspoilt landscapes and seascapes, designated and valued landscapes/seascapes and effects on visual amenity.

The severity of the visual and landscape impacts arising from cable installation activities will be related to the value and use of the area and the scale of the alteration of the appearance. There will be trenching or ploughing activities taking place in the intertidal zone and adjacent coastal area necessary for the burial of the cable, which will be visible. However, the impacts to the landscape and seascape will be localised and short term.

There will be landscape and visual impacts as a result of the presence of electricity substations and overhead transmission lines and poles connecting the offshore wind farm to the local electricity grid on land, and temporary disturbance of the seascape arising from the presence of subsea cable burial machinery and vessels.

5.9.2 MITIGATION MEASURES

Visual and seascape impacts can only be effectively mitigated at the landfall site and will include usual good construction practice, such as limiting the area to be disturbed; maintaining tidy and compact site compounds and ensuring full restoration of the site in consultation with the relevant authorities (Natural England, Environment Agency or the Local Planning Authority).

In addition, potential effects of cabling activities in the intertidal zone and adjacent coastal area may be minimised by timing trenching activities to avoid sensitive periods such as busy tourist seasons.

5.10 Marine and Coastal Archaeology

The potential archaeological resource that may be impacted by cable installation activities includes submerged palaeo-landscapes, including evidence of former human habitation or climate change; wrecks and related maritime remains and terrestrial archaeology, including in situ sites and / or findspots.

Potentially significant effects include:

- Direct loss or disturbance by cable installation activities; and
- Indirect disturbance via changes in sedimentation, such as increased erosion or accretion.

The protection of archaeological, cultural heritage and wrecks are provided by a number of Legislative Acts. The principal protection for underwater heritage in the UK's territorial waters is provided by the Protection of Wrecks Act 1983. More recently, the Natural Heritage Act (2002) has enabled English Heritage to assume responsibility for maritime archaeology in English coastal waters. Specifically the Joint Nautical Archaeology Policy Committee (JNAPC) brings together a wide range of organisations with a direct and active interest and expertise in the marine historic environment.

Relevant guidance provided by English Heritage and others includes:

- England's Coastal Heritage;
- Identifying and Protecting Palaeolithic Remains: Archaeological Guidance for Planning Authorities and Developers;
- Military Aircraft Crash Sites: archaeological guidance on their significance and future management;
- Joint Nautical Archaeology Policy Committee, 2006, Maritime Cultural Heritage and Seabed Development JNAPC Code of Practice for Seabed Development; and
- Wessex Archaeology (in consultation, 2006) Historic Environment Guidance Note for the Offshore Renewable Energy Sector.

5.10.1 POTENTIALLY SIGNIFICANT EFFECTS

Direct loss or disturbance

Cable installation activities including the anchoring of vessels can disturb the seabed in ways which could damage or destroy historic artefacts and submerged archaeological sites and features. In addition, indirect disturbance may occur from the longer term changes in the scouring and sedimentation patterns arising from cable installation and cable protection methods, exposing previously buried sites to degradation, destabilisation and corrosion.

Archaeological remains and artefacts are a finite and non-renewable resource and, as such, cannot be replaced or recover from damage caused to physical properties or archaeological context. All direct impacts upon archaeology would be permanent and, therefore, of significance. However, the scale of significance would depend upon the strength of the impact ranging from low, if the material is simply dislodged from its resting place, to high, if the material is crushed or damaged by the installation equipment.

Unlike aggregate extraction where the sediment is brought to the surface increasing the likelihood of identifying archaeological finds, the excavated sediment from cable burial machines is not brought to the surface. The sediment is ploughed or jetted to the side of the trench and thus there is no opportunity, at present, to investigate the occurrence of archaeological remains during cable installation activities, unless they are identified by the sonar systems, cable tone trackers or subsea video systems equipment housed on certain installation devices.

The significance of impacts on artefacts and submerged archaeological sites will be similar for all cable installation devices. If artefacts or wrecks lie on or just beneath the seabed surface, they will be displaced from their resting place, crushed or compacted by the cabling equipment (i.e. skids or tracks). In contrast, the significance of the impact on artefacts of wrecks situated on or just beneath the seabed surface will vary with the type of burial tool used. Rock cutting and chain excavating tools will have a more significant impact which rip, slice and scrape at the substrata, compared with jetting tools which liquefy or erode sediments. The impact will be less in cohensionless substrata where relatively low pressures are required to liquefy the sediments, compared with cohesive substrata whereby localised erosion and scouring of the sediments occurs.

Indirect disturbance via changes in sedimentation

During the operational phase, there is the potential for exposure of archaeological material through scour along the cable route. The scale of the impact will be site specific and depend on local hydrology and geology.

5.10.2 MITIGATION MEASURES

To ensure that comprehensive treatment is afforded to historic environment interests, it is recommended that early dialogue is initiated with English Heritage for the subtidal cable route and with the local authority (i.e. County Council) historic environment service for the intertidal and terrestrial sections of the cable route. Early negotiation will assist in the evaluation of any necessary mitigation as the project develops.

The basic principle with regard to any known or potential archaeological feature or site is one of avoidance. Where possible, within technical constraints, cable routes should be grouped together to reduce the area and minimise the impacts. Where avoidance is not possible, the archaeological/historical site should be investigated prior to cabling activities to determine its importance and any suitable mitigation measures necessary. To effectively mitigate any potential impacts on known archaeological sites and important land and seascapes within a study, all aspects of any archaeological work will be detailed by a Written Scheme of Investigation (WSI). This provides for all forms of archaeological mitigation that may be required in light of pre and post-installation investigations, including archiving and dissemination of results. It is usually then subject to the approval of the County Archaeologist and English Heritage. FEPA conditions usually stipulate that no works are to take place until a protocol has been submitted to the Licensing Authority which has been formally agreed with an Archaeologist representing the County Council adjacent to the site of work. The protocol must detail what action is to be taken to protect any archaeological and shipwreck remains identified in the Environmental Statement submitted in support of the applications for consent for the works (Cefas, pers. comm.).

Construction Exclusion Zones can also be used where known or potential archaeological sites or geophysical anomaly are located within the cable route and buffer zones. The size of the exclusion zone size usually depends upon the extent of the known or suspected archaeology, although they may be subject to movement, reduction or removal following further survey work prior to cabling activities. If cable routes cannot be altered to avoid sites of high importance, then subsequent evaluation may result via excavation or recording *in situ*.

Within the intertidal zone and adjacent terrestrial environment, close contact should be maintained with English Heritage and the local authority archaeological services with respect to any archaeological material that may be encountered. A watching brief may be necessary if trench excavation is proposed within the foreshore or adjacent terrestrial area.

6 Good practice measures

This section provides examples of good practice measures which could be adopted during all phases of project planning. Such measures could be used in conjunction with mitigation measures defined in **Section 5.0** to minimise the magnitude and significance of effects to the local environment.

Examples of good practice measures which could be adopted to reduce potential disturbance of cabling activities on intertidal and subtidal habitats, marine mammals, birds, fish and shellfish include:

- Early dialogue with the appropriate regulatory and advisory authorities (Department for Transport, Department for Environment Food and Rural Affairs, Centre for Environment, Fisheries and Aquaculture Science, Natural England, Countryside Council for Wales, Scottish Natural Heritage, the Environment and Heritage Service Northern Ireland, the Environment Agency and the Joint Nature Conservation Committee).
- Sensitive timing and routing of cable installation to avoid important feeding, breeding/spawning and nursery areas and seal haul out areas especially during sensitive periods (breeding season);
- Avoidance of areas of sensitive habitat such as biogenic reef.
- Sensitive timing and routing of maintenance vessels to reduce number of trips;
- For marine mammals and birds: preparation of on-site protocol in sensitive locations;
- For marine mammals and birds: briefing of cable installation contractor's personnel for on-site procedures and protocol; and
- Monitoring effects using a Before-After-Control-Impact (BACI) study.

Examples of good practice measures which could be adopted to reduce potential disturbance of cable installation activities on shipping and navigation include:

- Early dialogue with the Maritime & Coastguard Agency (MCA), Hydrographer of the Navy and local harbour authorities should be undertaken in relation to shipping and navigational issues;
- Planning, liaison and consultation with local experts and users (harbour masters, coastguard etc) to identify impacts to traffic and navigation;
- Production of Emergency Response Plans to minimise potential risks to human life and the environment; and
- Following good practice guidelines for ship collision avoidance and anchorage near cables, installations etc. (UKOOA, 1997, 2002, 2003).

Examples of good practice measures which could be adopted to reduce potential disturbance of cable installation activities on archaeology include:

- Early dialogue with English Heritage / Welsh Historic Buildings (CADW), Historic Scotland / Environment and Heritage Service (EHS) Northern Ireland and with the local authority (i.e. County Council) to discuss the potential impacts and mitigation measures of cabling activities on archaeological and historic issues; and
- Investigation of cable survey route in terms of potential archaeological / historical sites.

7 Gaps in understanding

Research for this report has highlighted a number of gaps in available data and in understanding of the actual impacts resulting from cable burial activities associated with the offshore wind farm industry. The general lack of understanding is due to the physical and biological effects of cable burial being very site specific, particularly with regard to sites with different sediment characteristics. What makes this even more difficult to interpret is that the majority of sites will experience a large variation of sediment types along the cable routes. There has also been a deficit in the monitoring of cable burial activities in the past as the impacts are regarded as secondary in terms of scale when compared with those from the installation and operation of the wind turbines.

There is limited centralised knowledge sharing both with the offshore wind farm industry and from other more established marine cabling industries such as subsea telecommunications and the oil and gas sector. Information that does exist is not widely disseminated, reviewed or synthesised for a wider audience or made publicly available.

There is limited documentation and research carried out to date on the quantification of material disturbed and brought into suspension from cable burial operations, in particular, from burial methods using jetting, cutting, dredging and excavating tools. This lack of basic information on the volumes of sediment brought into suspension limits the potential of modelling techniques and establishing the fate of sediment plumes. Research from other industries can be used for predicting potential effects but the scale of impacts is quite different (as identified in **Section 4.4**) and the effect will depend on the sensitivity of the receptor and the site conditions. Should the generation of a sediment plume be considered to be an area of concern, *in situ* monitoring of a number of different techniques and tools in one location, together with further plume modelling would be required in order to draw comparisons under the same site specific conditions. Confidence in the modelling could be attained by comparing predicted versus *in situ* results. The sediment monitoring requirements included in FEPA licences for UK Round 1 and potentially Round 2 offshore wind farm applications will also provide valuable data for the quantification of the impact of cable burial operations.

In addition, there is a general lack of understanding of the biological response to sediment plumes, arising from any activities that disturb the seabed, such as the sensitivity and tolerance of species and habitats to different levels of sediment plumes and different plume durations. Additional research in this area is therefore necessary in order to further this knowledge base to enable accurate predictions of sensitivity to be determined. There are, however difficulties in undertaking research to fill these gaps such as the problem associated with site specific differences changing the scale of the effects and the adaptability of species in different environments and at different times of the year. Targeted research involving the testing of different cable burial devices and tools in the same conditions (seabed types, wave and tidal conditions) could overcome part of this problem but the different levels of adaptability of species will need to be assessed on each occasion. This more generalised research requirement is much wider ranging than is necessary for cable burial alone as it involves a number of industries with an interest in the marine environment.

The need for further studies and monitoring to investigate the potential impacts needs to be put into context with the amount of sediment that is put into suspension during cabling in comparison to other activities (i.e. certain fishing techniques and dredging activity) and natural events (i.e. severe storms).

References

Introduction

Sinden, G. (2004). Oral evidence to: House of Lord Science and Technology Committee. Renewable Energy: Practicalities HL Paper 126-11 (as cited in SCD, 2005).

Sustainable Development Commission (SDC), (2005). Wind Power in the UK. A guide to the key issues surrounding onshore wind power development in the UK. May 2005.

Legislation

Centre for Environment, Fisheries and Aquaculture Science (CEFAS) (2004). Guidance Note for Environmental Impact Assessment in respect of FEPA and CPA requirements.

Department of Enterprise, Trade and Investment (DETI) (2004). A strategic framework for Northern Ireland. June 2004.

Department of the Environment (NI) (1998). Planning Policy Statement 1. General Principles. The Planning Service, an Agency within the Department of the Environment (NI). March 1998. Available on http://www.planningni.gov.uk/areaplans_policy/PPS/pps1/PPS1.pdf

Department of Trade and Industry (DTI). (2002). Future Offshore: A Strategic Framework for the Offshore Wind Industry. pp 88. Available at http://www.dti.gov.uk/files/file22791.pdf.

Department of Trade and Industry (DTI). (2004). Guidance Notes. Offshore Wind Farm Consents Process Guidance Notes, 2002. Department for Trade and Industry, Offshore Renewables Consents Unit. Marine Consents and Environment Unit. August 2004. pp 27. Available at: http://www.dti.gov.uk/energy/leg_and_reg/consents/guidance.pdf

Scottish Natural Heritage (2004). Marine Renewable Energy and the Natural Heritage. Policy Statement No. 04/01. May 2004.

Cabling Techniques

EMU (2004). Subsea Cable Decommissioning: A Limited Environmental Appraisal. Report for British Telecommunications plc, Cable & Wireless, AT&T. March 2004. pp 67.

Featherstone, J., Cronin, A., Kordahi, Mi. & Shapiro, S. (2001). Recent trends in submarine cable faults. SubOptic `01. May 2001. Kyoto, Japan.

Versuchsanstalt fur Wasserbau und Schiffbau, Berlin. In: Ott, W.P. and van Uchelen, J.C. (translators), California Inst. Tech., W.M. Keck Lab. of Hydraulics and Water Resources, Rep. No. 167.

Physical Change

Boom, J., (1976), “Fluidisation in Pipe Burial”, European Spring Meeting of SPE, Amsterdam, NL, SPE, Richardson, Texas, p.5764.1-5.

BS 6349. Part 5: Code of practice for dredging and land reclamation, 1991.

Cole, S., Codling, I.D., Parr, W., & Zabel, T. (1999). Guidelines for managing water quality impacts with UK European Marine sites. Report prepared by WRc for UK Marine SACs project, 441pp.

Dunn, I.S., (1959), “Tractive Resistance of Cohesive Channels”, Proc. Am. Soc. Civil Engnrs, Vol.85, No. SM3.

EMU Limited. (2005). Kentish Flats Monitoring Programme Turbidity Monitoring. April 2005. Report No. 05/J/1/01/0733/0500.

Flaxman, E.M., (1963), “Channel Stability in Undisturbed Cohesive Soils”, Proc. Am. Soc. Civil Engnrs, Vol.89, No.HY2.

Galagan, C., Isaji, T. & Swanson, C. (2003). Results of Model Simulations of Sediment Deposition from Cable Burial Operations in Lewis Bay, MA. December 2003. Applied Science Associates, Inc., Rhode Island, USA.

Hitchcock, D.R., Newell, R.C., Seiderer, L.J. (1998). Investigation of benthic and surface plumes associated with marine aggregate mining in the United Kingdom. Final Report. Contract Report for the US Department of the Interior Minerals Management Service.

Hjulstrom, F., (1935), “Studies in the Morphological Activity of Rivers as Illustrated by the River Fyris”, Geol. Inst. Univ. Upsala. Bull. 25, pp.221-528.

Hubbert, M., and Willis, D., (1957), “Mechanics of Hydraulic Fracturing”, Trans. AIME, Vol.210, pp.153-168.

Ishihara, K., (1993), “Liquefaction and Flow Failure during Earthquakes”, Geotechnique, Vol. 43, No.3, p.351-415.

Jaworski, G.W., Duncan, J.M., Seed, H.B., (1981), “Laboratory Study of Hydraulic Fracturing”, J. Geotech. Engng., ASCE, Vol.107, No. GT6, p.713-732.

John, S.A., Challinor, S.L., Simpson, M. Burt, T.N. & Spearman, J. (2000). Scoping the assessment of sediment plumes from dredging. Ciria Report C547.

Lincoln, J.B., (1985), "Subsea Pipeline Trenching", Proc. Australian Conf. on Coastal and Ocean Engng., Australian Inst. Engnrs., Vol.1, p.169-181.

Murdoch, L.C., (1993a), "Hydraulic Fracturing of Soil during Laboratory Experiments, Part 1, Methods and Observations", Geotechnique, Vol.43, No.2, p.255-265.

Murdoch, L.C., (1993b), "Hydraulic Fracturing of Soil during Laboratory Experiments, Part 2, Propagation", Geotechnique, Vol.43, No.2, p.267-276.

Murdoch, L.C., (1993c), "Hydraulic Fracturing of Soil during Laboratory Experiments, Part 3, Theoretical Analyses", Geotechnique, Vol.43, No.2, p.277-287.

Norfolk Offshore Wind (2002). Cromer Offshore Wind Farm, Environmental Statement, October 2002.

Parr, W., Clarke, S.J., van Dijk, P. & Morgan, N. (1998). Turbidity in English and Welsh waters. Report prepared for English Nature, Report no. Co 4301/1., 116 pp. Marlow: Water Research Centre.

Permanent International Association of Navigation Congresses (PIANC), Report of a working group of the permanent technical committee II (Supp. to PIANC Bull.No 47), 1984.

RPS (2005). London Array Offshore Wind Farm, Coastal Processes Investigation, ABP Mer Report No R.1179, (Appendix H, Review of Cable Installation Options), May 2005.

Seacon (2005). Sediment spillage during array cable installation at Nysted Offshore Wind Farm, January 2005, Report 0402-1-1-L001 rev.1.

Scira Offshore Energy Ltd (2006). Sheringham Shoal Offshore Wind Farm Environmental Statement. Non-technical Summary available from http://www.scira.co.uk/newsevents/documents/NTS.pdf

Shields, A., (1936), "Application of Similarity Principles and Turbulence Research to Bed-Load Movement", Mitteilungen der Preussischen.

Thanet Offshore Wind Limited. (2005). Thanet Offshore Wind Farm Environmental Statement.

Subtidal Ecology

Connecticut Siting Council (CSC). (2001). Draft Environmental Impact Report/ Draft Environmental Impact Statement (EIR/EIS) for the Monterey Bay Aquarium Research Institute's (MBARI) Monterey Accelerated Research System (MARS) Cabled Observatory. March 2005. Available at http://www.montereybay.noaa.gov/ new/2005/031505marseir.html.

Dernie, K.M., Kaiser, M.J., Richardson, E.A. & Warwick, R.M. (2002). Recovery of soft sediment communities and habitats following physical disturbance. *Journal of Experimental Marine Biology and Ecology*, 285 – 286: 415-434.

EMU Ltd. (2004). Subsea Cable Decommissioning – A limited environmental appraisal. Report for British Telecommunications Plc, Cable & Wireless, AT&T. pp67.

Greater Gabbard Offshore Winds Ltd., (2005). Greater Gabbard Offshore Wind Farm Environmental Statement.

Johnston, C.M., Turnbull, C.G. & Tasker, M.L. (2002). Natura 2000 in UK Offshore Waters: Advice to support the implementation of the EC Habitats and Birds Directives in UK offshore waters. JNCC Report 325, Peterborough. ISSN 0963 8091.

Kogan, I., Paull, C., Kuhnz, L., Burton, E. J., Von Thun, S., Greene, G. H., & Barry, J. P. (2003). Environmental impact of the ATOC/Pioneer Seamount Submarine Cable. Monterey Bay Aquarium Research Institute, C.A., Monterey Bay National Marine Sanctuary, C.A. Available to download from: http://montereybay.noaa.gov/research/techreports/cablesurveynov2003.pdf

Newell, R.C., Seiderer, L. J. & Hitchcock, D R. (1998). The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the seabed. *Oceanography and Marine Biology: an Annual Review,* 36: 127-78.

Norfolk Offshore Wind (2002). Norfolk Offshore Wind Farm Environmental Statement.

Savidge W.B. & Taghon G.L. (1988). Passive and active components of colonization following two types of disturbance on an intertidal sandflat. *Journal of Experimental Marine Biology and Ecology*. 115: 137-155.

Thanet Offshore Wind Limited. (2005). Thanet Offshore Wind Farm Environmental Statement.

Thrush, S.F., Pridmore, R.D., Hewitt, J.E. & Cummings, V.J, (1991). Impact of ray feeding disturbances on sandflat macrobenthos: do communities dominated by polychaetes or shellfish respond differently? *Marine Ecology Progress Series*, 69: 245-252.

Intertidal Habitats

Environment Agency (2005). Saltmarsh Management Manual. Report prepared by Royal Haskoning. Joint Defra / Environment Agency Flood and Coastal Erosion Risk Management R & D Programme.

Core Limited (2005). London Array Ltd Offshore Wind Farm Environmental Statement. June 2005.

Royal Society for the Protection of Birds (RSPB). (2005a). The Saltmarsh Creation Handbook: A Project Manager's Guide to the Creation of Saltmarsh and Intertidal Mudflat. pp128.

Natural Fish Resource

ABP Research. (1997). Vickers Shipbuilding & Engineering Ltd – GEC marine (VSEL) – Reactivation of shipbuilding facilities at the VSEL Shipyard: Impacts to nature Conservation Interests. Report No. R707.

Bray, R.N., Bates, A.D. and Land, J.M. 1997. *Dredging: a handbook for engineers.* Second edition. London: Arnold.

Centre for Marine & Coastal Studies (2003). A baseline assessment of electromagnetic fields generated by offshore wind farm cables. Report to Collaborative Offshore Wind Research into the Environment (COWRIE) group, Crown Estates.

COWRIE (2003). Investigation into the effects of electromagnetic fields (EMF) generated by offshore wind farm cables under various conditions. Available at http://www.offshorewindfarms.co.uk/Research/ResearchAreas/Electro-magneticFields.aspx#lbl15.

EMU Environmental (2004) Subsea Cable Decommissioning – A limited environmental appraisal. Report for BT, Cable & Wireless, AT&T.

English Nature. (2006) Post consent application correspondence associated with the Thanet Offshore Wind Farm S36 Consent , 20th January 2006.

Gill, A.B. & Taylor, H. (2001) The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon elasmobranch fishes. Countryside Council for Wales. Contract Science Report 488.

Holt, T.J., Rees, E.I., Hawkins, S.J., Seed R. (1998) Biogenic Reefs (volume IX). An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project). 170 pages. Available at http://www.ukmarinesac.org.uk/pdfs/biogreef.pdf.

Marra, L.J. (1989). Sharkbite on the SL submarine lightwave cable system: history, causes and resolution. IEEE Journal of Oceanic Engineering. 14 (3): 230-237.

Nedwell, J., Langworthy, J., and Howell, D., 2003. Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore wind farms, and comparison with background noise. Subacoustec report to COWRIE, reference 544R0424. May 2003. Subacoustech Ltd, Chase Mill, Winchester Road, Bishop's Waltham, Hampshire S032 1AH, UK. 55pp.

Nedwell, J.R. and Howell, D.M., 2004. A review of offshore wind farm related noise sources. Subacoustech report to COWRIE, reference 544R0310. May 2004. Subacoustech Ltd, Chase Mill, Winchester Road, Bishop's Waltham, Hampshire S032 1AH, UK.

Nedwell, J. R., Workman, R. and Parvin, S.J. (2005) The assessment of likely effects of piling noise at Greater Gabbard and its comparison with background noise, including piling noise measurements made at Kentish Flats. Subacoustec Report 633R0115, October 2005.

Norfolk Offshore Wind (2002). Norfolk Offshore Wind Farm Environmental Statement.

Poddubny, A.G. (1967). Sonic tags and floats as a means of studying fish response to natural environmental changes to fishing gears. In conference on fish behaviour in relation to fishing techniques and tactics. Bergen, Norway: 793-802. FAO, Rome.

Posford Duvivier Environment & Hill, M.I. 2001. Guidelines on the impact of aggregate extraction on European Marine Sites. Countryside Council for Wales (UK Marine SACs Project).

Vella, G., Rushforth, I., et al. (2001) *Assessment of the Effects of Noise and Vibration from Offshore Wind Farms on Marine Wildlife*. Report from University of Liverpool Centre for Marine and Coastal Studies Environmental Research and Consultancy to the Department of Trade and Industry Sustainable Energy Programmes. ETSU W/13/00566/00/REP, DTI Pub URN 01/1341. Available at http://www.dti.gov.uk/energy/renewables/publications/pdfs/w1300566.pdf

Commercial Fisheries

CEFAS, 2004 "Offshore Wind Farms: Guidance Note for Environmental Impact Assessment in Respect of FEPA and CPA Requirements", June 2004.

CIRIA (2003). Coastal and marine environmental site guide (C584).

Drew, S.C. & Hopper, A.G. (1996) "Fishing and Submarine Cables Working Together". Guidelines produced by Marine Data Systems for the International Cable Protection Committee.

Elsam Engineering & ENERGI E2, 2005. "Review Report 2004 The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farm: Environmental impact assessment and monitoring." Prepared for The environmental Committee of the Danish Offshore Wind Farm Demonstration Projects, October 2005.

Marine Mammals

Brown, E.G., & Prior, A., (1997/8). Recreational Disturbance to Breeding Seabirds & Seals on Mousa, SSSI. Scottish Natural Heritage.

Defra (2005) Nature Conservation Guidance on Offshore Windfarm Development A guidance note on the implications of the EC Wild Birds and Habitats Directives for developers undertaking offshore windfarm developments.

Duck, C. D. and Thompson D., (2004). The status of British Common Seal populations. SCOS Briefing paper 04-5 on Scientific Advice on Matters related to the Management of Seal populations: 2004, UK Special Committee on Seals, Advice 2004.

English Nature, (2004a). The Southern North Sea Marine Natural Area. External Relations Team, English Nature, Northminster House, Peterborough PE1 1UA.

Hammond, P. S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.F. and Øien, N. (2002). Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology, 39: 361-376.

Hammond, P.S., Gordon, J.C.D., Grellier, K., Hall, A.J., Northridge, S.P., Thompson, D., Harwood, J. (2003). Background information on marine mammals relevant to Strategic environmental Assessments 2 and 3. Report by the Sea Mammal Research Unit for the DTI.

Jansy, M., Reynolds , J., Horowitz, C. and Wetzler, A. (2005). Sounding the Depths. Natural Resources Defense Council, Los Angeles.

Joint Nature Conservation Committee, (2004). Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys, April 2004.

Laist, D. W., Knowlton, A.R., Mead, J.G., Collet, A.S., and Podesta. M. (2001) Collisions between ships and whales. Marine Mammal Science, 17 (1):30-75.

Nedwell, J.R. and Howell, D.M., 2004. A review of offshore wind farm related noise sources. Subacoustech report to COWRIE, reference 544R0310. May 2004. Subacoustech Ltd, Chase Mill, Winchester Road, Bishop's Waltham, Hampshire S032 1AH, UK.

Nedwell, J., Langworthy, J., and Howell, D., 2003. Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore wind farms, and comparison with background noise. Subacoustec report to COWRIE, reference 544R0424. May 2003. Subacoustech Ltd, Chase Mill, Winchester Road, Bishop's Waltham, Hampshire S032 1AH, UK. 55pp.

Sakhalin Energy Investment Company Limited (2005) Marine Mammal Protection: A framework for mitigation and monitoring related to Sakhalin Energy Oil and Gas operations, Sakhalin Island, Russia.

UK Special Committee on Seals, Advice 2004. Scientific Advice on Matters related to the Management of Seal populations: 2004. Available at http://smub.st-and.ac.uk.

Ornithology

Royal Society for the Protection of Birds (RSPB) (2005b). Wind Farms and Birds.

Shipping and Navigation

Department of Trade and Industry (DTI). (2005a). Guidance on the assessment of the impact of offshore wind farms: methodology for assessing the marine navigational safety risks of offshore wind farms. pp 156.

ICPC (1996). Fishing and Submarine Cables – Working Together.

Thanet Offshore Wind Limited (2005). Thanet offshore Wind Farm Environmental Statement. November 2005.

UK Offshore Operators Association Limited (UKOOA). (1997). Guidelines for the establishment and buoyance of safety zones around subsea installations. Issue 2.

UK Offshore Operators Association Limited (UKOOA). (2002). Guidelines for anchor handling in the vicinity of UKCS installations, pipelines and their subsea equipment. Issue 2. October 2002.

UK Offshore Operators Association Limited (UKOOA). (2003). Guidelines for ship/installation collision avoidance. Issue 1.

Whitehead, D. & Comerford, M. (2002). A strategy for Scotland's coasts and inshore waters. Scottish Coastal Forum.

Seascape and Visual Character

Department of Trade and Industry (DTI). (2005b). Guidance on the assessment of the impact of offshore wind farms: seascape and visual impact report. Report prepared by Enviros Consulting Ltd for the Department of Trade and Industry. The Countryside Council for Wales, the Countryside Agency, English Nature, Scottish Natural Heritage and the British Wind Energy Association. pp135. Available at: www.dti.gov.uk/ renewables/pdfs/seascape_rep.pdf.

Marine and Coastal Archaeology

Joint Nautical Archaeology Policy Committee, 2006, Maritime Cultural Heritage and Seabed Development JNAPC Code of Practice for Seabed Development

Wessex Archaeology (in consultation, 2006) Historic Environment Guidance Note for the Offshore Renewable Energy Sector

Guidance

GE Gunfleet Limited (2002). Gunfleet Sands Offshore wind farm. Non-technical summary. 14pp.

Metoc plc (2005). Offshore Cable Installation (Burial) Review Study for GE Energy. Metoc Report No. 1368. October 2005. pp284.

Offshore Wind Power Ltd. (2002). Inner Dowsing offshore wind farm. Volume 1 non-technical summary. 32pp.

Further Reading

ABPmer & Metoc plc (2002). Potential effects of offshore wind developments on coastal process. ETSU W/35/00596/00/REP.

Allan, P. G. (1998). Selecting appropriate cable burial depths – a methodology. IBC Conference on submarine communications. The future of network infrastructure, Cannes, November 1998. Available at http://www.setech-uk.com/pdf/Paper4.pdf.

Amec Energy Ltd (2004). Blyth Harbour wind farm – operation aspects. Report for DTI.

Anderson, J. M. (2002). Decommissioning pipelines and subsea equipment. *Underwater Technology*, **25** (2): 10pp.

BWEA (1994) Best Practice Guidelines for Wind Energy Development: British Wind Energy Association, November 1994. pp27.

BWEA (2002). Guidelines for Health & Safety in the Wind Energy Industry.

BWEA (2002). Consultation for Offshore Wind Energy Developments: Best Practice Guidelines. pp30. Available at http://bwea.com/pdf.bpg.pdf.

BWEA (2005). A guide to Wind Energy: Why Wind? Available at http://www.britishwindenergy.co.uk/ref/whywind.html.

Centre for Environment, Fisheries and Aquaculture Science (CEFAS). (2004). Offshore wind farms: Guidance note for environmental impact assessment in respect of FEPA/CPA requirements. Version 2 – June 2004. Prepared by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS, Lowestoft) on behalf of the Marine Consents and Environment Unit (MCEU). pp 45.

Cordah (2001). Human activities in the North Sea relevant to SEA2. Technical Report produced for Strategic Environmental Assessment – SEA2. Technical Report TR_007. August 2001. Department of Trade and Industry. pp30.

DEFRA (MAFF 1995). Guide to the Preparation of Shoreline management Plans. Shoreline Management Plans: A guide for Coastal Defence Authorities.

DEFRA (2005). Nature Conservation Guidance on Offshore Windfarm Development. A guidance note on the implications of the EC Wild Birds and Habitats Directives for developers undertaking offshore wind farm developments. March 2005. pp 132.

Department of Trade and Industry (DTI). (2000). Decommissioning of Offshore Installations and Pipelines under the Petroleum Act 1998. Guidance Notes for Industry. DTI Offshore Decommissioning Unit. pp 103.

Department of Trade and Industry (DTI). (2000). Guidance on Electricity Works (EIA) Regulations, 2000.

Department of Trade and Industry (DTI). (2005). Guidance on the assessment of the impact of offshore wind farms: methodology for assessing the marine navigational safety risks of offshore wind farms. pp 156.

EMU (2004). Subsea Cable Decommissioning: A Limited Environmental Appraisal. Report for British Telecommunications plc, Cable & Wireless, AT&T. March 2004. pp 67.

ENERGI (2004). Review Report 2004. The Danish offshore wind farm demonstration project: Horns Rev and Nysted offshore wind farm environmental impact assessment and monitoring. Prepared for The Environmental Committee of the Danish Offshore Wind Farm Demonstration Projects.

English Nature, Royal Society for the Protection of Birds, World Wildlife Fund-UK, British Wind Energy Association. (2001). Wind Farm Development and Nature Conservation: A guidance document for nature conservation organisations and developers when consulting over wind farm proposals in England. March 2001. pp 19. Available at http://www.britishwindenergy.co.uk/ref/bpg.html.

Friends of the Earth Scotland (1997). Planning for Renewables. July 1997.

Hill, M., Briggs, J., Minto, P., Bagnall, D. Foley, K. & Williams, A. (2001). Guide to best practice in seascape assessment. Maritime Ireland / Wales INTERREG Report No. 5. March 2001. pp 58. . ISBN 1393 9025.

Hiscock, K., Tyler-Walters, H. & Jones, H. (2002). High level environmental screening study for offshore wind farm developments – marine habitats and species project. Report from the Marine Biological Association to the Department of Trade and Industry New and Renewable Energy Programme. Available at http://ww.og.dti.gov.uk/offhosre-wind-sea/reports/index.htm.

ICPC (2002), Fishing and Submarine Cables: Working Together. pp 48.

Metoc plc (2000). An assessment of the environmental effects of offshore wind farms. ETSU W/35/00543/REP.

MCGA marine guidance note (2004). Proposed UK offshore renewable energy installations (OREI) – guidance on navigational safety issues (MGN 275).

Ministry for the Environment (2006). Environmental best practice guidelines for the offshore petroleum industry. Maritime New Zealand. March 2006. pp14.

OSPAR (2003). Guidance on a common approach for dealing with applications for the construction and operation of offshore wind farms. Presented at a meeting of the OSPAR Commission, Bremen, 23-27 June 2003. OSPAR Ref. 2003-16: 5 pp.

Söker, H. *et al* (2000).: North Sea Offshore Wind – A Powerhouse for Europe. Technical Possibilities and Ecological Considerations. A Study for Greenpeace. Hamburg, Germany: Greenpeace, 2000. Available at http://www.greenpeace.de/GP_DOK_

3P/STU_LANG/C04ST05.PDF.

UK Offshore Operators Association Limited (UKOOA). (1997). Guidelines for the establishment and buoyance of safety zones around subsea installations. Issue 2.

UK Offshore Operators Association Limited (UKOOA). (2002). Guidelines for anchor handling in the vicinity of UKCS installations, pipelines and their subsea equipment. Issue 2. October 2002.

UK Offshore Operators Association Limited (UKOOA). (2003). Guidelines for ship/installation collision avoidance. Issue 1.

Versuchsanstalt fur Wasserbau und Schiffbau, Berlin. In: Ott, W.P. and van Uchelen, J.C. (translators), California Inst. Tech., W.M. Keck Lab. of Hydraulics and Water Resources, Rep. No. 167.

Appendix A: Standards and codes of practice relevant to cable installation & the offshore wind industry

General

The standards set out below should be regarded as defining the minimum required for subsea cables associated with an offshore wind farm.

Minimum Requirements

Works should comply with all appropriate statutory acts and regulations, including, but not limited to, the latest revisions of the:

- Health & Safety at Work Act 1974;
- Management of Health & Safety at Work Regulations 1999;
- Health & Safety (First Aid) Regulations 1981;
- The Reporting of Injuries Diseases & Dangerous Occurrences Regulations 1995;
- The Workplace (Health, Safety & Welfare) Regulations 1992;
- Personal Protective Equipment at Work Regulations 1992;
- The Manual Handling Operations Regulations 1992;
- The Provision & Use of Work Equipment Regulations 1998;
- The Lifting Operations & Lifting Equipment Regulations 1998;
- Health & Safety (Display Screen Equipment) Regulations 1992;
- Control of substances Hazardous to Health Regulations 1999;
- The Noise at Work Regulations 1988;
- Electricity at Work Regulations 1989;
- The Merchant Shipping Act 1988;
- Construction (Design & Management) Regulations 1994;
- Construction (Health, Safety & Welfare) Regulations 1996;
- Confined Space Regulations 1997;
- Fire Precautions (Workplace) Regulations 1997;

- The Fire Precautions Act, 1971;
- The Manual Handling Operations Regulations, 1992;
- The Transport of Dangerous Goods (Classification Packaging and Labelling) and use of Transportable Pressure Receptacles Regulations, 1996;
- The Transport of Dangerous Goods (Safety Advisors) Regulations, 1999;
- The Electrical Equipment (Safety) Regulations, 1994;
- The Construction (Head Protection) Regulations, 1989;
- The Pressure Systems Safety Regulations, 2000;
- The Pressure Equipment Regulations, 1999;
- The Ionising Radiations Regulations, 1999;
- The Control of Asbestos at Work Regulations, 1998;
- The Control of Lead at Work Regulations, 1998;
- The Highly Flammable liquids and Liquefied Petroleum Gases Regulations, 1972;
- The Petroleum-Spirit (Plastic Container) Regulations, 1989;
- The Safety Representatives and Safety Committees Regulations, 1977;
- The Electricity Act, 1989;
- The Health and Safety (Consultation with Employees) Regulations, 1989;
- The Health and Safety Information for Employees Regulations, 1989;
- The Health and Safety (Safety Signs and Signals) Regulations, 1996;
- The Health and Safety (Enforcing Authority) Regulations, 1998;
- The Health and Safety (Training for Employment) Regulations, 1990;
- The Working Time Regulations, 1998;
- The Control of Major Accident Hazard Regulations, 1999;
- Electricity Safety, Quality and Continuity Regulations 2002;
- Marine Guidance Note MGN 275(M);
- The Grid Code, Issue 3, Revision 13, January 2006;
- Guidance Notes for Power Park Developers, Grid Code Connection Conditions Compliance: Testing & Submission of the Compliance Report, June 2005 – Issue 1;
- The National Grid and EDF Connection Offers, in particular Appendix F of the NG offer, a copy of which is provided;
- The Distribution Code and the Code to the Distribution Code of Licensed Distribution Network Operators of GB – Issue 05, August 2004;

- The Distribution Safety Rules of EDF Energy Networks; and
- GB Security and Quality of Supply Standard.

Unless noted to the contrary, all equipment, materials and labour should be supplied, designed and constructed in accordance with the applicable sections of the latest revisions of the following:

- British Standards (BS);
- ISO standards (ISO);
- DNV standards (DNV);
- Electricity Networks Association standards (ENA) – applicable to possible DNO future owned equipment; and
- International Electro-technical Commission standards (IEC).

Electrical Supply Characteristics and Conditions

Aside from the Grid Code, Distribution Code and Connection Agreement conditions the latest editions of the following should be applicable to the electrical connection in line with standard UK practices:

- Engineering Recommendation P28 – Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom;
- Engineering Recommendation P29 – Planning Limits for Voltage Unbalance in the United Kingdom;
- Engineering Recommendation G5/4-1 – Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom;
- Engineering Recommendation G59/1 – Recommendations for the Connection of Embedded Generating Plant to the Regional Electricity Companies' Distribution Systems;
- Engineering Recommendation G75 – Recommendations for Embedded Generating Plant Connecting To Public Electricity Suppliers' Distribution Systems Above 20kV or with Outputs Over 5MW;
- ENA Technical Specification 41-24 – Guidelines for the Design, Installation, Testing and Maintenance of Main Earthing Systems in Substations; and
- Engineering Recommendation S34 – A Guide for Assessing the Rise of Potential at Substation Sites.

Power Cables

The latest editions of the following standards should be considered where appropriate along with other relevant international or national standards as consistent with good UK engineering practices:

- IEC 60228 – Conductors of insulated cables;
- IEC502 – Extruded solid dielectric insulated power cables for rated voltages from 1kV up to 30kV;
- IEC60840 Tests for power cables with extruded insulation for rated voltages above 30kV (Um = 36kV) up to 150kV (Um = 170kV);
- IEC 60885-3 – Partial discharge tests;
- IEC 287 – Calculation of continuous current rating of power cables (100% load factor);
- IEC 853 – Calculation of cyclic and emergency current rating of cables;
- BS 1441 – Galvanised steel wire for submarine cables;
- ENATS 09-16 – Tests on power cables with XLPE insulation and metallic sheath and their accessories, for rated voltages of 66kV (Um = 72.5kV), 110kV (Um = 123kV) and 132kV (Um = 145kV);
- CEGB – TDM 99/45 and 99/56;
- ICEA S68 516 – Ethylene propylene rubber insulated wire and cable for the transmission and distribution of electrical energy;
- AEIC CS6-87 or 96 – Specifications for ethylene propylene rubber insulated shielded power cables rated 5kV through 69kV;
- BS 6469 – Insulating and sheath materials of electric cables;
- ER 55/4 – Bonding systems; and
- ERA Report F/T 186 – Power cable ratings.

Optical Fibre Cables

The latest editions of the following standards should be considered where appropriate along with other relevant international or national standards as consistent with good UK engineering practices:

- IEC 793-1 Optical fibres part 1: Generic specification;
- IEC 793-2 Optical fibres part 2: Product specification;
- IEC 794-1 Optical fibre cables part 1: Generic specification, measurements and tests;
- IEC 794-2 Optical fibre cables part 2: Product specification;
- IEC 1073 -1 Splices for optical fibres and cables part 1: Generic specification;

- IEC 1073-2 Splices for optical fibres and cables part 2: Splice organisers and closures for optical fibre cables;
- ITU-T G.651 Characteristics of a 50/125 micro metre multimode graded index optical fibre cable;
- ITU-T G.652 Characteristics of a single mode optical fibre cable;
- ITU-T G.653 Characteristics of a dispersion-shifted single-mode optical fibre and cable;
- ITU-T G.654 Characteristics of a cut-off shifted single-mode optical fibre and cable;
- ITU-T G.655 Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable;
- ITU-T G.656 Characteristics of a fibre and cable with non-zero dispersion for wideband transport;
- ITU-T G.664 Optical safety;
- ITU-T L13.3 Sheath joints and organisers of optical fibre cables in the outside plant;
- BS EN 60793 Optical fibres – testing;
- BS EN 60811 Insulation and sheathing materials for cables;
- BS EN 61663-1 Lightening protection – fibre optic installations;
- BS EN 60874-10-3 Connectors for fibres and cables – BFOC/2.5 adaptor;
- BS EN 61073 Mechanical splices and fusion splices for optical cables;
- BS EN 187000 Generic specification for optical fibre cables;
- BS EN 187101 Optical telecommunication cables to be used in ducts or direct buried application;
- BS EN 188000 Generic specification for optical fibres;
- BS EN 188100 Sectional specification: single-mode (SM) optical fibre; and
- BS EN 188101 Family specification: single-mode dispersion unshifted optical fibre.

Electricity Supply Industry Requirements

If the project is a Round Two proposal, it will require BERR consents and licensing. Under the generation licence (which is required for generating plant over 100MW) there will be a requirement to become party to a number of core industry agreements. The developer will need to meet the following consents and licensing requirements:

- A generation licence (via Ofgem and granted by Secretary of State).

- Under the British Trading and Transmission Arrangements (BETTA), generation licensees shall be required to become party to the Balancing and Settlement Code (BSC) to include completion of systems and procedures testing processes;
- Generation licensees are required to be party to The Grid Code, Issue 3, Revision 13, January 2006 – National Grid, which defines the operating procedures and principles governing the National Grid's relationship with all users of the GB Transmission System, and the procedures for planning and operation;
- Generation licensees are required to adhere to the GB Distribution Code;
- Generation licensees are required to be party to the Connection and Use of System Code (CUSC);
- In addition, the developer shall be required to comply with the technical requirements on a site specific basis with the local Distribution Network Operator (DNO) and National Grid. These shall include, but not be limited to Appendix F of the National Grid Connection Offer; and
- Wayleaves may be required for new electrical lines and infrastructure and contain specific requirements.

Other Codes

Work should also fully comply with the requirements of: Maritime and Coastguard Agency – Marine Guidance Note MGN 275 (M).

Printed in UK on recycled paper.
Department for Business, Enterprise and Regulatory Reform. www.berr.gov.uk
First published January 2008. URN 07/1680.