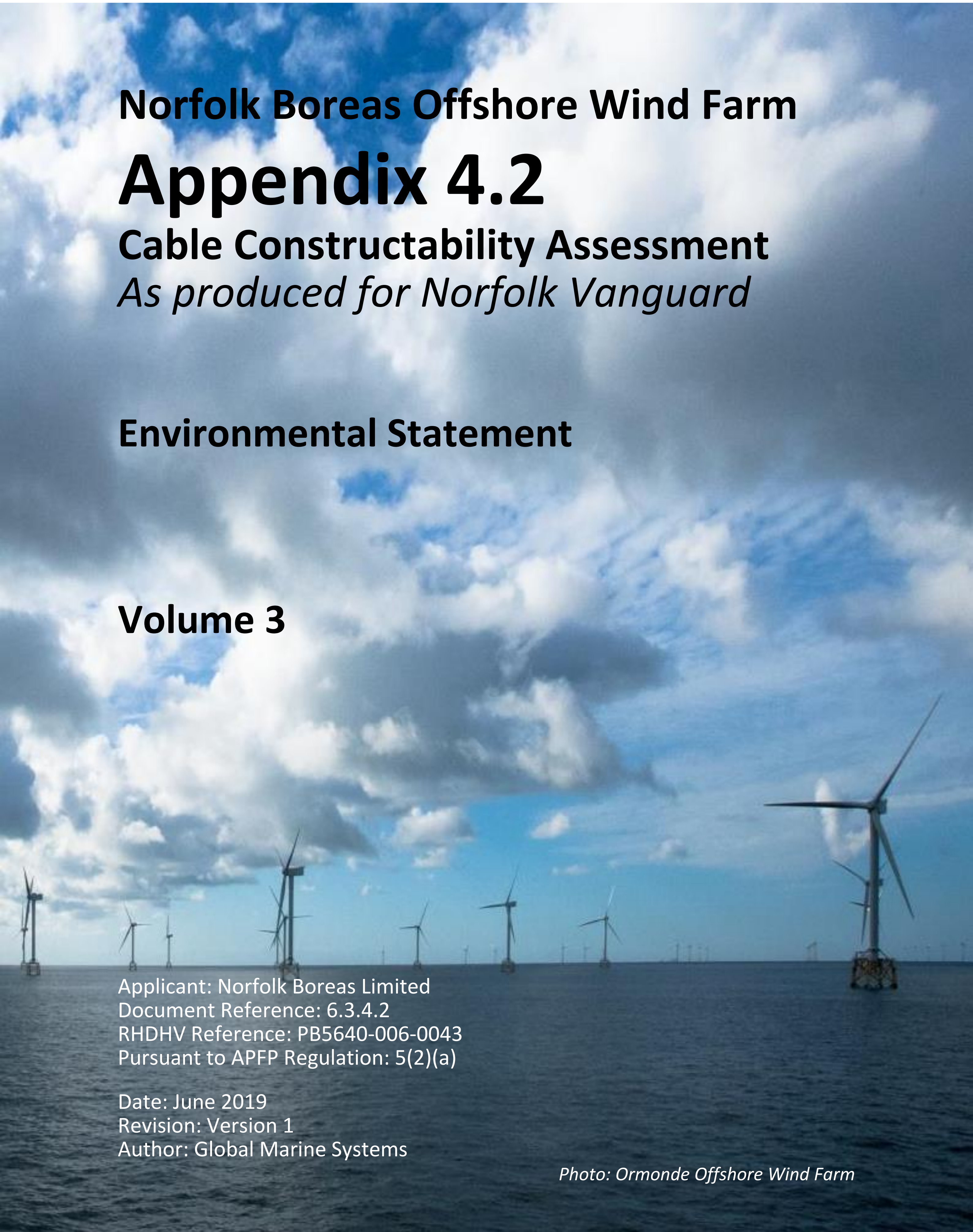

Norfolk Boreas Offshore Wind Farm

Appendix 4.2

Cable Constructability Assessment

As produced for Norfolk Vanguard

Environmental Statement

Volume 3

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Photo: Ormonde Offshore Wind Farm

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GLOBAL MARINE SYSTEMS LIMITED

EAN TRANCHE 1

CABLE CONSTRUCTABILITY ASSESSMENT

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01	Exec Summary Bibliography Various	- - -	Added Added All comments from Vattenfall addressed	SW

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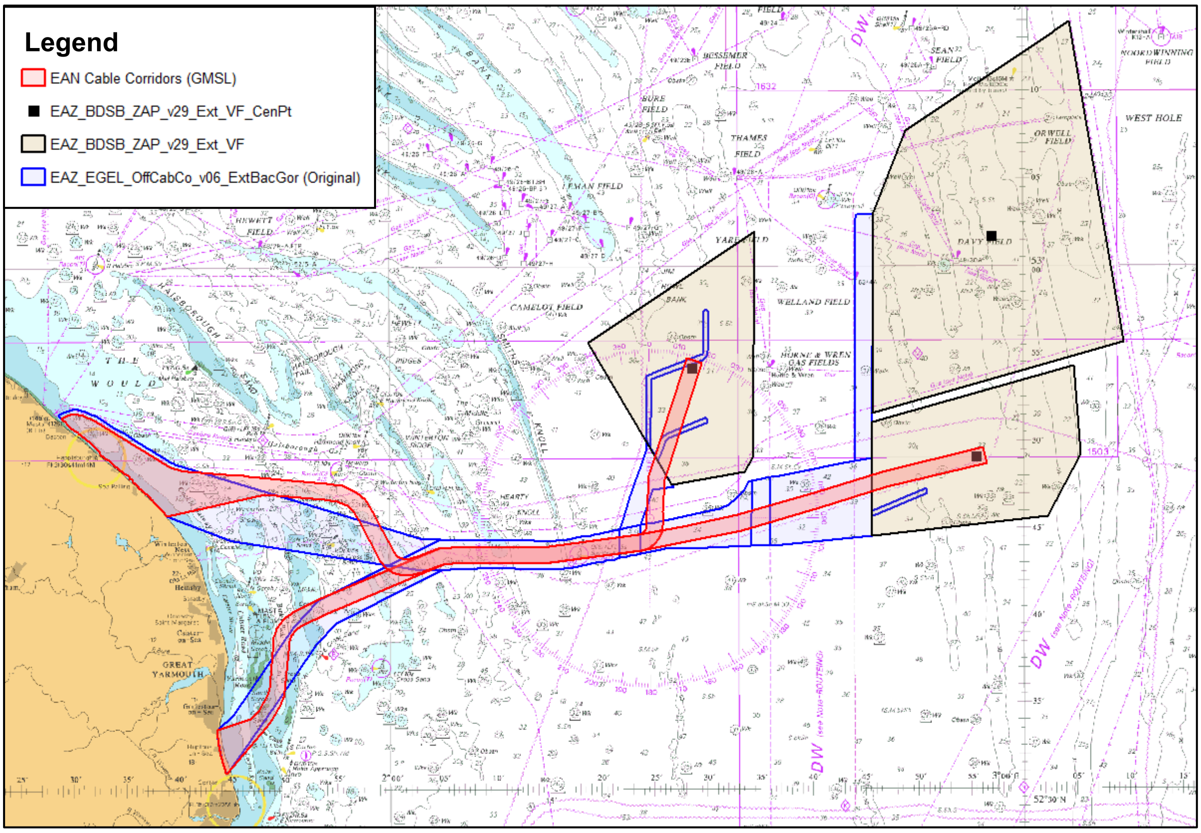
EXECUTIVE SUMMARY

This Cable Constructability Assessment (CCA) for the East Anglia North Tranche-1 offshore windfarm project studies the submarine power cable corridors connecting the potential offshore substations in the east and west array zones to two landfall regions on the Norfolk coast in England.

Routing options and cable constructability have been investigated for the export cable corridors. Two areas of coastline were used as the potential landfall locations, as advised by Vattenfall Wind Power. These areas were;

- NORTH - an area south of the Bacton pipeline landfalls, Bacton – Waxham
- SOUTH - an area south of Gorleston (Great Yarmouth), Hopton - Corton

The study recommends routing corridors to connect the east and west array zones with these landfalls, generally routing to avoid or optimise interaction with existing seabed infrastructure and avoid an existing nearby windfarm and areas of dredging activity. The original Vattenfall and recommended GMSL cable corridors are shown in the overview below.



The study proposes corridor widths for survey which allow for practical installation, whilst ensuring future maintenance can be carried out in line with industry guidelines and benefitting from GMSL's experience. The requirements of both HVDC and HVAC cables, variations in the cable count per corridor and varying water depths are all discussed and corridor widths proposed for the most likely combinations. The resulting GMSL recommended survey corridor width is 1710m. This allows for a 'worst case' scenario and starts at a nominal HDD duct exit point at the 7m water depth contour near the shore and ends at the assumed central locations for the east and west arrays.

The investigation of all the major construction constraints and influences are summarised in the following table.

Constraint/ Influence	Description	Impact on cable corridors
Bathymetry & Bedforms	The project area features a wide variation in bedforms from large sandbanks to small sand ripples. In many places the shallow water over the tops of the sandbanks are a navigational hazard for large cable lay vessels. The combination of loose sandy sediments and high seabed energy result in high levels of bedform mobility.	The cable corridors have tried to avoid or limit the areas where they cross shoal areas with less than 15m charted depth of water. This is has resulted in less direct corridor routes in areas within 25km of the shoreline. Because the east and west array areas are sited in mobile sandwave zones, it has proven difficult to mitigate the risk this poses to maintaining good cable burial protection.
Fishing	Fishing in the project area consists of inshore static gear and potting from a small local fleet and beam trawling carried out by UK, Belgian and Dutch fleets. The most intense trawl fishing is found east of 002° 4' E, and this poses a direct risk of damage to shallow or unburied cables.	The cable corridors are not able to avoid the trawl fishing areas, due to the ubiquitous nature of the fishing effort.
Offshore Renewables	The Scroby Sands offshore windfarm is located 2.5km from shore, just north of Great Yarmouth. It has thirty 2MW turbines which are sited in an array which covers 4km². Export cables connect the OWF to Newtown, Gt Yarmouth.	The cable corridors have been designed to avoid the Scroby Sands windfarm with an additional margin to prevent any possibility of compromising future cable maintenance for either party and to avoid any unnecessary cable crossings.
Aggregate Extraction	A large area of seabed to the east of Gt Yarmouth is licenced for the extraction of aggregates destined for the construction industry. These areas are licenced by the crown estate and are worked by large dredging vessels. The effective area licenced is approximately 20km x 20km.	Due to the risk of cable damage from dredging activities the cable corridors have avoided the licenced aggregate extraction areas with an additional margin to account for any potential errors in navigational positioning of dredging vessels.
Pipelines and Cables	There are numerous hydrocarbon industry pipelines which make landfall at Bacton. Two of these PL1339 Bacton-Zeebruge and BBL Balgzand-Bacton are most influential as they either bound the cable corridors or have to be crossed to reach the array areas. There are numerous in service and out of service telecommunication cables in the project area. Most of these land at Winterton. The two most influential in service cables are UK-Netherlands 14 and North Sea Com which have to be crossed to reach the array areas.	The number of cable crossings have been minimised for all cable corridors and where necessary the crossing angles have been designed to be as close to 90° as possible to limit the interaction between them. The cable crossing counts vary for each GMSL corridor option: NORTH - West: 3 x Cable, 2 x PL NORTH - East: 2 x Cable, 1 x PL SOUTH - West: 2 x Cable, 2 x PL SOUTH - East: 1 x Cable, 1 x PL
MetOcean	The most significant MetOcean factor for cable constructability are the strong tidal currents found in the seas around Norfolk. A highest peak current speed of 3.4 knts is reported by the UKHO. In	The cable corridors have tried to limit the area over which they cross the highest seabed energy levels, however the ability to achieve this is limited due to the other more significant constraints on the corridors and because the current

Constraint/ Influence	Description	Impact on cable corridors
	almost all areas tidal currents of up to 2.5 knts occur. The effect on seabed energy levels is increased in areas of shallow water such as the approaches to shore and the tops of sandbanks, where wave energy contributes further.	strengths remain significant across all areas of the project.
Marine Traffic (Anchors)	The majority of the marine traffic in the project area is coastal transit traffic. There are concentrations of activity east of Great Yarmouth which represent aggregate dredging. Also evident are concentrations and transits associated with the hydrocarbon industry to the north of the EAN T1 array areas and the Scroby Sands OWF. The most intense marine traffic areas occur within 35km of the Norfolk shoreline.	The cable corridors have tried to limit the area over which they cross shipping lanes, however the ability to achieve this is limited due to the other more significant constraints on the corridors.
Shallow Geology	Geologically the seabed in this region is primarily sandy, exact distribution of sediment types varies, with patches of sandy gravel (typically 30-80% gravel) most commonly being found on the shoreward faces of sandbanks. These sandy Holocene deposits largely overlie the Brown Bank Formation, which is composed more of silts and clays with a sandier basal layer. In some places he Twente Formation may lie between the two. The depth of the Holocene sandy layer varies due to the large bedforms found in the area. In some places the older sediments may be exposed at the surface.	Cable burial protection should be achieved in the sediments found across the project area to preliminary target depths using standard industry burial tools such as ploughs and jetting ROV's. Because of this and other more significant constraints on the corridors, the corridors have not been significantly influenced by the surface sediment distribution.
Unexploded Ordnance	Due mainly to activities from WW1 and WW2 the project area is known to contain UXO which may include mines, torpedoes, shells, bombs and small arms munitions. The location of one known UXO position has been presented.	The cable corridors have avoided the known UXO position and have also avoided any wreck clusters (which apart from forming a physical obstruction may host UXO), however subsequent studies and surveys should tackle this risk more comprehensively.

Two previous cables installed in the project area have been used to learn lessons and aid the planning and preparation for the EAN Tranche-1 project. The cables studied in depth were UK-Germany 5 and UK-Netherlands 14.

The result of detailed analysis of the installation reports, marine survey records and cable fault histories shows that the most significant cable security risk to the export cables is likely to be the combination of two factors. Where mobile sandwaves and trawl fishing occur together, both the cables eventually suffered cable damage resulting in faults. The cables were originally buried to an average of 0.8m-0.9m below the seabed. Both cables had a 'honeymoon period' after installation where the depth of cover over the cable was presumably sufficient to protect them, but eventually the mobile sediments reduced this cover to a point where it was insufficient to protect the cables from trawl damage.

A second potential risk identified through the previous cable system records, but not proven to the same level of confidence, occurs in areas with a combination of mobile sediments and high vessel traffic. Here faults due to dragged anchors may have occurred in locations with similarly reduced depth of burial cover.

These risks are a major concern and key to achieving a secure cable route for the EAN Tranche-1 export cables will be to bury the cables below the mobile sediment layer.

Another concern regarding constructability is applicable mainly to the SOUTH corridors. These must cross some sandbanks with very shallow depths. This will prevent the cables from being installed from a single vessel solution and require a shallow drafted vessel to cross these areas. The practical installation challenges this presents are significant. It will also most likely require a marine joint to connect the shore end and shallow area portion of the cable to the longer offshore portion. Power cable joints are typically avoided wherever possible, due to cable heating and the limitations this places on system performance. There is one area on the NORTH corridors which crosses a sandbank, but it only partly occludes the corridor and remains at a depth which may still be acceptable for a larger cable lay vessel (dependant on the final installation solution).

Based on the threat assessments related to fishing and anchors, GMSL recommend a depth of 1.0m across the whole of the export corridor. This should be increased to 2.5m where the cable crosses high vessel traffic lanes to protect against the anchor threat. Crucially these depths need to be achieved below the mobile sediment layer. Therefore determining the volume of mobile sediment where the final routes cross sandwave areas will be critical to ensure cable security. 1.0m exceeds the penetration estimates for trawl fishing gear and 2.5m exceeds the depth of the majority of the estimated largest vessel’s anchor penetration.

The burial tools judged suitable for the project are power cable ploughs and suitably powerful jetting ROV’s. In some areas (maybe all) along the route these tools may be capable of achieving a burial depth to a level which provides security for the cables, however it may be necessary to consider presweeping mobile sandwaves to attain a burial depth which prevents cable faults.

The report ends by making recommendations on the types of survey activities which should be carried out in the future in order to refine the cable routes, assess the mobility of the bedforms and protect the cable from the UXO risk.

Abbreviations

The following abbreviations have been used within this report.

AIS	Automatic Identification System
AOI	Area of Interest
BGT	Bacton Gas Terminal
BGS	British Geological Survey
CCA	Cable Constructability Assessment
CFP	Common Fisheries Policy
CLB	Cable Lay Barge
CLV	Cable Lay Vessel
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
DA	Double Armour
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DP	Dynamic Positioning
DSE	Direct Shore End
DWT	Deadweight
EA	Environment Agency
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMF	Electromagnetic Field
EU	European Union
FRS	Fisheries Research Services
GIS	Geographic Information System
GMSL	Global Marine Systems Limited
HDD	Horizontal Directional Drilling
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICPC	International Cable Protection Committee
JNCC	Joint National Conservation Committee
LAT	Lowest Astronomical Tide
LP	Landing Point
MMO	Marine Management Organisation
NFFO	National Federation of Fishermen's Organisations
OOS	Out of Service

OSS	Offshore Substation
OWF	Offshore Windfarm
PLDN	Plough Down
PLGR	Pre-Lay Grapnel Run
PLB	Post Lay Burial
PLIB	Post Lay Inspection & Burial
PLSE	Pre-Lay Shore End
PLUP	Plough Up
ROV	Remote Operated Vehicle
RPL	Route Position List
SA	Single Armour
SAL	Single Armour Light
SBP	Sub-Bottom Profiler
SFF	Scottish Fishing Federation
SSS	Side Scan Sonar
SCUK	Subsea Cables UK
TAC	Total Allowable Catch
TJP	Transition Joint Pit
UK-GER5	UK-Germany 5
UK-NL14	UK-Netherlands 14
UKHO	United Kingdom Hydrographic Office
UKOOA	UK Offshore Operators Association
USW	Unrestricted Submarine Warfare
UXO	Unexploded Ordnance
VMS	Vessel Monitoring System
WD	Water Depth
WGS84	World Geodetic System 1984
WW1	World War 1
WW2	World War 2

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1.0 INTRODUCTION

1.1 Project Overview

Global Marine Systems Limited (GMSL) has been commissioned by Vattenfall Wind Power to undertake a Cable Constructability Assessment (CCA) for the East Anglia North Tranche-1 submarine power cable corridors. The corridors connect potential Offshore Substations (OSS) in the East and West array zones to two landfall regions on the Norfolk coast in England.

1.2 Background

In December 2009, ScottishPower Renewables (Iberdrola) and Vattenfall Wind Power were awarded rights to develop offshore wind capacity off the coast of East Anglia as part of the Crown Estate's Round Three programme. In August, 2015, the parties announced that they had reached agreement to separately develop projects in the zone. Vattenfall will develop projects in the northern half of the zone and ScottishPower Renewables will develop projects in the southern half of the zone.

Vattenfall is taking forward the EAN Tranche 1 project in the northern area, and is in advanced discussions with The Crown Estate to define the detail of further projects in this section of the zone.

Vattenfall Wind Power are in the early design stages of the new project and are investigating routing options and constructability. Two areas of coastline are currently being assessed for suitability for cable landfall in conjunction with onshore cable routing considerations. These areas are

- NORTH - an area south of the Bacton pipeline landfalls, Bacton – Waxham
- SOUTH - an area south of Gorleston (Great Yarmouth), Hopton - Corton

Two routing corridors have been identified associated with these landfalls, generally routing to avoid key environmental constraints and areas of dredging activity. These original Vattenfall cable routing corridors are shown in Figure 1 below.

The current assumption is that there would be up to 6 cables – 4 to the western area and 2 to the eastern area, however consideration also needs to be given to future development possible to the North of the eastern area.

The extent of the offshore corridors has been set as the assumed central locations for the eastern and western areas.

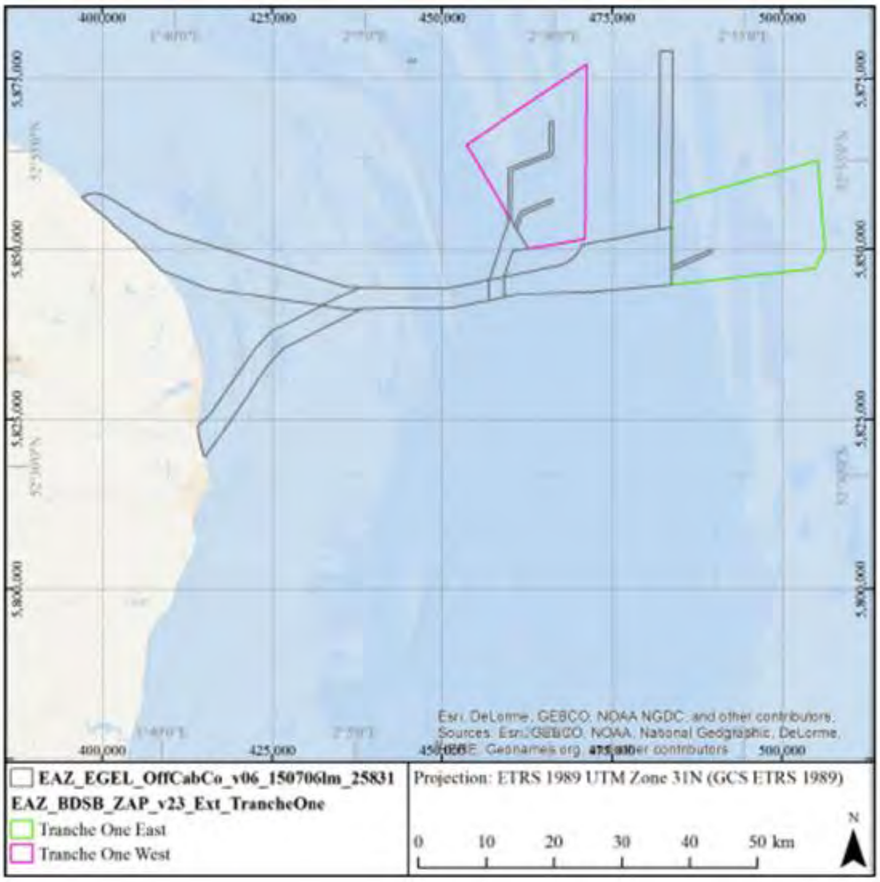


Figure 1 Original Cable Corridor Overview

1.3 Aim/Objective

The aims of this CCA are to firstly review and assess the existing site data and studies available.

Secondly to identify two routeing corridors, based initially on the original Vattenfall corridors, from the landing areas to the centralised points within the western and eastern array areas for the EAN Tranche-1 offshore windfarm which reflect cable constructability influences and practical considerations. The main practical aspects of cable installation are discussed in this CCA.

Thirdly to understand the environment of constraints and influencing factors on the cable route corridors, they are identified and described in section 4.3.

The impact of risk factors on the cable route corridor security, are studied in sections 5.2 and 5.3 and comprise the following:

- Previous cable projects and cable faults in the Area of Interest (AOI)
- Seabed characteristics
- MetOcean characteristics
- Fishing
- Marine Traffic and Anchors
- Seabed Infrastructure
- Unexploded Ordnance (UXO)

Each of these sections identifies the potential impact on the export cable corridor security and perceived risks. Finally section 6.0 covers recommendations for future survey.

A bibliography and set of 4 charts are included in Appendices.

1.4 Project Area of Interest

The Area of Interest (AOI) for the CCA is the seabed surrounding the original cable corridors and the western and eastern array areas. It is broadly defined as the area bounded by the following geographic points.

1. 53° 18.0’ N, 001° 24.0’ E
2. 53° 18.0’ N, 003° 18.0’ E
3. 52° 30.0’ N, 003° 18.0’ E
4. 52° 30.0’ N, 001° 24.0’ E

These points and the resulting AOI can be seen with the original cable corridors and the western and eastern array areas in Figure 2.

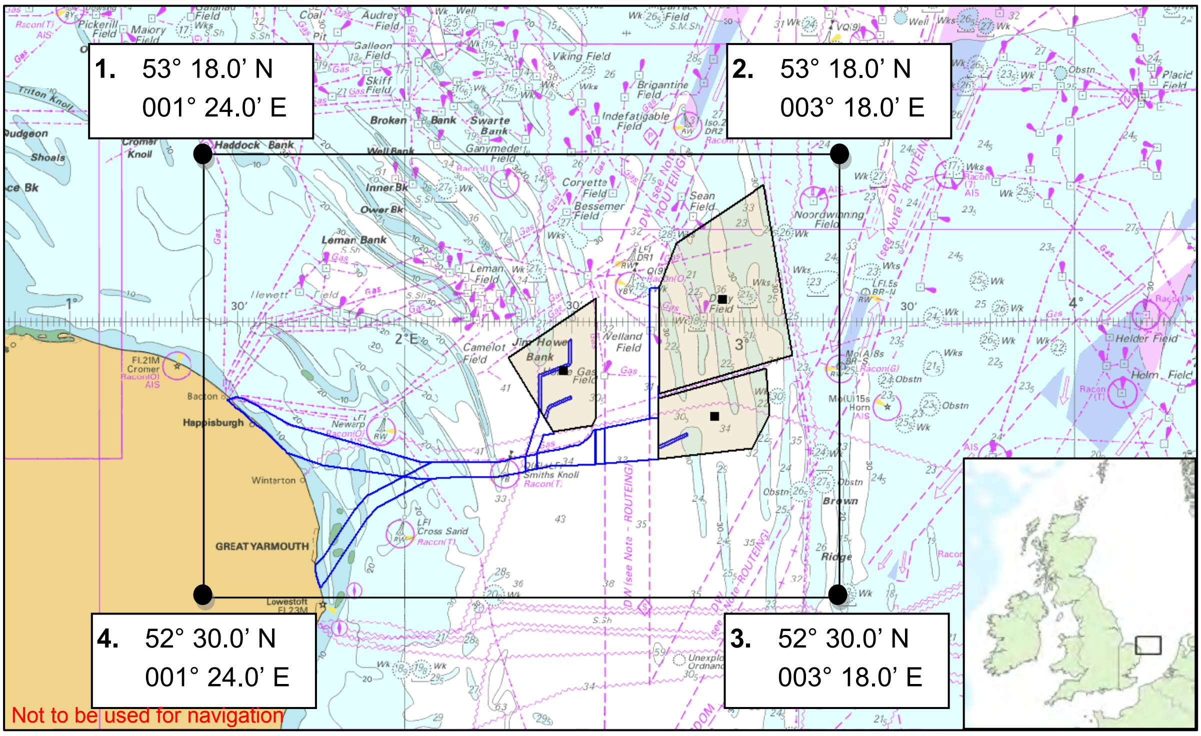


Figure 2 Project Area of Interest

1.5 Deliverables and Timelines

Deliverable	Due Date
Draft Issue Report, Charts	12th Jan 2016
Final Issue Report, Charts and GIS data	3rd Feb 2016

2.0 PROJECT DOCUMENTATION REVIEW

2.1 Sources

The following data sources were used during this CCA

- Vattenfall Supplied Data
  - Reynolds International – Reprocessing and re-interpretation of sub bottom profiling data and development of a ground model for the East Anglia North zone Oct 2015 (Report and charts)
  - ANATEC AIS polyline datasets (Edlei, Fruitful Harvest, Jubilee Pride 2013)
  - EMU East Anglia zone geophysical survey GIS data 2013
- All BT Records for UK-Netherlands 14 and UK Germany 5
  - UK-Germany 5 assessment of seabed mobility report (Plymouth Uni)
  - UK-Germany 5 Plough Assessment Survey (PAS)
  - All BT cable repair reports (25) and fault data
  - UK-GER5 and UK-NL 14 route position lists
  - UK-GER5 Survey charting
  - UK-NL14 Survey Charting
- EMODNET bathymetry shaded DEM and isobaths
- The Crown Estate aggregate licencing areas, dated 13th Aug 2015 (shapefiles)
- Marinetraffic AIS marine traffic density images 2014 (geotiffs)
- JNCC seabed energy dataset (combined wind and wave) UKSeaMap dated 9th Dec 2010 (shapefiles)
- MMO VMS 2010 gridded level 3 fishing data via SCUK
- FRS, CEFAS, UKOOA, NFFO, SFF - Fisheries Sensitivity Maps in British Waters 1998
- Seazone Wrecks and Obs database 2015
- Norfolk chalk reef report – Seasearch East

The complexity of the seabed and sub-surface conditions at the EAN Tranche-1 site will require careful assessment and potentially more detailed follow up surveys. GMSL's recommendations on further survey work are contained in section 6.0.

3.0 PRACTICAL ASPECTS OF EXPORT CABLE INSTALLTION

3.1 Introduction

In order to appreciate some of the findings and recommendations of this report it is helpful to review some common practical aspects of submarine power cable construction. This section describes some typical aspects for shore end and offshore cable installation operations. The final cable installation methodology will be determined at a later stage, but may comprise one or more of the operations described here.

3.2 Shore End Operations

Shore end operations are those which occur on land and the intertidal zone during the cable installation. Some of the most common shore end considerations are discussed in this section.

Where submarine power cables reach landfall a joint is made to the terrestrial power network. This takes place at the transition joint pit (TJP). The TJP contains and protects the marine/terrestrial cable joint. It is usually a rectangular area with a concrete construction. The dimensions are normally determined by the number of cables to be accommodated and the size of the ducts for the cables. The position for the TJP is likely to be landward of the beach, above the high water mark. Local factors at the landing point will influence the position of the TJP. These can vary from access for construction plant, the location of environmentally or archeologically sensitive areas, or the capabilities of Horizontal Directional Drilling (HDD) equipment to cope with the profile of the coast or any sea defences.

The cable should be protected along its whole length from the TJP to the shoreline, through the intertidal zone and seawards as it proceeds offshore. The most popular method of cable protection is burial. This has a proven track record of protecting the cable from human and natural risks and eliminates any danger to the public.

Burial of the cable is most commonly achieved in two ways.

The first of these is to use construction excavators to open a trench for the cable between the TJP to the furthest possible extent seawards to a position where marine burial tools become effective. The exact transition point from terrestrial to marine burial tools will be project specific. Marine cable burial tools can be placed further up the beach at high water, reducing the area where excavators are needed. Trenches can either be pre-dug, or the trench is excavated and backfilled after the cable has been pulled ashore. Trench widths vary depending on the shore ground conditions and construction methods (open trenching vs trench support systems).

The depth of burial within the intertidal and nearshore areas will depend on the cable design, and the area's sediment mobility. The thermal dissipation properties of the ground and cable, if too deeply buried, may risk overheating and subsequently limit power transmission. Alternatively a particular section of the coastline may be at risk of sediment erosion. Final route designs within the export corridors should take account of these issues before recommending the depth of burial will be required in this zone. A minimum depth of cover may be required above a forecasted seabed level (accounting for erosion) to ensure continual protection and no exposure over the design life of the cable.

The second most common approach to achieving burial is the use of HDD techniques. This is a method particularly suited to the following;

- Avoiding disruption to existing sea defences or other constructions with significant foundations
- Avoiding disruption to protected environmental features or endangered species
- Achieving a landing at sites with a high energy environment such as steep or unstable cliffs
- Achieving a landing in areas with dangerous nearshore surf conditions

- Avoiding disruption to very popular recreational beaches
- Avoiding disruption to sites of historic importance

If HDD is required then the duct may be drilled from the land or offshore. More typically it is conducted from land. If from land, then heavy construction plant access must be available at the bore/duct entry point. If the HDD duct is drilled from land, the exit point can be designed to be either above or below MLW but diver intervention is required if the exit point is underwater. HDD duct distances are limited by the geology of the site, the appropriate drilling technology and methodology and drill rig size. On the Norfolk coast GMSL have experience of a 360m duct connecting the TJP to an offshore exit point at a depth of 7m (LAT).

For the EAN Tranche-1 project Vattenfall have asked GMSL to assume the use of HDD technology for the cable landings. To reach the 7m water depth isobath will require an estimated HDD duct length of between 1,000m and 1,400m for the (South) Hopton - Corton landing and 600m and 900m for the (North) Bacton – Waxham landing. These distances are all potentially within the capabilities of HDD technology, but longer ducts are likely to increase the cost if the geological environment is similar.

3.3 Offshore Installation Considerations

The offshore cable installation considerations applicable to the project depend on the cable installation solution and most importantly choice of cable installation vessel and burial tools. Some of the most common installation considerations are discussed in this section.

Shallow water cable operations can be a complex and time consuming aspect of the overall cable installation. One of the first considerations is the depth of water required by the installation vessel to safely hold its position inshore during shore end operations. This will determine the closest approach the vessel can make to the landing point shoreline.

A Cable Lay Barge (CLB) with a flat bottom can be used to install either a complete cable or specific sections of a cable route in shallow water. This might be the shore end section from land or an HDD exit point to the closest approach point for a Cable Lay Vessel (CLV) At this point the CLV can safely hold its position and undertake cable jointing operations or float the cable towards shore or the HDD entry point before continuing with the installation.

Some flat bottomed barges are able to ground out, given an adequate survey is undertaken and local conditions allow. They can be either self-propelled or rely on support vessels to provide towage and assistance. They also tend to operate with an anchor spread, requiring working space which is dependent on water depth but can typically be in excess of 200-300m either side of the cable route. Anchor spread patterns must account for other vessel operations and seabed users.

From a financial perspective, having to mobilise two installation spreads, with the associated issues of cable jointing and increased mobilisation activities, can lead to an increase in overall project cost. Therefore, a route which does not require multiple installation spreads, is generally a more cost effective solution. Whilst this is normally true, if the export cable is a long distance and uses a heavyweight cable, it may then require multiple loads and subsequently offshore joints. The solution will ultimately depend on the capacity of the installation vessel(s) chosen and final cable design. From a power transmission point of view, subsea joints are generally avoided if at all possible, due to the limitations they place on the cable's transmission performance.

A large, self-propelled CLV, usually a cable ship, able to accommodate a long length of cable on a high payload carousel or turntable is considered to be most appropriate for installation of large and long export cables. The capabilities of such CLVs have increased recently with newer higher capacity vessels coming onto the market. Whether such a vessel is able to install the export cables for EAN Tranche-1 in one length is not known at this time as the final lengths and cable designs have not been chosen, however it is conceivable that the vessels available to the project at the time of installation would have this capability.

As a guide, a depth of between 10m and 15m LAT is typically deemed the minimum depth of water required to operate a CLV. The exact depth is influenced by the particular vessel, the captain, the amount of cable onboard (which may also influence the lay direction) and the operator's assessment of risk to the vessel. A typical CLV may draw 7 or 8m, when laden. This study uses 15m water depth as an indicator of navigational risk for a CLV. This is discussed more in sections 4.3.6.2 (Navigation Hazard) and 4.4 (Resulting Corridors).

Burial offshore can be achieved through the use of ploughs, water jetting or sometimes rock cutting (hard ground trenching). Power cable ploughs are large (~14-16m long), heavy (~30-45T) and designed for use with the types of larger diameter cable, typical of export cables. They are towed behind the installation vessel and one of their merits is simultaneous installation and burial. Ploughs are often the most economic form of cable burial but various situations can affect their performance. The shallow geology and characteristics of the surface sediments will affect the depth of burial and progress rate of the plough. Ploughs can operate in loose sands and soft to firm clays. They are not suitable in areas with large boulders which can obstruct or destabilise and topple a plough. The plough towing force has a direct impact on the plough's potential performance, with high bollard pull vessels providing significant advantages.

Seabed bedforms (sandwaves and megaripples) can prevent consistent burial performance. This can be due to the local excessive seabed slopes destabilising the plough (risking plough toppling) and causing rapid variations in tow tensions as the plough transitions from ascending to descending the flanks of each sandwave. The relationship between the plough's length and sandwave wavelength can be such that the burial depth varies, simply due to the plough's geometry in respect to the seabed. This sandwave problem is particularly relevant for the EAN Tranche-1 corridors, which contain several areas of marked seabed bedforms. The specific areas and risks due to bedforms are explored further in sections 4.3.6 and 5.3.3 respectively.

Water jetting to bury cables is typically undertaken after the cable is laid onto the seabed as a separate operation. The most common way of jetting is the use of a Remote Operated Vehicle (ROV). These use water pumps to direct seawater through high pressure nozzles to cut into the seabed sediments and fluidise the seabed to open up and form a trench into which the cable descends. ROV's require a stable vessel/platform to launch, recover and operate from and good position keeping capabilities whist the ROV is underwater.

When burying a power cable the thermal properties of the seabed will affect the cable's heat dissipation and so the cable may be sensitive to the depth of burial. Both a minimum and maximum depth of cover may be specified. Too deep and the cable may risk overheating, too shallow and it may be at risk from external aggression.

The different burial tools will have different turning abilities on the seabed. This is important at this stage because the export corridors must be able to accommodate numerous cable, the appropriate cable separation distances and the rates of turn of typical burial tools. Therefore extreme changes in export corridor direction have been avoided. Based on GMSL's experiences of designing and installing previous export cable routes, a minimum turning radii of 600m to allow for a cable on the inside edge of the corridor should be adopted if plough burial methodologies are to be viable. The following section 3.4 (Cable Separation Planning) which expands on the topic of cable separation and appropriate corridor design.

Seabed slopes can destabilise cable burial tools. Excessive slopes can cause the tool (Plough/ROV) to topple and therefore has the potential to damage the tool and the cable product. It should be noted that both the UK-Germany 5 and UK-Netherlands 14 telecoms cables were installed using a cable plough over sandwaves with flank slopes up to 20°. The susceptibility of a burial tool to toppling is also affected by the force and direction of tidal currents, whether the plough share or ROV jetting swords are engaged in the seabed (acting like a keel on a yacht) and for ploughs, whether a steering side force (via a the tow wire) is being applied in the same direction as a slope. GMSL typically recommend a maximum upslope angle of 12-14°, downslope angle of 10-12° and side slope angle of around 5° for plough operations depending on local conditions.

Seabed obstructions such as boulders, wreckage and debris form obstacles for the cable and burial tools. Obstacles may prevent cable burial and put the burial tool at risk of damage via direct impact, ensnaring (causing subsequent damage on recovery) or instability, causing the tool to topple.

Similar to obstruction avoidance, it is recommended that wherever possible interaction between the EAN Tranche-1 export cables and existing seabed infrastructure is avoided. Sometimes the cable(s) being installed cannot avoid crossing other existing seabed infrastructure such as other cables and pipelines, in these cases the number of crossings should be kept to a minimum and the crossing angles optimised to as close to 90° as possible.

Cables laid on the seabed require some slack (additional cable in excess of the physical geographic distance from each point along the route). The cable slack selected must allow for the cable lay methodology and the seabed topology.

3.4 Cable Separation Planning

GMSL have been asked by Vattenfall to engineer export corridors which can accommodate initially the development of 6 export cables, with enough room for 6 further cables lying north of the original development.

Two assumptions have been made which affect the recommendation on cable separation. They are related to the type of electrical current technology used by the project. They are:

Scenario 1 - An initial development of 6 separate HVAC cables with no necessity to place bundle them for EMF radiation purposes. 2 cables to the eastern site and 4 cables to the western site.

Scenario 2 – An initial development of 4 HVDC cables where the routes will feature bundled pairs to reduce the effects of EMF radiation. 2 cables to the eastern site and 2 cables to the western site.

In order to ensure the recommended export corridors are of sufficient width to accommodate these cables, an assessment has been made based on the key objectives cited in The Crown Estate published, Red Penguin Associates Ltd 2012 document – ‘Export transmission cables for offshore renewable installations, Principles of cable routeing and spacing’. These are;

- *Appropriate spacing to minimise the risk of multiple cable hits from anchors inadvertently released with the vessel underway*
- *Minimising the effects of induced EMF on navigation and the ecology*
- *Appropriate spacing to minimise the risks to existing cables during subsequent cable installation or maintenance*
- *Avoiding interaction between transmission cables therefore avoiding or minimising the need for crossing and/or proximity agreements*

Each of the objectives is addressed in turn in the following subsections.

3.4.1 Anchor Hit Risk separation requirements

Anchors pose a significant hazard to submarine cables, being designed to penetrate the seabed. Ships anchors are generally deployed as a temporary mooring or to stop the ship in an emergency such as when the ship suffers an engine failure. Recent evidence would suggest that the incidents of inadvertent anchor release whilst the vessel is underway are more common than was at first believed. Although they remain a rare event, there is still the potential to cause serious damage to a series of cables over a wide area.

If the future EAN Tranche-1 export cables pass through areas of high marine traffic movement and increased cable protection through deeper cable burial cannot be achieved then other solutions to cable protection are needed. One solution to reducing the risk is to increase the cable separation distances to try to prevent multiple hits from a single dragged anchor. The need for this measure is unquantifiable at the moment; however high levels of traffic are known to exist in the AOI. Once the exact cable numbers and adopted corridors are known, this issue should be readdressed.

3.4.2 Induced EMF separation requirements

If HVDC technology is used by the EAN Tranche-1 cables then these are likely to be in bi-polar pairs. The spacing between the cables in the bi-pole has to be very small and is likely in this case to bundle them together in order to minimise the impact on magnetic compasses.

The magnetic field of cables combine with the Earth's field and can cause a possible deflection of a magnetic compass from true magnetic north and there is a concern this may interfere with vessels using an automatic pilot, when navigating in the immediate vicinity of subsea HVDC cables. The amount of deflection in the compass will depend on:

- Distance between the conductors of the bipolar cables
- Magnitude of the DC current
- The total vertical distance, including burial depth, between the compass and the pair of bipolar cables
- Magnitude of the local geomagnetic field and the orientation of the cables within the field
- The cable route heading.

As the solution to this problem is close proximity of the bi-pole cables it has been assumed each pair will be bundled together. Note however, the decision on cable technology and design has not been taken at this stage in the project.

HVAC cables have different EMF issues which are not fully understood. A study carried out by Vattenfall in 2010 comments on HVAC that “no research results were found that suggested that present sub-sea power cables posed as a threat to marine environment due to EMF” (Olsson et al 2010) our conclusion is until any evidence suggests otherwise, the cable routes should not be influenced by EMF radiation concerns.

3.4.3 Interaction with other transmission cables

To minimise interaction with other transmission cables we can consider two broad areas. The prevention of interaction with other existing cables already in-situ, and secondly the interaction between the EAN cables as each tranche and development is constructed.

The only existing transmission cables in the AOI are those serving the Scroby Sands OWF. It is clear that crossing these cables is something the EAN project should avoid.

Regarding interaction between the various phases of the EAN project – none of the export cables routes which are finally engineered should cross each other. Section 3.4.4 explains how a minimum separation distance for installation between cable pairs has been calculated and a contingency for seabed obstacle and feature avoidance included in order to achieve this. The final installation methodology and sequencing for the various cable pairs will determine if the cable installation activities pose a risk to other cables. The first cable installed will be free from any restrictions, but subsequent cables may be at risk if an anchor positioned vessel with a multiple anchor spread is used. At this stage it is not possible to tell what risk there will be (if any), however it is anticipated that a DP vessel without the need for anchors is more likely to be the main installation solution, which would alleviate this concern. Therefore at this stage no adjustment to the cable separation distance has been included to prevent interaction. Closer to shore and in areas of shallow water (<10m) there may be a need to deploy anchors from installation vessels. In such circumstances a common restriction is that anchors cannot be set within 100m of a cable where the anchor line would be recovered towards the power cable and within 50m where the anchor line would be recovered away from the power cable.

3.4.4 Installation and Maintenance separation requirements

Should an export cable require a marine repair joint it will be deployed by the installation vessel in a bight, laid to one side of the original cable route. The maximum horizontal offset of this bight is determined by a combination of the physical characteristics of the installation vessel and the depth of the seabed at the cable repair site. The key vessel dimensions are shown in Figure 3.

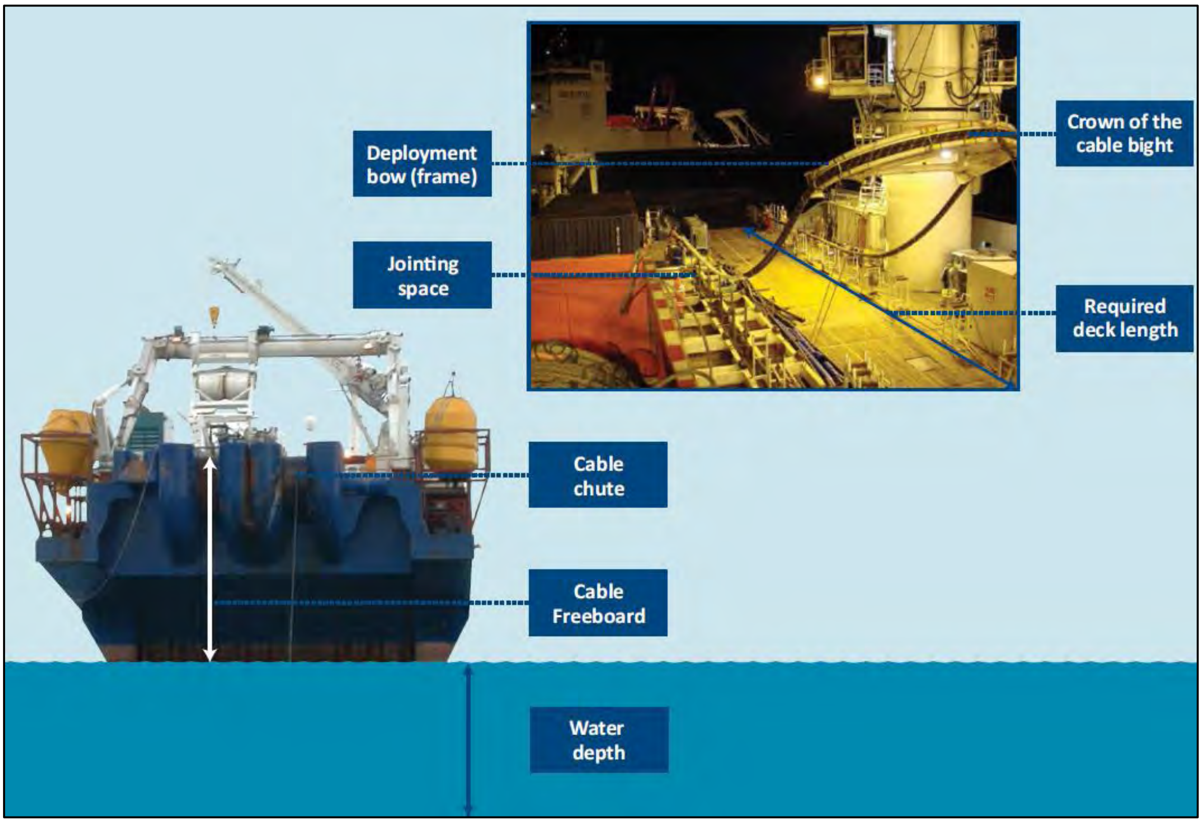


Figure 3 Dimensions and Terms Relating to Cable Repair Bights

There are 4 dimensions which will make up the repair bight length, The depth of water, the deck length from the cable chute to the jointing space, the crown of the cable bight and the cable freeboard from the water level to the cable chute. These add together to form the repair bight length. Some space adjacent to the repair bight is advised to allow for future access to the repaired section of cable. The distance this bight then lays to the side of the original cable route (a) and the access space (b) is shown in Figure 4.

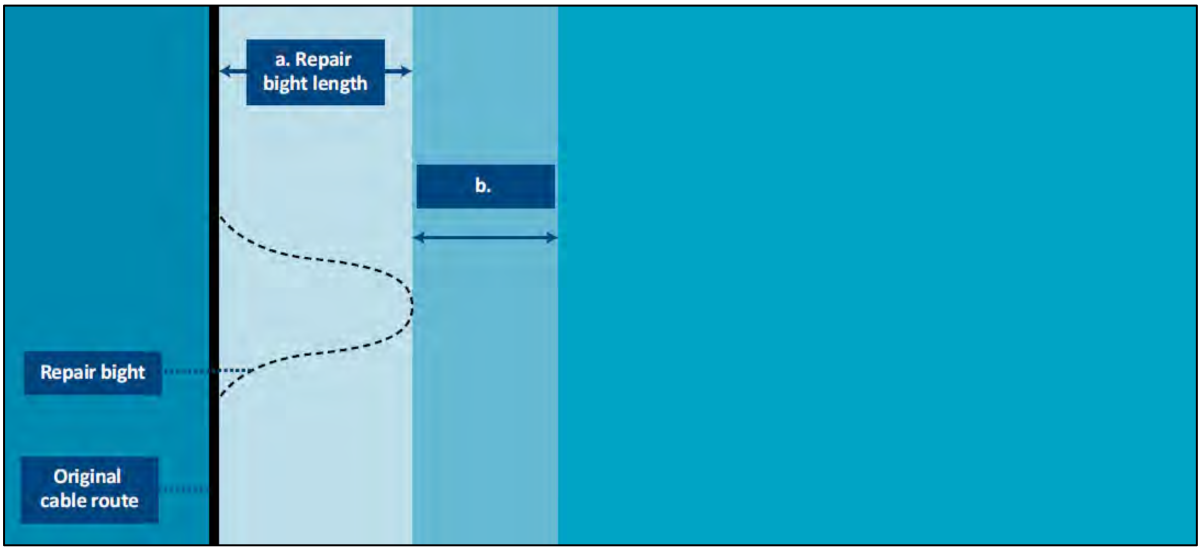


Figure 4 Final Repair Bight Layout Diagram

The Crown Estate, Principles of cable routeing and spacing, advises on the appropriate size of the access space (b) based on the water depth at the repair site. This table is reproduced here as Table 1.

Water depth (metres)	Cable repair bight displacement (metres)	Additional corridor width for future access to repair bight (metres)
	'a'	'b'
Minimum	Water depth + freeboard + repair bight crown + deck length	50
10-100	Water depth + freeboard + repair bight crown + deck length	100
100-200	Water depth + freeboard + repair bight crown + deck length	200

Table 1 Cable Repair Bights - Minimum Dimensions

The following calculations are based on this guidance for the EAN Tranche-1 export cables and a nominal vessel based on a modern large capacity DP2 cable lay vessel.

Minimum Water Depth

Water Depth Minimum (LAT) =	7m
Estimated repair vessel deck space dimension =	47m
Estimated repair vessel bight crown dimension =	5m
Estimated repair vessel cable freeboard dimension =	6m
Minimum Dimension (a), Cable Repair Bight =	65m
With 10m contingency to avoid overlay =	75m

Maximum Water Depth

Water Depth Maximum (LAT+ max tidal range 4m) =	52m
Estimated repair vessel deck space dimension =	47m
Estimated repair vessel bight crown dimension =	5m
Estimated repair vessel cable freeboard dimension =	6m
Minimum Dimension (a), Cable Repair Bight =	110m
With 10m contingency to avoid overlay =	120m

The water depth from HDD exit (nominal 7m LAT) to the assumed central locations for the eastern and western arrays does not exceed 48m, LAT based on Admiralty navigation charts. The additional corridor width for future access advised by The Crown Estate Principles of cable routeing and spacing is 100m for the vast majority of the corridors, with the exception of the closest portion of the corridor near to the HDD exit point where is drops to 50m.

However GMSL believe the future access distances are only required for the outer cables or when passing a seabed feature which represents a navigational risk (e.g. a shoaling bank). Most importantly the separation distance between cables should be able to accommodate a repair bight at any point along each cable with a modest contingency to prevent overlaying adjacent cables (10m). This repair bight space could be accommodated on one or both sides of the cable.

A potential solution for cable separation with the HVDC scenario is presented in Figure 5. The figure is divided into the two extremes of water depths found along the EAN Tranche-1 corridors. 7m is represented with a green background and 48m with a purple background. 4 pairs of bi-pole HVDC cables are shown, 2 pairs for the first development and 2 pairs for the second. This provides for the maximum space requirement scenario, where all 4 pairs of HVDC cables are bundled and installed in the same corridor.

The spacings of 105m and 210m from the outer cable corridor boundary to the outer cable pairs are based on the repair bight size in each depth of water plus the appropriate future access space as presented in Figure 4 and Table 1.

The separation between cable pairs of 75m and 120m allow for a repair bight plus 10m to be laid either side of the original cable route.

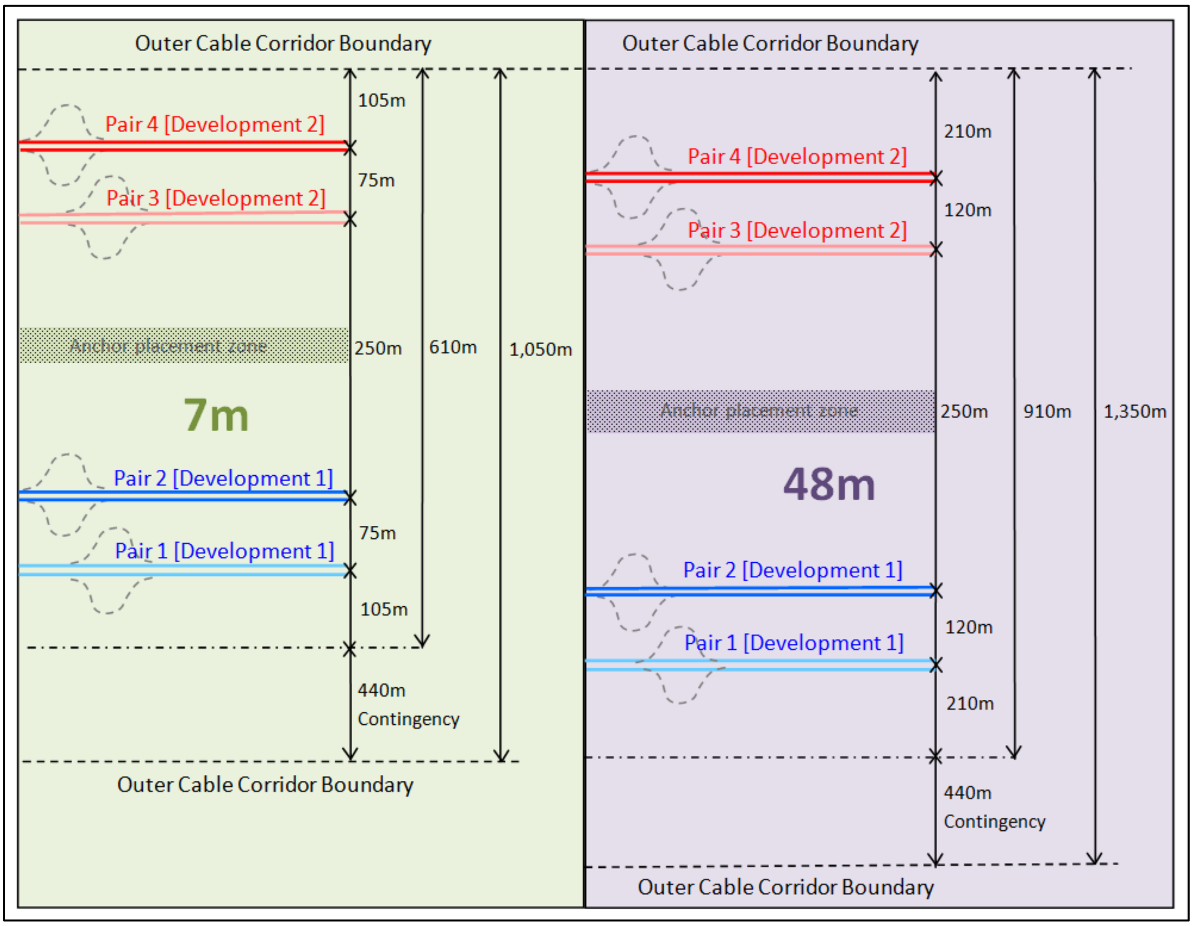


Figure 5 HVDC Cable Separation Calculation Diagram

A central anchor placement zone with a width of 250m has been created to accommodate any vessels needing to set anchors to hold position whilst installing or maintaining the cables. The width of the anchor placement zone is based on previous experience of exclusion zones for anchors which are dependent on the direction the anchor will be recovered. When recovering away from an adjacent cable a 50m exclusion zone is commonly requested. When recovering towards an adjacent cable with zone increases to 100m.

A potential solution for cable separation with the HVAC scenario is presented in Figure 6. As with Figure 5, it is divided into the two extremes of water depths found along the EAN Tranche-1 corridors. 7m is represented with a green background and 48m with a purple background. 12 HVAC cables are shown in total, 6 for the first development and 6 for the second. This provides for the maximum space requirement scenario, where all 12 HVAC cables are installed in the same corridor.

As with the HVDC scenario, the spacings of 105m and 210m from the outer cable corridor boundary to the outer cable pairs are based on the repair bight size in each depth of water plus the appropriate future access space from Figure 4 and Table 1.

The separation between cables is slightly different. The individual cables have been grouped into pairs 20m apart with separation distances of either 75m or 120m allowing for a repair bight and an additional 10m to be laid to one side of the original cable route. The 20m separation is based numerous factors. Power cable plough widths, water depth and plough steering and positional accuracy. For this project 20m has been calculated to be an approapriate figure and allows for ploughing, post lay jetting etc without risk of disturbing or damaging the other cable. The larger separation distances allow for future repair bights.

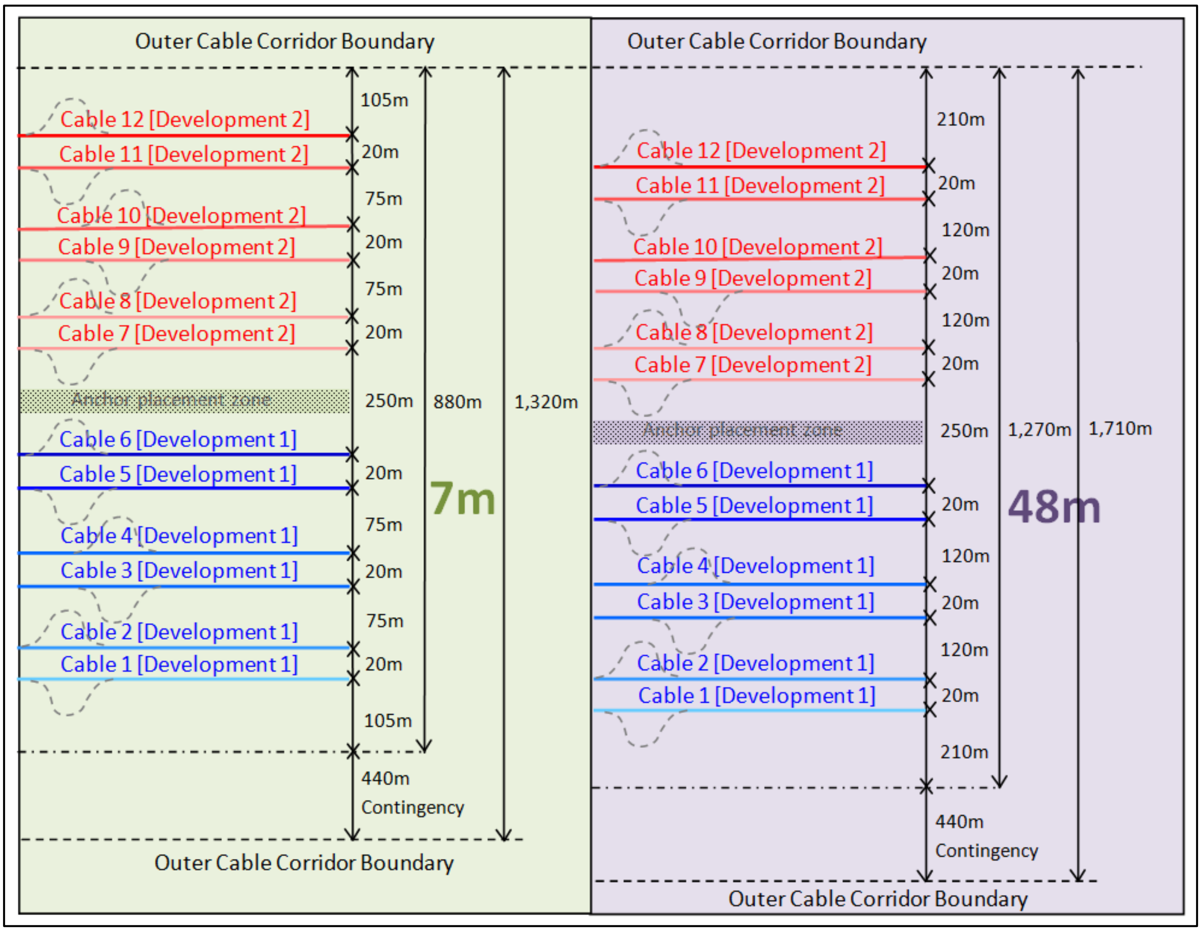


Figure 6 HVAC Cable Separation Calculation Diagram

The same central anchor placement zones of 250m have been retained to allow for anchor positioned vessels to operate along the corridor, should they be required by the final installation solution.

The final cable separation distances should be reviewed as the project develops and the cable technology, installation solution and methodology are fixed.

A contingency figure of 440m has been added in all cases to allow for reasonable avoidance of seabed features or obstructions not found at this stage but subsequently discovered during survey. The 440m figure is arbitrary but based on experience. Vattenfall could opt to reduce this figure or even eliminate it and move towards a route development strategy at the survey stage. Route development is the extension of the survey corridor based on a near real time decision process during the survey campaign. It is a higher risk approach and needs careful survey management. It normally requires the client survey representative to make have the authority to make decisions on additional survey lines whilst offshore, and requires an experienced representative.

As can be seen from Figure 5 and Figure 6, the maximum cable corridor sizes suggested are 1,320m at the 7m water depth, increasing to 1,710 for 48m. The actual corridors recommended by this report are shown and described in section 4.4 of this report and use the largest 1710m width throughout as a minimum.

4.0 EXPORT CABLE CORRIDOR INDENTIFICATION

4.1 Introduction

This assessment uses the original Vattenfall Wind Power corridors as a starting position and examines each of the constraints or constructability influences which exist within the AOI and their geographic locations. The result is a set of GMSL recommended EAN Trache-1 export cable corridors shaped by these constraints and influences which are presented and described in section 4.4.

The various figures within this section of the report display the original Vattenfall corridors (Vattenfall GIS ref: EAZ_EGEL_OffCabCo_v06_ExtBacGor) for reference.

4.2 Original Vattenfall Design Criteria

The original Vattenfall Wind Power design criteria for the EAN Trache-1 export cable corridors were the following;

1. 1 km minimum width for each export cable corridor option (where possible, at least 2 km has been maintained)
2. Crossings with other cables and pipelines to be achievable between 60° and 90°, but as close to 90° as possible
3. A 255 m buffer to be maintained from active cables
4. No routes through aggregate extraction areas
5. Crossings at the Deep Water (DW) routeing channel within the East Anglia zone to be as short as possible (i.e. crossing angle 90°)

All these original constraints are respected and built upon by the constructability influences identified in section 4.3 below.

4.3 Description of Constraints and Influences

4.3.1 Pipelines

Bacton Gas Terminal (BGT) situated on the coast of Norfolk currently supplies a third of the UK's demand for natural gas and acts as the primary interconnector between the UK and continental Europe. BGT plays an important role in processing and distributing the natural gas exploited from the North Sea to its end consumer. Operated by Shell, the gas terminal accepts natural gas from numerous offshore pipelines from the North Sea, of which two pipelines are used to export gas to both Belgium and The Netherlands.

There are two pipelines that cross or are in close proximity to the export cable corridors and these are listed in Table 2.

Name (Fluid)	ID	Dia	Operator	Notes
BACTON TO ZEEBRUGE (GAS)	PL1339	40"	Interconnector UK Ltd	A crossing of this pipe and the export corridors is unavoidable
BBL BALGZAND TO BACTON (GAS)	PL2225	36"	BBL Company	This pipe effectively forms the northern boundary of the corridor

Table 2 Pipelines in Close Proximity

The Bacton to Balgzand gas pipeline connects The Netherlands to the UK and is highlighted in orange in Figure 7 that will influence the highlighted cable corridor. Heading to the west, the pipeline travels through the proposed EAN Tranche 1 array and heads in parallel towards BGT. Although the pipeline will not contact the export cable corridor, it is recommended that a minimum separation distance is maintained between the final export corridors and pipeline of 505m. 500m is the most commonly accepted proximity limit for ploughing operations and hydrocarbon pipelines and is referenced in ICPC Recommendation No.2 Iss10B (Recommended Routing and Reporting Criteria for Cables in Proximity to Others). An additional 5m contingency has been added to this.

The Bacton to Zeebrugge gas pipeline connects BGT to Zeebrugge in North West Belgium and has the capacity to transport 20 billion cubic meters per annum (bcm/y). Shown on Figure 7 in green, the Bacton to Zeebrugge pipeline turns to the south in the Haisborough Gat and must cross the proposed export cable corridor. The crossing is inevitable for both export cable corridor options shown in Figure 7. The crossing will require detailed engineering and negotiation with the pipeline owner and confirmed in a formal crossing agreement prior to installation. The export corridors should allow for crossing angles as close to the optimum 90° as possible. The ICPC guidelines for carrying out pipeline crossings can be found in ICPC Recommendation No. 3 Iss 10A. Pipeline data in Figure 7 comes from UKOilandGasData.

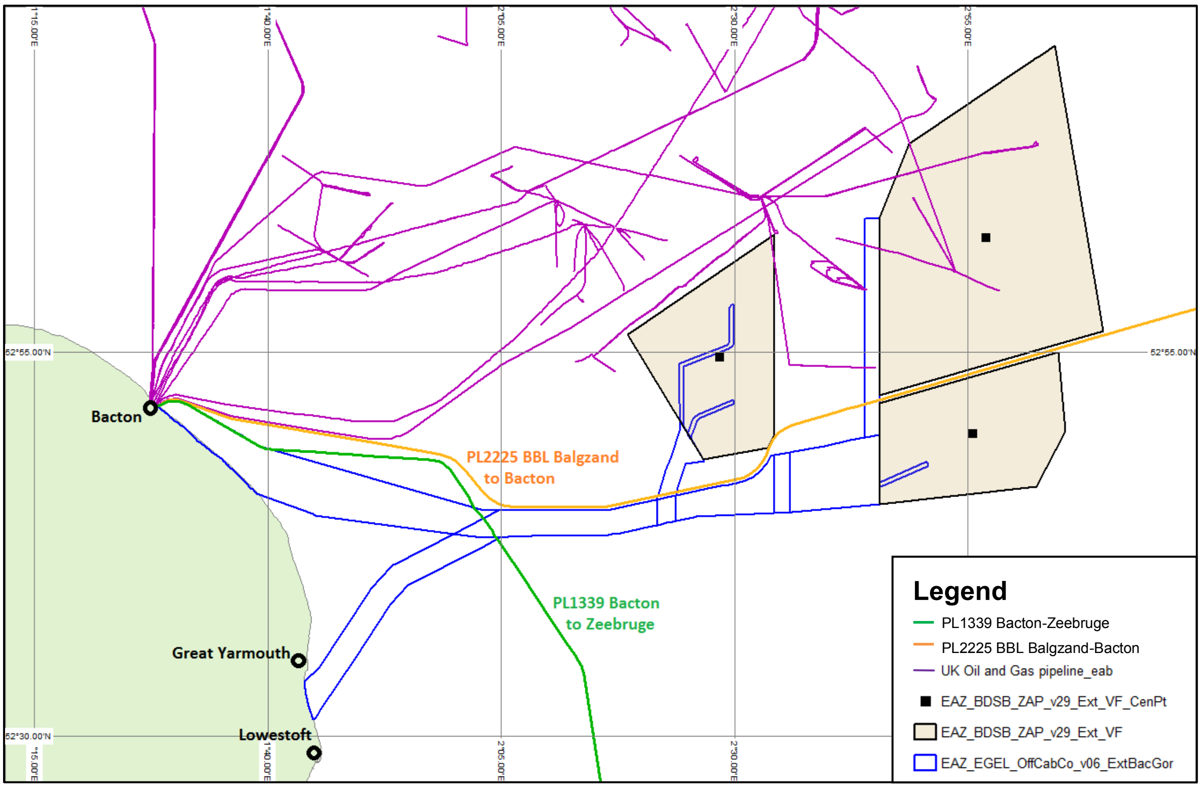


Figure 7 Pipeline Infrastructure

4.3.2 Drilling Activity

Significant numbers of both exploratory and production wells exist in the AOI, near to the cable route corridors or located within the EAN Tranche 1 array areas (UK Oil and Gas Data). To simplify, Figure 8 highlights the well heads that are in close proximity to the export cable corridors and are further detailed in Table 3.

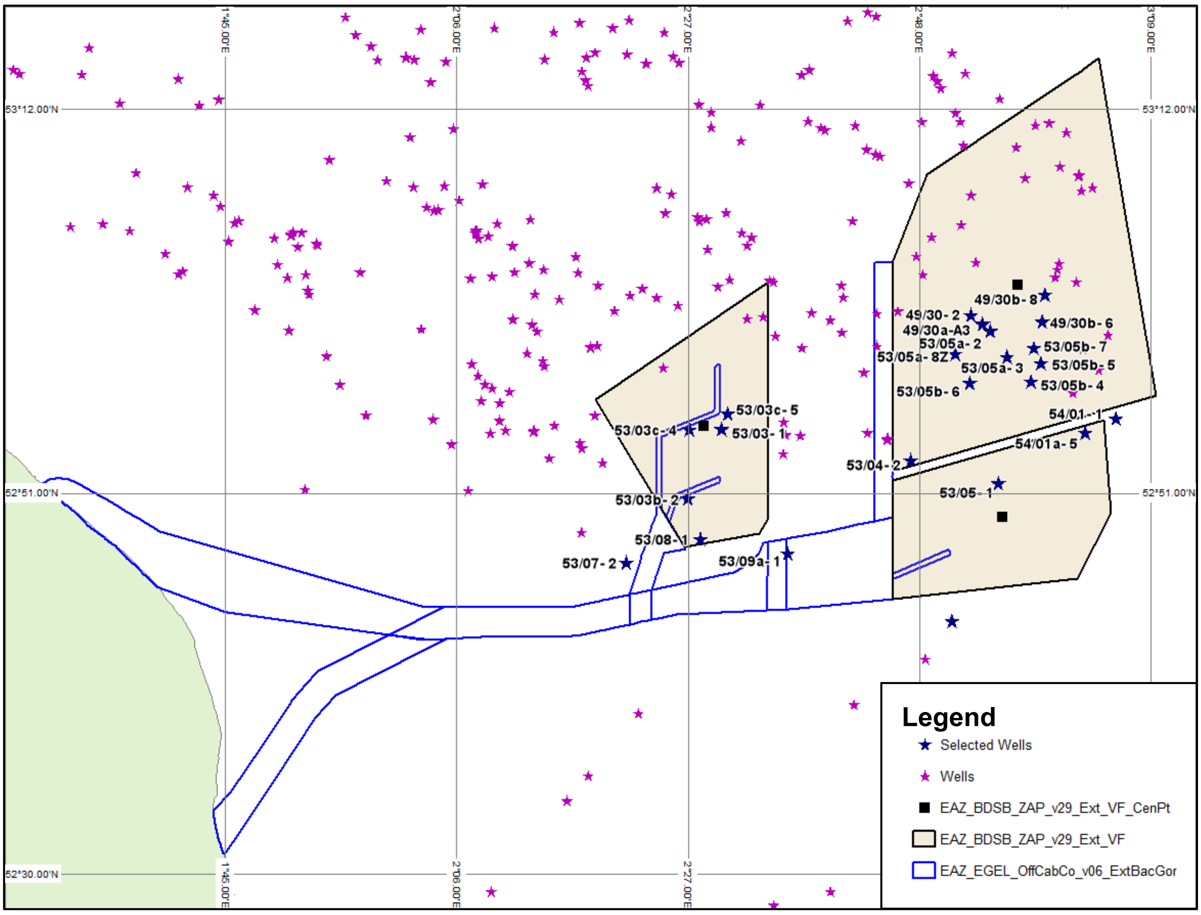


Figure 8 Hydrocarbon Wells

Well heads can potentially damage installation equipment such as a plough or cause abrasion of the outer cable layers leading to faults if the cable is laid over the wellhead. There is the additional hazard of spud can depressions left by drilling rigs which may damage or trap a plough or cause a cable to remain in suspension. As an influence on the cable corridors, exploratory wellheads in isolation are unlikely to present a significant obstruction, however production wellheads or wellhead clusters may be a concern. In these circumstances avoidance of clusters or production wellheads connected to pipelines are advised to minimise the effect on the final export routes.

Care should be taken during future marine surveys to positively locate all known and unidentified wells within the export cable corridors using side scan sonar and magnetometer recordings.

A database of known well locations held by UKOilandGasData was searched for well positions close to the cable route. Table 3 contains a summary of the wells highlighted in Figure 8 which are near to or within the proposed cable corridors and their status, whether completed, suspended or plugged and abandoned (P & A).

Wellname	Long	Lat	Current Owner	Well Status	Intent	Completion Date
53/05a- 8Z	2.854898	52.97807	PERENCO	P & A	EXPLORATION	22/05/2007
53/05a- 2	2.907833	52.99889	PERENCO	P & A	EXPLORATION	01/03/1989
53/05a- 3	2.933267	52.97528	PERENCO	SUSPENDED	APPRAISAL	05/09/1989
49/30a-A3	2.896111	53.00521	PERENCO	COMPLETED	DEVELOPMENT	20/10/1995
53/05b- 6	2.876892	52.95145	PERENCO	P & A	EXPLORATION	07/04/1998
53/05b- 7	2.973914	52.98339	PERENCO	COMPLETED	APPRAISAL	09/06/2006
49/30- 2	2.878611	53.01331	PERENCO	P & A	EXPLORATION	25/01/1970

53/05b- 4	2.969472	52.95275	PERENCO	P & A	EXPLORATION	07/03/1994
53/05b- 5	2.984531	52.96947	PERENCO	SUSPENDED	EXPLORATION	28/02/1996
53/05- 1	2.920056	52.85969	PERENCO	P & A	EXPLORATION	06/03/1969
54/01- 1	3.098061	52.91889	CONOCOPHILLIPS	P & A	EXPLORATION	28/07/1967
49/30b- 6	2.986528	53.00739	PREMIER	P & A	EXPLORATION	21/07/1990
53/03b- 2	2.450583	52.84575	BG GROUP	P & A	EXPLORATION	27/09/1989
49/30b- 8	2.990672	53.03197	APACHE	P & A	EXPLORATION	22/03/2001
53/08- 1	2.469722	52.80861	CHEVRON	P & A	EXPLORATION	28/03/1968
53/09a- 1	2.601694	52.79547	HESS	P & A	EXPLORATION	26/04/1989
53/07- 2	2.3575	52.78694	BP	P & A	EXPLORATION	21/02/1968
53/10- 1	2.85	52.73333	CHEVRON	P & A	EXPLORATION	20/06/1965
53/03- 1	2.501667	52.90917	CHEVRON	P & A	EXPLORATION	20/08/1966
54/01a- 5	3.051525	52.9059	TULLOW	P & A	EXPLORATION	27/08/2005
53/04- 2	2.787778	52.88056	TULLOW	P & A	APPRAISAL	17/08/1967
53/03c- 4	2.453083	52.90884	TULLOW	P & A	EXPLORATION	01/04/1994
53/03c- 5	2.511128	52.92337	TULLOW	P & A	APPRAISAL	26/01/1997

Table 3 Hydrocarbon Wells in Close Proximity to the Export Cable Corridors

In addition to these existing wells, block operators may be planning new drilling campaigns. Block operators should be able to indicate whether there will be any drilling activity close to the cable corridors, in which case the corridors and may need to be reviewed.

4.3.3 Offshore Renewables

The UK has a target of generating at least 15% of its electricity from renewable sources by 2020 (European Parliament, 2009). This is currently intended to be met largely through the expansion of wind power, particularly offshore. At the present time there are 1,452 operational turbines offshore in 27 wind farms (RenewableUK, 2015) with many other areas proposed.

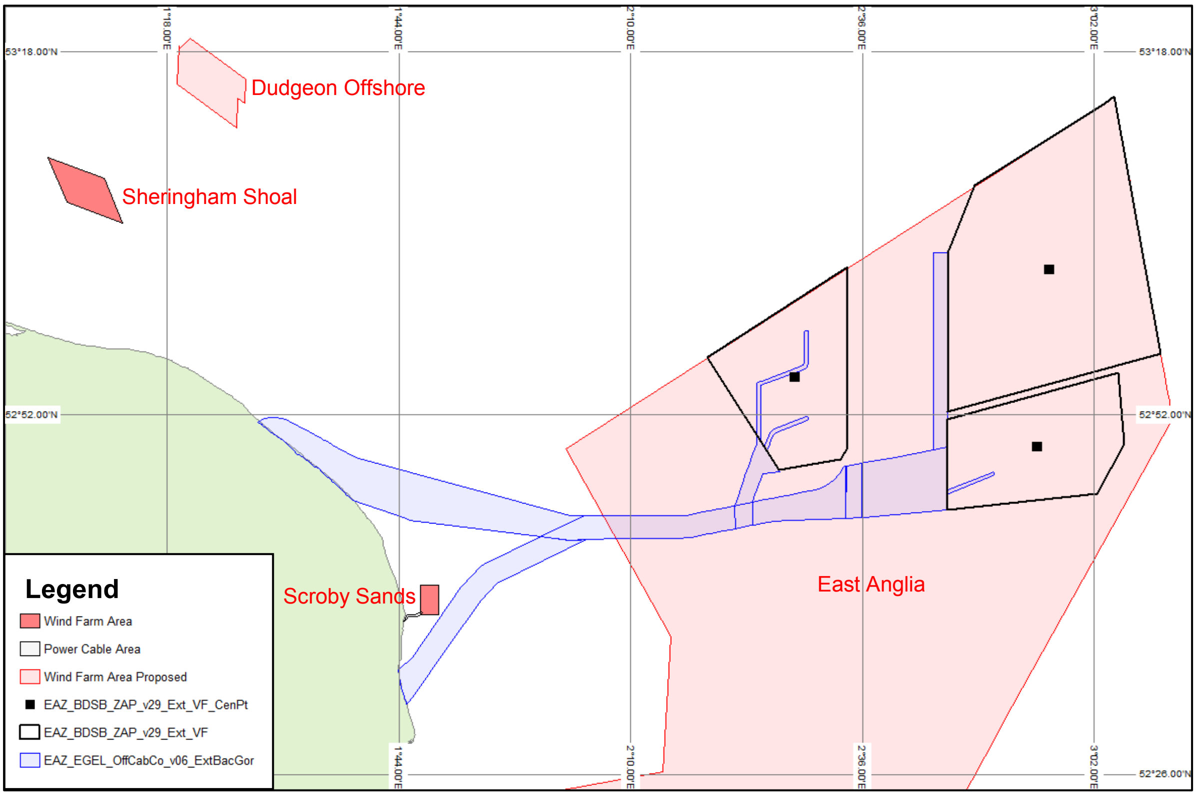


Figure 9 Offshore Windfam Locations in AOI

The nearest operational wind farm to the EAN Tranche 1 export cable corridor is Scroby Sands Wind Farm situated to the north of the Southern corridor option approximately 2.5km offshore of Great Yarmouth. Commissioned by Powergen Renewables in 2004, the wind farm consists of 30 X 2MW turbines with a total generating capacity of 60MW. The total area of Scroby Sands equates to 4km², the boundaries are highlighted in Table 4. Its location and export cable routes are shown in Figure 10, with the 3 electrical circuits (Red, Blue and Green) each of 10 turbines connect to the National Grid at Admiralty Road Substation in Great Yarmouth

UK National Grid Reference			
Easting	Northing	Easting	Northing
655765	310945	656806	312673
655917	312384	657400	312200
655629	313600	657264	310997
657241	313600	655765	310945

Table 4 Scroby Sands Site Boundary. (E.ON UK 2006)

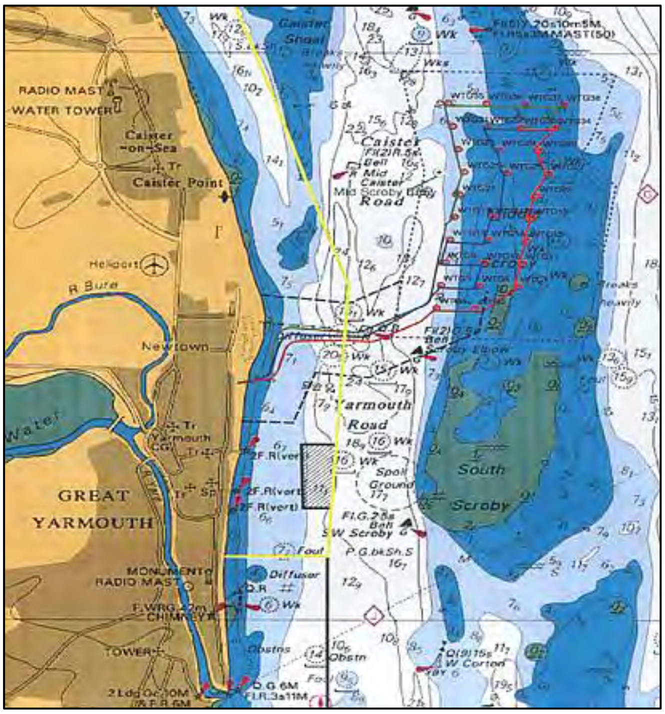


Figure 10 Scroby Sands Wind farm Location (E.ON UK 2006)

By avoiding the Scroby Sands windfarm and export cable routes there is no conflict with EAN Tranche 1 export cable corridors. ICPC Recommendation No.13 provides guidance that separation from windfarms should be at least 500m.

It is important to note that although the export cable corridors are not expected to affect other active or planned renewable developments, the East Anglia Wind Farm zone itself is extensive and broad with various development areas in place. Undoubtedly Vattenfall and Iberdrola (Scottish Power Renewables) the joint developers of the East Anglia Wind Farm zone will be co-ordinating development plans. This interfacing is encouraged by GMSL for the EAN Tranche-1 corridors.

4.3.4 Telecommunication Cables

There are 12 submarine cables that cross or are in close proximity with the original Vattenfall EAN Tranche 1 export cable corridors, 6 of these are Out of Service (OOS). The details of these systems are contained in Table 5 below.

Name	Cable type	Owner	Contact
UK – Netherlands 14	In Service Fibre Optic	BT, C&W and KPN	Glenn Lipsham, BT Senior Operations Manager Tel: [redacted] Email: glen.lipsham@bt.com
North Sea Com 1 Seg 3	In Service Fibre Optic	Tampnet	Anders Tysdal, Tampnet Technical Manager [redacted] Email: at@tampnet.com
UK – Germany 5	OOS Fibre Optic	BT	Glenn Lipsham, BT Senior Operations Manager [redacted] Email: glen.lipsham@bt.com
UK – Denmark 1	OOS Coaxial	BT	
UK - Germany 4	OOS Coaxial	BT	
UK – Denmark 3	OOS Coaxial	BT	

UK – Germany 2	OOS Coaxial	BT	
UK – Germany 3	OOS Coaxial	BT	
Lowestoft - Norderney	OOS Telegraph	BT	
Bacton – Borkum 3	OOS Telegraph	BT	
Bacton – Borkum 2	OOS Telegraph	BT	
Bacton – Borkum 1	OOS Telegraph	BT	

Table 5 Telecomunication Cables in close Proximity to EAN Tranche-1

There are two active fibre optic cables that cross the proposed cable corridors:

UK – Netherlands 14 - This fibre optic cable crosses the northern export cable corridor option and travels parallel to the proposed export cable route before crossing EAN Tranche-1 West export cable corridor. The UK–Netherlands 14 cable then passes through the proposed EAN Tranche-1 East array and carries on eastwards.

North Sea Com 1 Seg 3 - This fibre optic cable crosses the central trunk of the export cable corridor and lies parallel to the EAN Tranche-1 West cable corridor. The cable also passes through the proposed Tranche 1 West array area.

There is one OOS fibre optic cable that crosses the proposed cable corridors:

UK-Germany 5 - This OOS fibre optic cable passes through the central section of the northern export cable corridor and the eastern end of the main trunk and EAN Tranche-1 East array

There are five OOS coaxial cables that cross the proposed cable corridors:

UK-GER 2, 3, 4 & UK DEN 1, 3 - All these coaxial cables land at Winterton, Norfolk.

There are four OOS telegraph cables that cross or are situated in close proximity to the proposed export cable corridors:

Bacton – Borkum 1, 2, 3 - These three telegraph cables cross the far northern boundary of the northern export corridor option. The three cables all make landfall at Bacton. Unless a landing is selected at the far western end of the North corridor landing site zone, these cables are unlikely to interact with final export routes.

Lowestoft – Norderney - This telegraph cable runs through the far eastern section of the export cable corridor and eastern EAN Tranche-1 array area.

All these cables are shown in (Figure 11)

All in-service cables crossed by the export cable corridors will require formal crossing agreements OOS cables do not generally require crossing agreements, The most likely course of action will be to clear these cables prior to installation of the EAN Tranche 1 export cables. ICPC guidelines are a helpful reference for cable crossing and clearance matters.

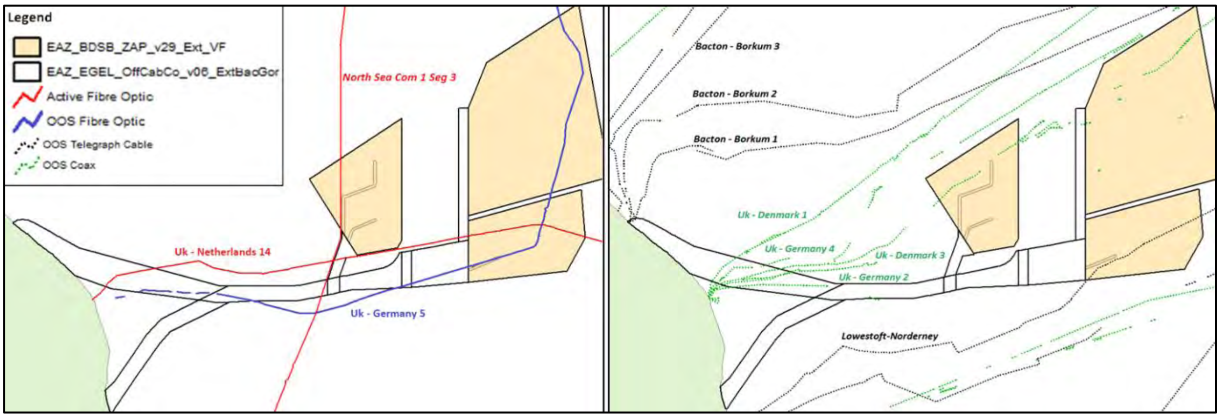


Figure 11 Submarine Telecomunication Cables

4.3.5 Aggregate Extraction (Dredging)

Dredging and dumping operations have a direct impact on the seabed and therefore are a potential threat to the cables route survey, installation and future security and any area where dredging takes place should be avoided at all costs. The Crown Estate keeps a record of and can provide a licence for all dredging areas in the UK waters. In 2014 the area of seabed licenced in the UK for dredging was 726km² however only 11.8% of this area was actually dredged (BMAPA 2015). A more detailed representation of dredged locations within licenced areas can be located on The Crown Estate website however avoidance of the licenced boundaries is still essential. Shown in Figure 12 are the licenced dredging areas that are situated in close proximity to the export cable corridor.

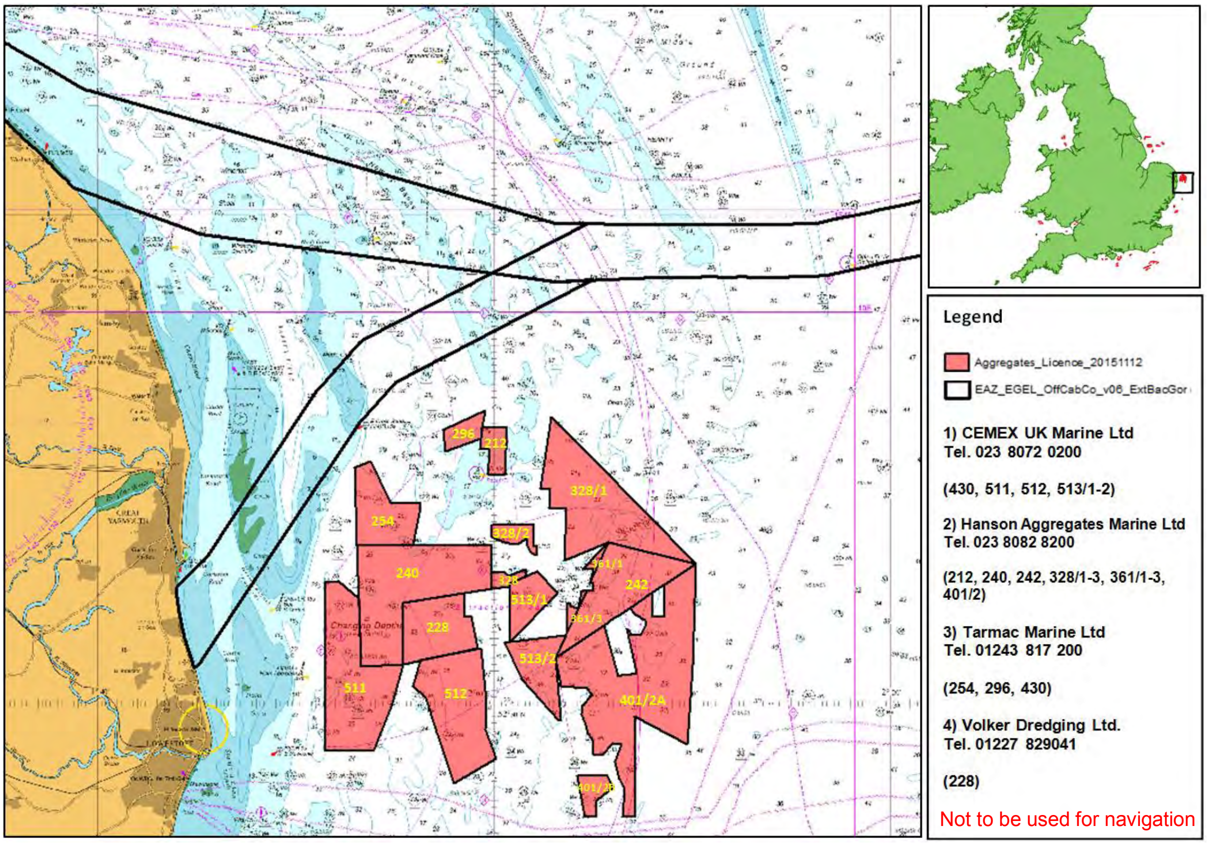


Figure 12 Licenced Dredging Areas

Of the two export corridor options, the southern cable route passes to the west of the licenced area issued by The Crown Estate. In Figure 12 above, the closest point between the original Vatenfall cable corridor and licenced boundary is Tarmac Marine’s 254 at a distance of 1.2km. ICPC recommendation No. 15 recommends a spacing of at least 500m from dredging activities and the export cable route, however GMSL recommend extending this margin if possible. This should therefore accommodate reasonable future expansion of the aggregate licence areas as well as the potential for navigational error.

4.3.6 Bathymetry and Seabed

The most prominent bathymetric features in the region close to the export corridor options are large sandbanks. Most lie to the north of the potential cable routes but several are crossed, particularly close to shore (Figure 13).

Sediment movement in the southern North Sea is generally a result of tidal currents rather than the actions of waves, storms or currents resulting from the circulation of water in the North Sea (BGS, 1992). Large amounts of movement can also occur as major storm surges drain off of the land and into the sea.

One of the major products of the strong, regular and strongly bipolar tidal currents is systems of large banks of sediments, primarily sand and gravel. The banks are large (Broken Bank to the north is over 30m in height, 1.1km wide and 32.5km long), coast-parallel features with an asymmetric profile. The seaward facing face of each bank can be many times steeper than the landward side, reaching up to 7° (Cooper, Townend, & Balson, 2008). The banks were initially formed from glacial outwash sediments and may be fed by continuing coastal erosion at the present day. SBP evidence suggests that the banks are slowly (c.1m yr^{-1}) migrating to the northeast but it is unconfirmed whether that this movement continues to the present day. They are however elongating to the northwest, the direction of overall regional sediment transport.

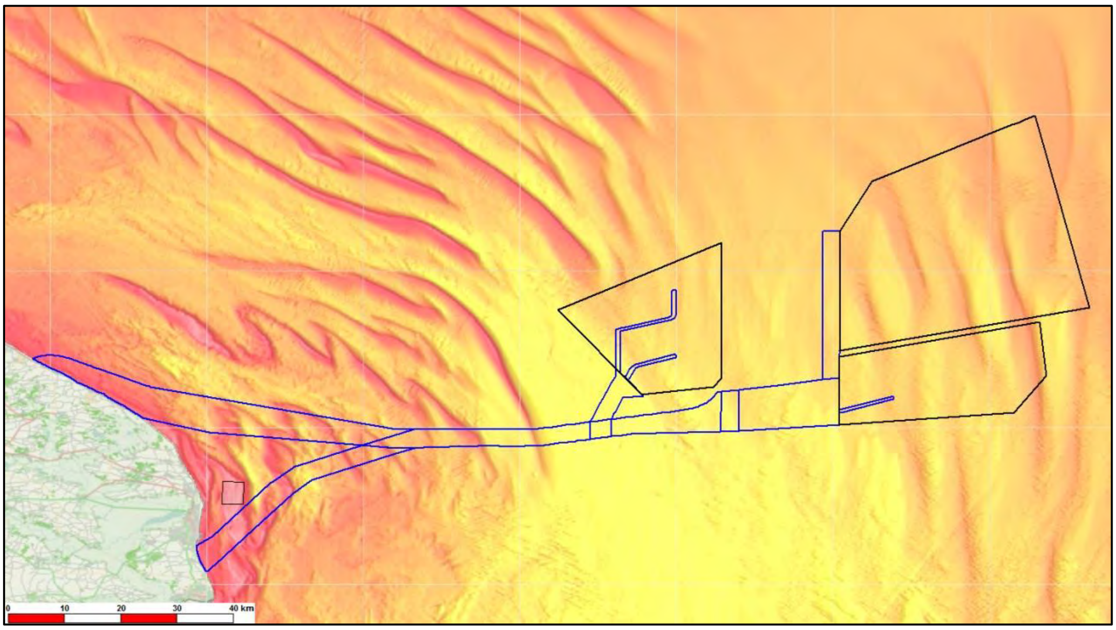


Figure 13 Sandbanks offshore of East Anglia (EMODNET)

The banks are composed of layers of coarse and fine sand. The coarse sand is deposited during the usual mode of sedimentation, with tidal currents moving existing material around, often in the form of smaller sandwaves. The finer sand and even occasional mud layers are deposited as a result of heavy storm activity stirring up fines elsewhere which are subsequently redeposited on the banks. The sedimentology over the export corridors is discussed further in section 4.3.9 below.

4.3.6.1 Small Scale Features

As well as the sandbanks described above there are smaller features that can disrupt the cable during installation, with the additional threat that as much more active features they may move and expose the cable at the seabed.

Sandwaves are found worldwide. The term covers many different types and scales of bedforms, from centimetre-scale ripples to sandbanks that can be tens of metres tall. A brief overview of sandwave classifications is given in Table 6 below, though nomenclature is not standardised and other terms are in use.

Because of the localised steep gradients in areas of sandwaves, the stability of burial equipment may be at risk. Large sandwaves can also reduce the burial depth that can be achieved, as shown with a cable plough in Figure 14 below.

Even if full burial is achieved the cable can later become exposed and suspended between bedforms as they move. This will happen if the amplitude of the sandwaves is greater than the depth of burial of the cable. Whether a particular sandwave is active is usually indicated by an asymmetrical cross-section in survey data.

Name	Relief	Wavelength	Length

Ripples	Typically less than 100mm	Function of grain size and bottom orbital velocity.	May be continuous or form a complex network.
Megaripples	0.4m to 1.5m	0.6m to 30m	Tens to hundreds of metres.
Sandwaves	1.5m to 25m	Typically 30m to 500m but 1km or more is possible.	Hundreds of metres to tens of kilometres.
Sandbanks	5m to 50m	Single distinct feature or a series.	Many tens of kilometres.

Table 6: Nomenclature for Bedforms (Gass & Team, 1984)

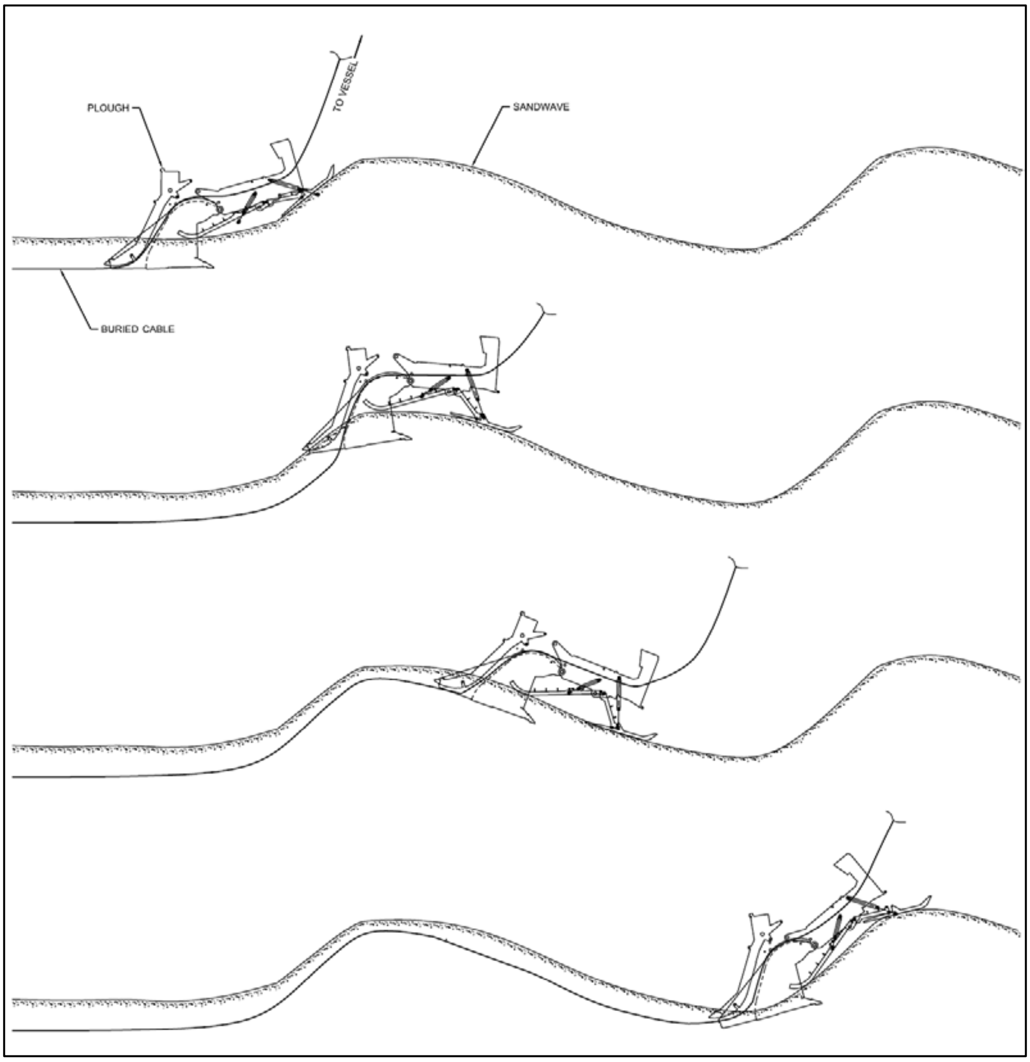


Figure 14 Interaction of a Cable Plough with Megaripples (Allen)

Bedforms of all sizes are seen in the survey data supplied by Vattenfall. The sand waves are believed to travel in a clockwise fashion around the banks (Collins, Shimwell, Gao, Powell, Hewitson, & Taylor, 1995). From the Collins paper it would appear that the sandwaves align themselves roughly perpendicular to the sand banks, orienting closer to parallel the closer to the sand bank's ridge they are. This is visible in the bathymetry data acquired over the East Anglia windfarm locations. (Figure 16).

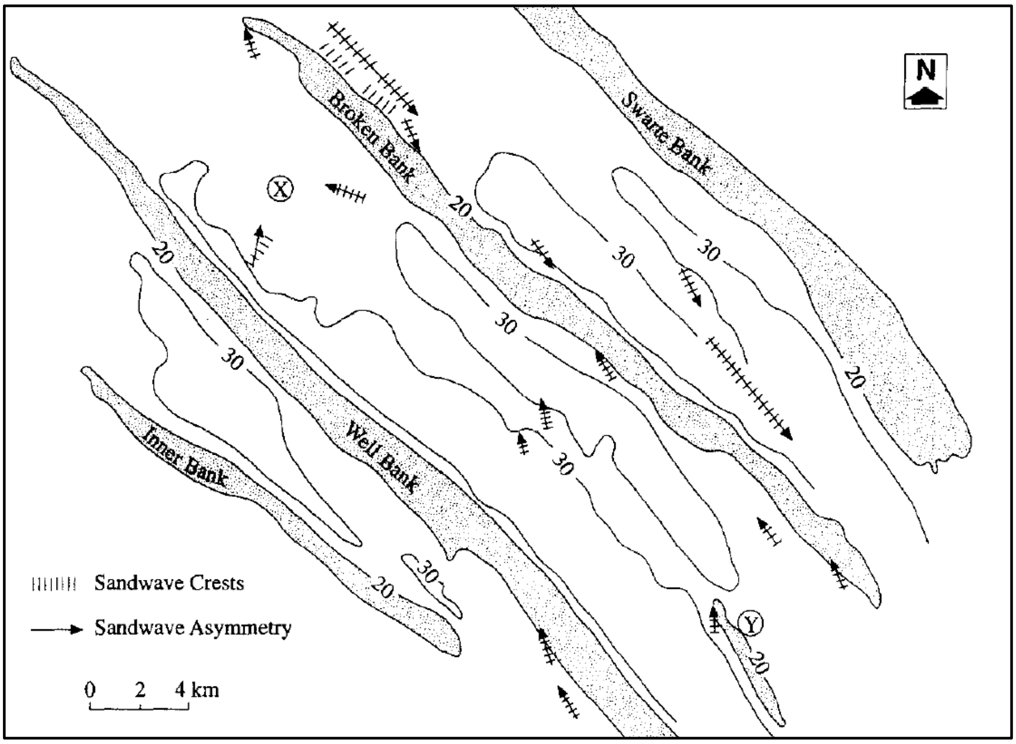


Figure 15 Sandwave Distribution & Orientation, Broken Bank (after Collins et al., 1995)

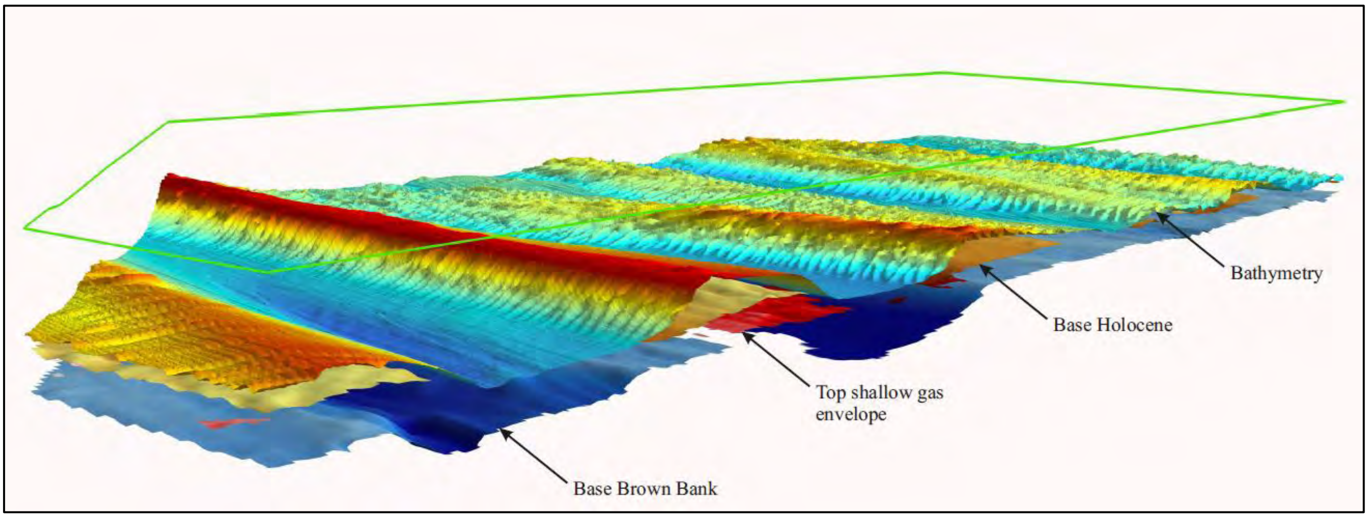


Figure 16 3D visualisation of the EA FOUR Ground Model, 40x Vertical Exaggeration (Reynolds International, 2015)

To facilitate burial of the cable to a depth below the mobile sediment layer it may be advisable to carry out works to remove sediment to the level of the base of the troughs and flatten the seabed. These works, if carried out, would need to be carried out as close as possible to the commencement of cable installation to avoid the bedforms re-establishing themselves before the cable is installed. See section 5.3.3 for more detail on this method of risk mitigation.

4.3.6.2 Navigation Hazard

In addition to potentially causing problems for cable protection, large sandbanks can pose a navigational hazard and can therefore limit the draft of the vessel that can be used to install the export cables. A nominal minimum chart depth of 15m for a power cable CLV has been used to assess this risk (Figure 17). As explained earlier in this report, if significant sections of the export route are shallower than this depth a multiple vessel solution may be required, using a shallower draft vessel to carry out the inshore section. This will increase the complexity of the installation operations and likely drive up cost.

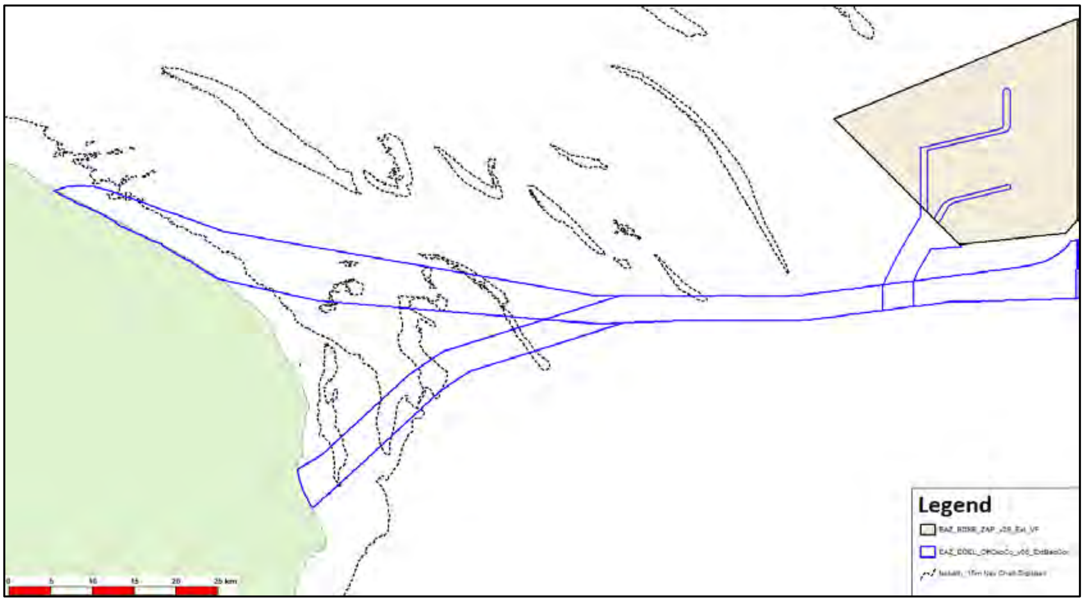


Figure 17 15m Isobath

4.3.7 MetOcean

The EAN Tranche-1 export cable corridors are located in the southern North Sea, a very shallow region where the water depth over the corridors does not exceed 48m.

Specific parameters vary considerably across the area but a key driving factor affecting the cable can be tidal or oceanic currents. The sections below discuss the currents, waves and tides found across the EAN Tranche-1 export cable corridors.

Currents

Currents in the southern North Sea flow anticlockwise, travelling down the eastern coast of Great Britain before turning north and flowing up the coast of Belgium and the Netherlands (Figure 18). There is a small northeastern current through the Dover Strait which reinforces this.

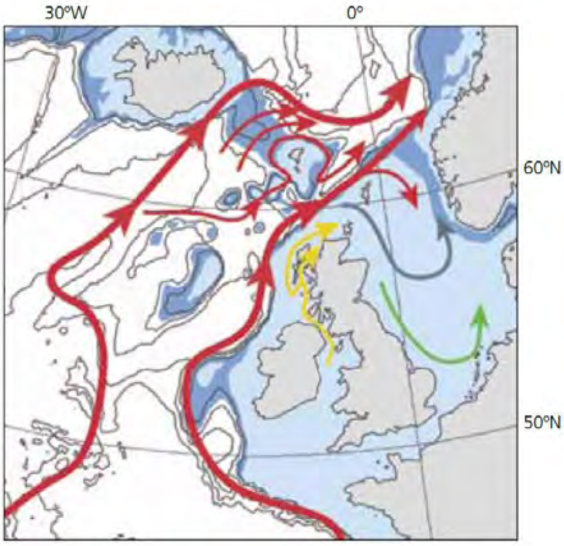


Figure 18 Circulation in the North Sea and the Atlantic

Despite this overall, time-averaged circulation the dominant current direction and strength at any particular time is dictated by the tides. These can completely overwhelm and reverse the currents described above.

Tides & Tidal Currents

The Norfolk sandbanks lie close to the Norfolk coast on the western side of the southern North Sea and they are subject to high tidal flow rates, especially in the area from Sea Palling to Great Yarmouth, up to 20km offshore. Here the tidal currents can reach a peak of 3.4 knots according to Admiralty charts. Tidal currents are intensified by the sandbanks and flow at locally increased rates over the tops of the larger banks with shallow water depths. These intensified flow rates over the top of the sandbanks extend to many of those over 20km from the coast. They are subject to a range of current strengths which are strongest on the banks closest to shore and which reduce offshore. The directions of the tidal currents are generally aligned with the coast.

The effect on cable installation of these high tidal currents was reported in the installation records for UK-GER5 and UK-NL14 cables (section 5.2.5), where installation operations were interrupted inshore, during stronger tidal current flows.

Waves

Swell and wind waves are an important factor for operations along the EAN Tranche-1 export cable corridors. Waves frequently break during rough weather over some of the shallowest tops of the Norfolk sandbanks particularly when strong northerly winds oppose north going tidal currents. Rough seas or swell conditions may therefore result in work being significantly delayed.

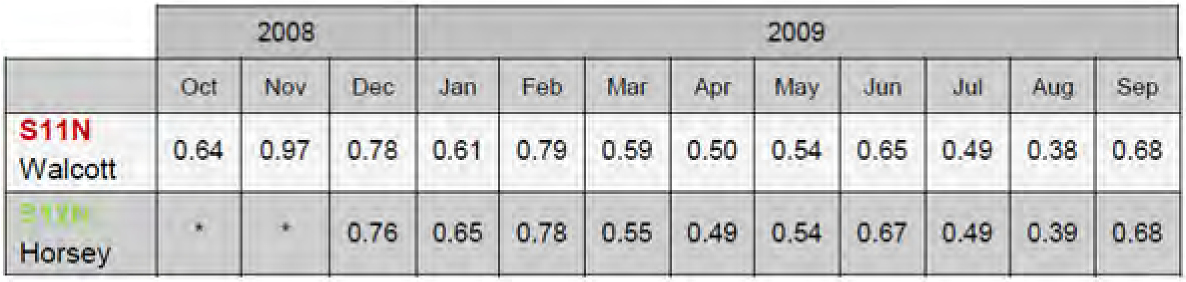
Rough seas are common throughout the region between October and March. Waves exceeding 4m in height, which would effectively preclude installation, occur on 15% of occasions in winter as opposed to 2% of the time in the summer months.

The North Sea is very exposed to swell from the northern quadrant and most waves come from this direction. In the winter and autumn swell from the west and south increases but these waves are generally weaker than those from the north and east. Swell conditions permitting cable work can occur at any time of year but are most common in summer and autumn.

Of interest to the EAN Tranche-1 project may be The Environment Agency (EA) and Gardline Environmental waverider buoy which is maintained off the coast at Happisburgh (WMO ID: 6201051). Located at 52°49'.58N, 001°32'.97E. Data from this buoy is publically available from CEFAS via their website http://wavenet.cefas.co.uk.

The EA also have a coastal met instruments at Horsey and Walcott. The monthly significant waveheights for these two stations are available between Oct 2008 and Sep 2009 are presented in Table 7. The locations of the Environment Agency met instruments are shown in Figure 19.

The yearly average significant waveheights (Hs) at Walcott for 2006-2009 vary from 0.58m to 0.71m and for Horsey they vary from 0.58 to 0.73m. Maximum waveheights reached 1.49m at Walcott in Nov 2008. Maximum values always occur during the winter months.



	2008			2009								
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
S11N Walcott	0.64	0.97	0.78	0.61	0.79	0.59	0.50	0.54	0.65	0.49	0.38	0.68
S1YN Horsey	*	*	0.76	0.65	0.78	0.55	0.49	0.54	0.67	0.49	0.39	0.68

Table 7 Significant Waveheights Walcott and Horsey – Metres (Hs) 2008-2009

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Figure 19 Environment Agency Met Instrument Locations in Norfolk (EA)

The Joint Nature Conservation Committee (JNCC) UKSeaMap 2010 project has produced a seabed habitat map for the UK marine area. Part of this project was mapping of seabed energy levels. This combined the effects of wind and tidal currents to map the combined peak seabed kinetic energy. These were classified into low, moderate and high energy zones within UK waters. These zones are shown for the AOI in Figure 20. This clearly shows how the energy levels match the high tidal current and shallow seabed areas described earlier.

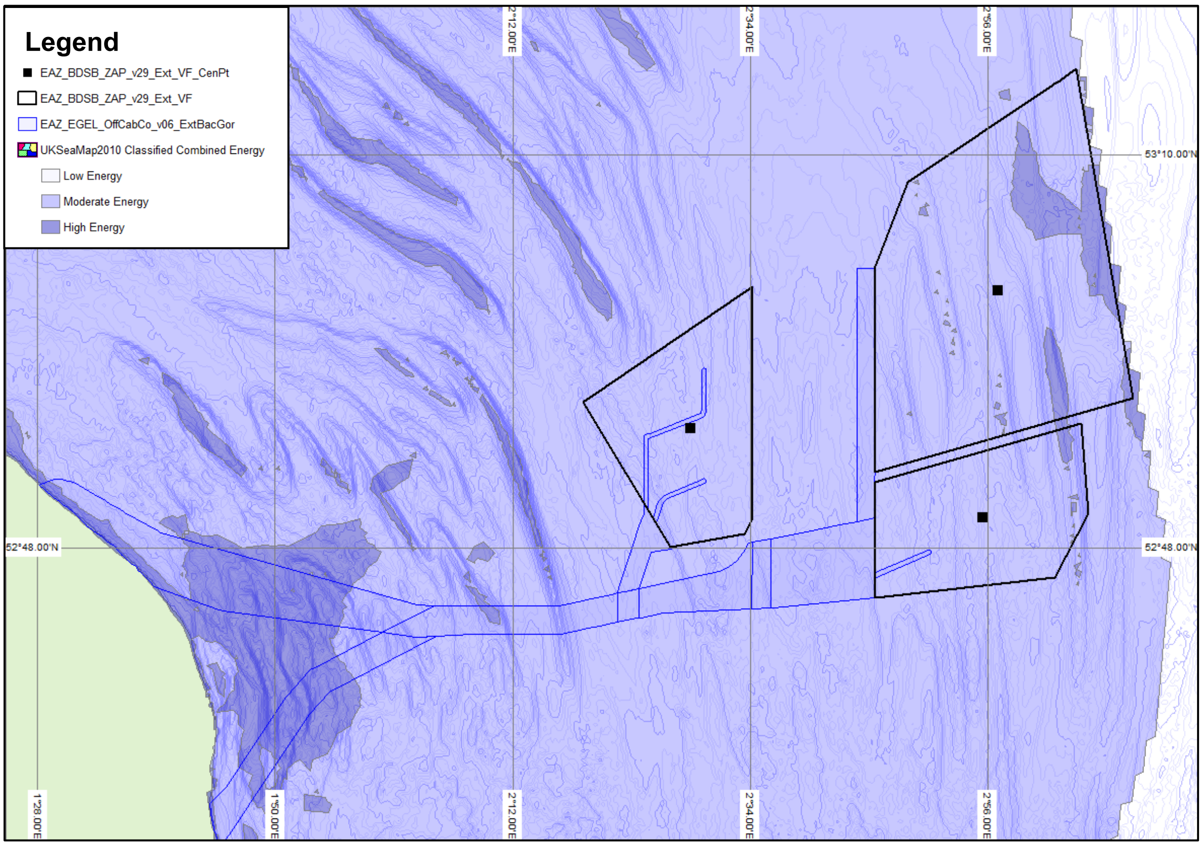


Figure 20 UKSeaMap 2010 Seabed Energy Levels

Meteorology

The North Sea climate is driven by both maritime and continental climate subsystems. It is heavily influenced by warm water flowing in from the Atlantic. Consequently the variability in temperatures and winds tends to be unpredictable to forecast for more than a few days ahead. Any major extremes are generally driven by maritime storm events.

The climate is generally mild and temperate, with minimum temperatures rarely lower than 5°C and maximum temperatures not usually exceeding 30°C. hours are variable. In summer the days are over sixteen and a half hours long, whilst in winter they reach under eight hours for a period. Winds are most commonly from the southwest. Winds exceeding force seven occur on around 10% of the days in Jan-Feb at Weybourne from the southwest, the closest station to the export corridors. There is not a large variation in rainfall levels throughout the year. Mean precipitation is in the order of 665mm per year, with highest rainfall occurring between June and November and the least between February and May.

4.3.8 Wrecks and Obstructions

Wreckage presents an abrasive threat, and may hold the cable in suspension from the seabed. As the North Sea is relatively shallow, the abrasion threat will be further intensified due to the localised wave action on the sea surface.

Wreckage and associated debris is an obstruction to cable burial and is likely to prevent burial and indeed result in cable suspensions above the seabed. Subsequent secondary entanglement with fishing gear is therefore another risk to a cable laid over wreck sites.

Some shipwrecks may be considered of archaeological importance and therefore careful route corridor planning to avoid areas of dense wreckage is advised. GMSL recommend that all wreckage found during subsequent corridor survey operations are avoided by a distance of at least 1 x water depth for cable installation – therefore affecting export cable route separation and most likely to require the use of contingency space within the export corridors to achieve successful cable routes which avoid interaction with wreckage. Experience has shown that this is achieved fairly easily with isolated wrecks but is more difficult when wrecks are clustered in such proximity to each other that their effect on cable separation distances becomes very restrictive.

The amount of wrecks and seabed obstructions in the North Sea is relatively high in terms of density compared to a global average. The distribution within the AOI is shown in Figure 21. This quantity of wrecks is a result of multiple historic wars, particularly the two world wars and maritime trade crossing some areas in the AOI which are difficult to navigate in poor weather conditions. The distribution of wrecks and obstacles appears to be fairly random and overlaps both export cable route corridors. Generally more wreckage is situated towards the UK coastline and is densest along the nearshore of the southern cable corridor. The distribution of wreckage along the northern corridor is relatively sparse compared to the south; however some ‘clustering’ of wrecks and obstacles remain.

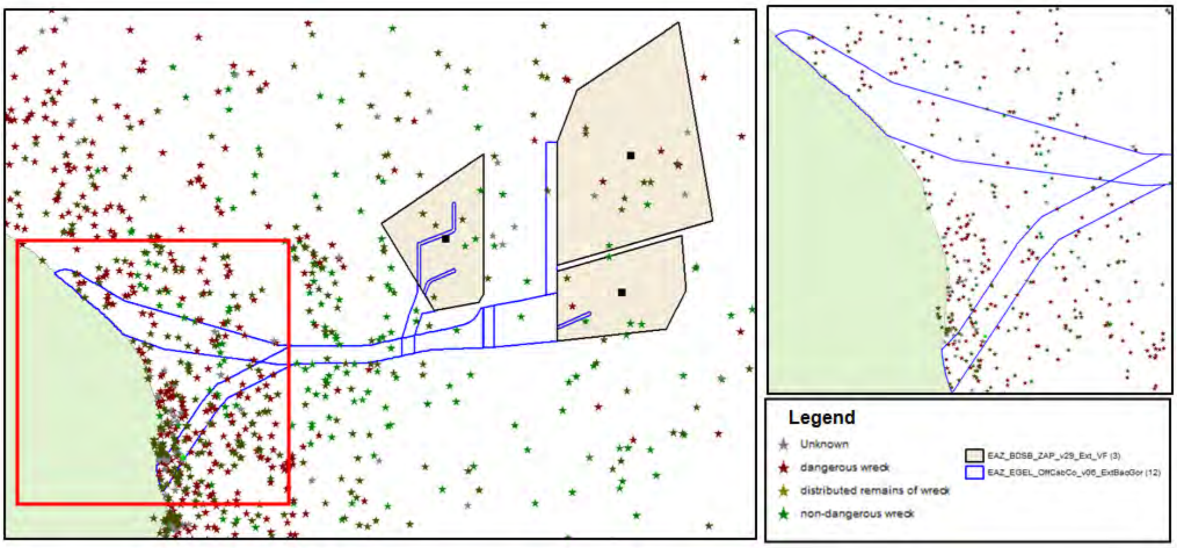


Figure 21 Wrecks and Obstructions (Seazone)

4.3.9 Surface seabed sediments and burial Potential

Geologically the seabed in this region is primarily sandy, as shown by the British Geological Survey (BGS) 1:250,000 scale maps of seabed sediments around the UK (Figure 22). When overlain on the EMODNET bathymetry data a general pattern emerges where the crests of the sandbanks are seen to be sandier whilst gravel becomes more common in the troughs between banks. This picture is reinforced by the higher-resolution survey data supplied by Vattenfall, although the exact distribution of the sediment types varies, with patches of sandy gravel (typically 30-80% gravel) most commonly being found on the shoreward faces of sandbanks (Figure 23). UKHO charts of the area report broken shells making up a significant portion of the seabed.

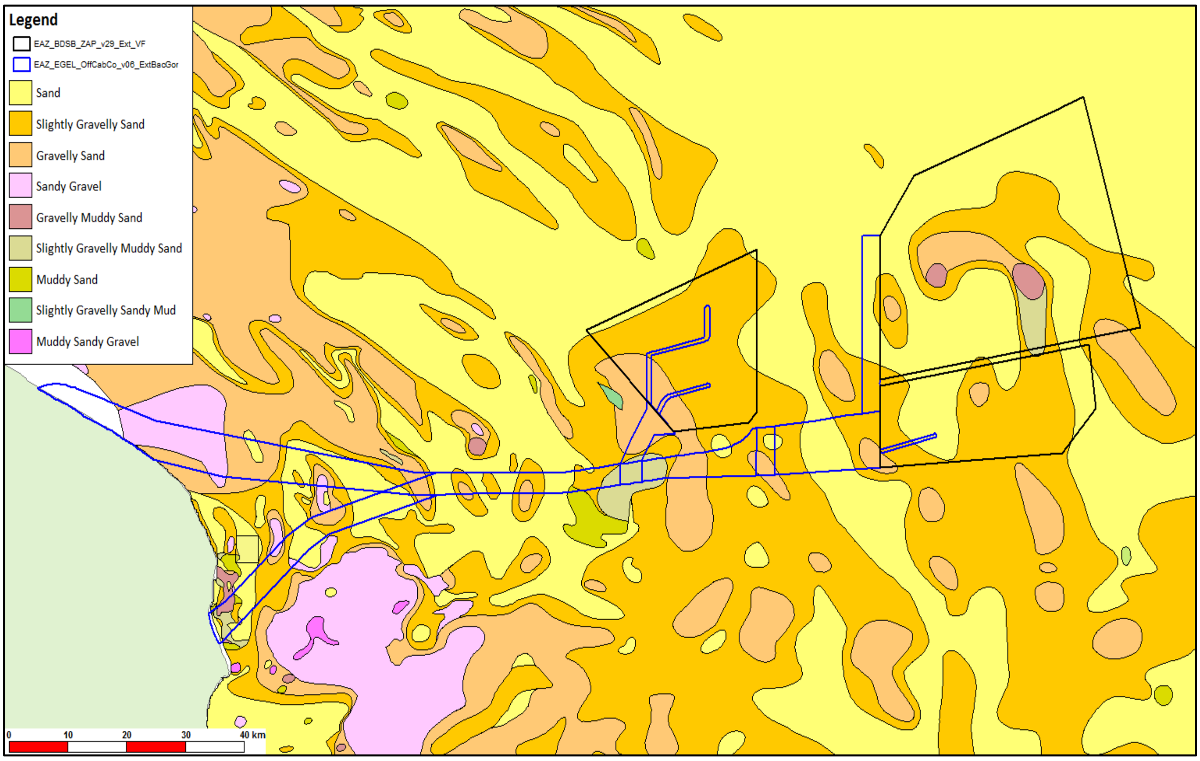


Figure 22 Seabed Sediments offshore of East Anglia (BGS)

Figure 23 Sandy Gravel Distribution (EMU 2013)

The reports J15360.271 and J15360.273 compiled by Reynolds International and supplied to GMSL by Vattenfall suggest that the seabed character is a result of sandy Holocene deposits largely overlying the Brown Bank Formation, which is composed more of silts and clays with a sandier basal layer. In some area the Twente Formation may lie between the two, though as this formation is largely composed of sand it is difficult to distinguish from the Holocene sands in sub-bottom profiler data and is usually only between 4 and 5m thickness. The Holocene layer is of highly variable thickness and in many areas, particularly between sandbanks, the older sediments may be exposed.

All of these sediment types are expected to be within the capability of existing cable burial equipment used by the submarine cable industry (ploughs and jetting ROV's). The Brown Bank Formation may be partially consolidated (Rijsdijk, Passchier, Weerts, Laban, van Leeuwen, & Ebbing, 2005) in which case it has the potential to be an obstacle to jet trenching.

Further north, diver surveys a few hundred metres offshore of the Norfolk coast have reported finding highly consolidated clays exposed at the seabed which fractures into blocks (Figure 24). It is likely that this extends further south, possibly into the northern export cable corridor landing zone near to Bacton. As this area remains unmapped by the BGS (Figure 22) it is not presently possible to confirm this hypothesis.

Figure 24 Highly consolidated clays at the seabed in Norfolk (Seasearch)

A chalk reef exists offshore of the Norfolk coast north of around 52°53'N (Seasearch East, 2011). The presence of chalk at the seabed may prevent burial of the cable by most tools depending on its strength. Fortunately the reef is reported to start north of the export cable corridors under consideration in this report.

4.3.10 Fishing

The most frequent cause of faults on submarine cable systems is by fishing activity. Of the 4400 telecom cable faults recorded worldwide, over one third were caused by fishing (source: GMSL database, Dec 2015). Therefore understanding the fishing activity that takes place in the EAN Tranche-1 AOI is an extremely important topic in this report.

Within the UK EEZ, the North Sea fisheries are regulated under the EU Common Fisheries Policy (CFP). UK quotas are allocated and managed according to a methodology agreed by UK Fisheries Administrations.

The EU Council of Fisheries Ministers sets total allowable catches (TACs) for over 130 fish stocks. In setting these TACs, account is taken of various factors, including the latest scientific advice on the condition of the stocks. Each year the UK and other EU member states receive a fixed percentage share of these TACs, based on historic fishing activity.

The UK's quota is then shared out among 23 producer organisations, the inshore fleet (under 10m vessels) and vessels not in membership of a producer organisation based on the fixed quota allocation units (FQA) held by the individual vessels in membership of each group, or by a group collectively.

Of the 23 producer organisations, 11 are administered by the Marine Management Organisation (MMO), 10 by Marine Scotland and 2 are administered jointly by the MMO and the Department for Agriculture and Rural Development (Northern Ireland).

The producer organisations manage their quotas as they see fit, and take responsibility for ensuring that they do not overfish their allocations

In the AOI the fishing methods of most concern are the bottom contact types. Bottom contact fishing methods include demersal trawling, beam trawling and shrimping. Other methods such as pelagic, potting and static gear are of less concern. This section discusses the evidence of where fishing takes place, which EU nations are fishing in the AOI and finally the types of fishing methods used in the AOI.

In order to ascertain where fishing effort take place along the proposed cable route in European waters VMS data has been used. The fishing vessel monitoring system (VMS) is a program of fisheries surveillance, in which equipment that is installed on fishing vessels >12m long provide information about the vessel's position and activity.

The EAN Tranche-1 export cable corridors are within ICES block IVc and the MMO VMS data for all UK and foreign vessels in 2010 were used by this study. This data is available via SCUK and is supplied in a gridded format. UK fishing vessels effort distribution for 2010 is shown in Figure 25. This shows that the UK fishing effort is outside the export corridors. Allowing for annual variation there may be some future encroachment, however GMSL have checked the 2009 and 2011 MMO VMS datasets and they do not differ significantly.

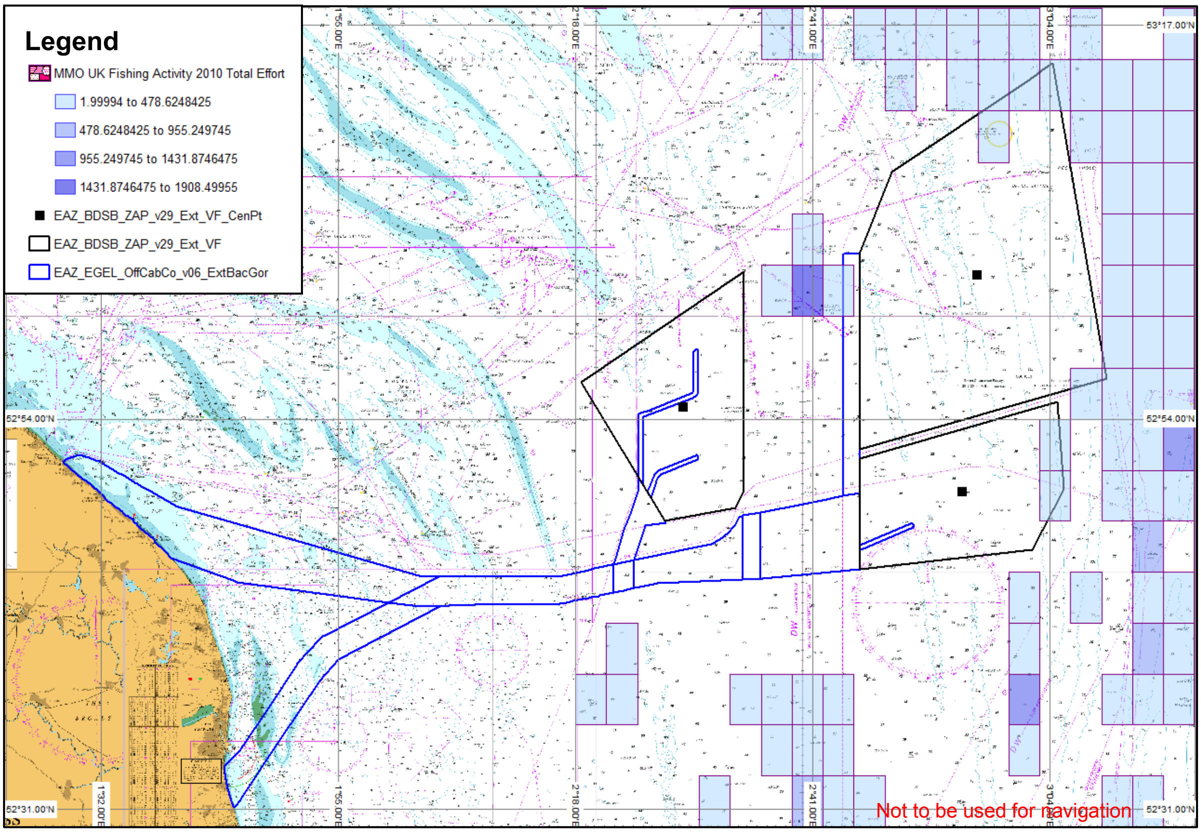


Figure 25 UK VMS Fishing Effort 2010 [mins/yr] (MMO)

There are two other EU nations which have recorded fishing effort inside the AOI. The most important of these is the Netherlands. The Dutch effort is shown in Figure 26. This does cover parts of the export corridor, and the 2009 and 2011 effort distribution is widely similar.

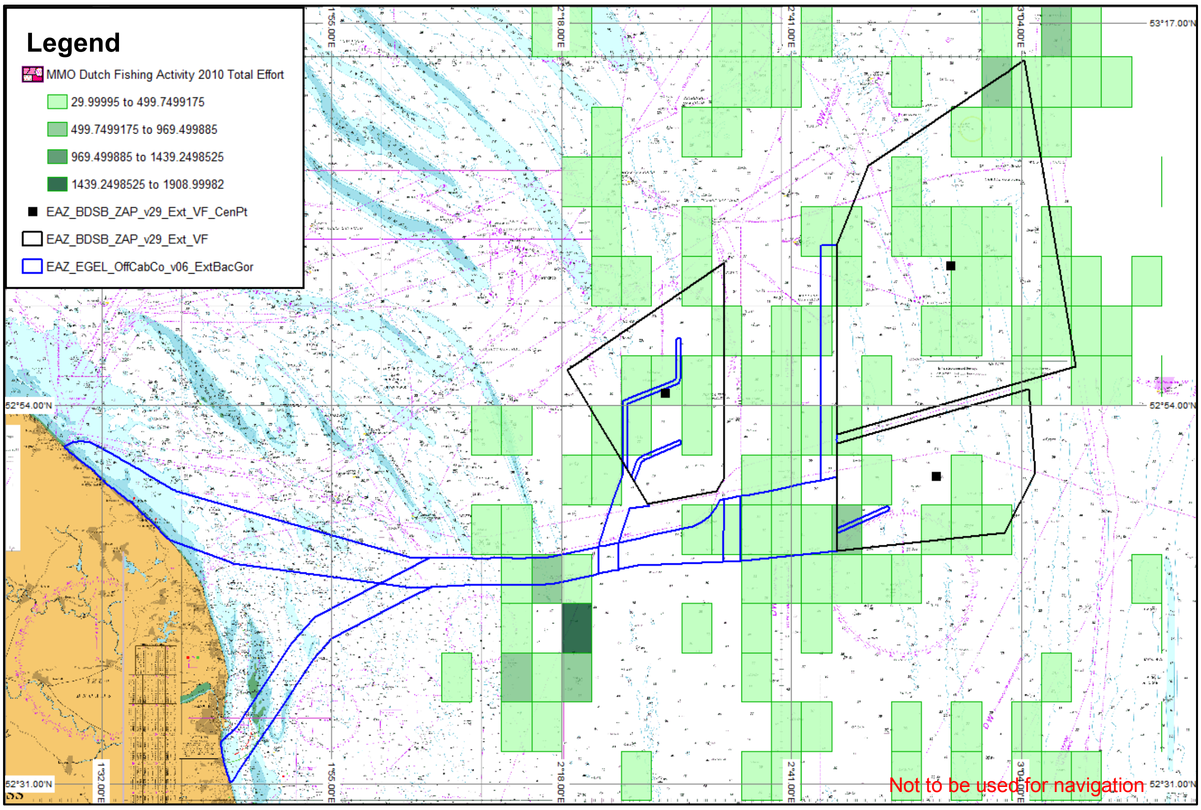


Figure 26 Netherlands VMS Fishing Effort 2010 [mins/yr] (MMO)

The second EU nation with fishing effort within the AOI is Belgium. The Belgian effort covers part of the export corridor at just one grid location which can be seen in Figure 27. Once again, 2009 and 2011 effort shows very similar distribution.

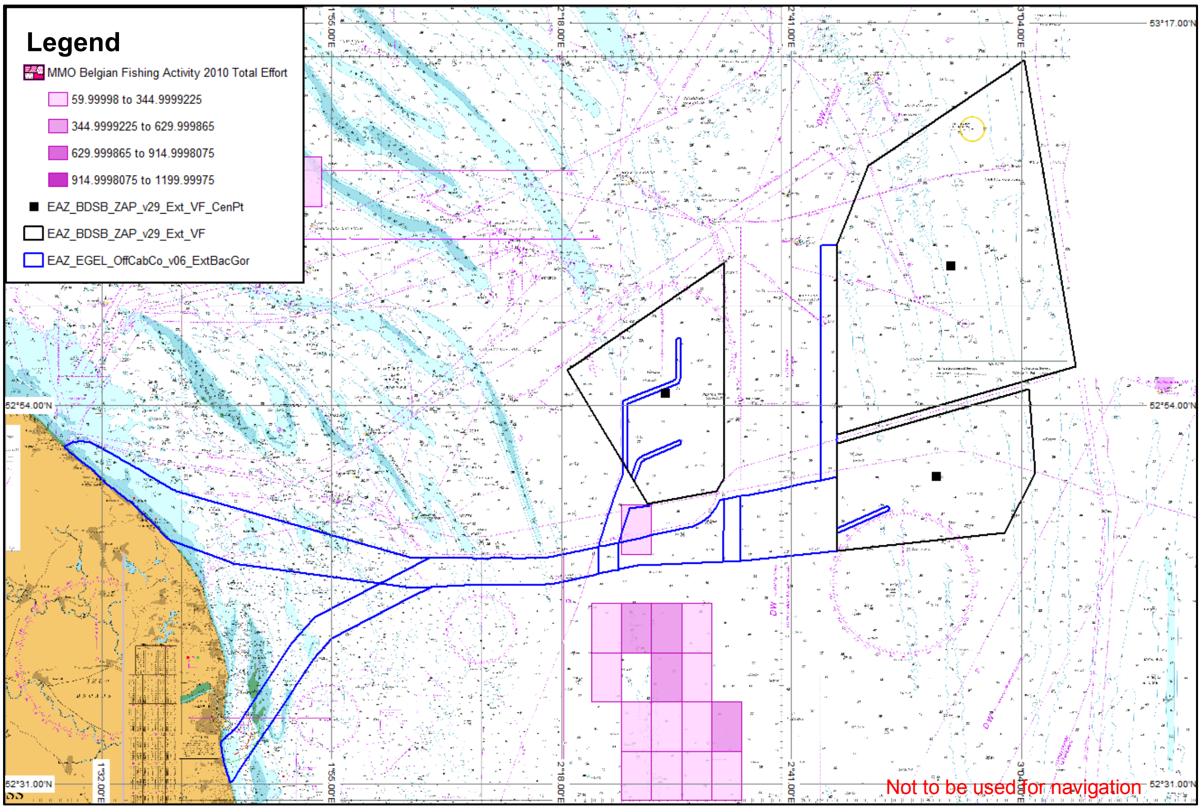


Figure 27 Belgian VMS Fishing Effort 2010 [mins/yr] (MMO)

Therefore the most significant fishing is conducted by Dutch vessels inside the AOI.

Whilst the effort shown for 2010 provides a fairly contemporary record of fishing effort, fishing grounds change annually, and as quotas and stocks change so the areas fished change over time. Therefore whilst a good indicator of recent effort the distribution may change in the future.

Whilst Figure 25, Figure 26, and Figure 27 give very good indications of the density of fishing effort taking place in the AOI, in order to determine what type of fishing methods are being utilised, charts produced by UKOOA, SFF and NFFO in 1998 (Fishery Sensitivity Maps in British Waters report) showing the types of fish and methods employed by UK and foreign fishermen around the UK and have been used as indicators for the fishing methods found in the AOI. The first of these presented is Figure 28 which is the demersal trawling effort for UK vessels. This shows the AOI features the lowest two categories of effort, so a small proportion of the UK, Dutch and Belgian fishing effort identified earlier in this section of the report, is probably demersal trawling inside the AOI.

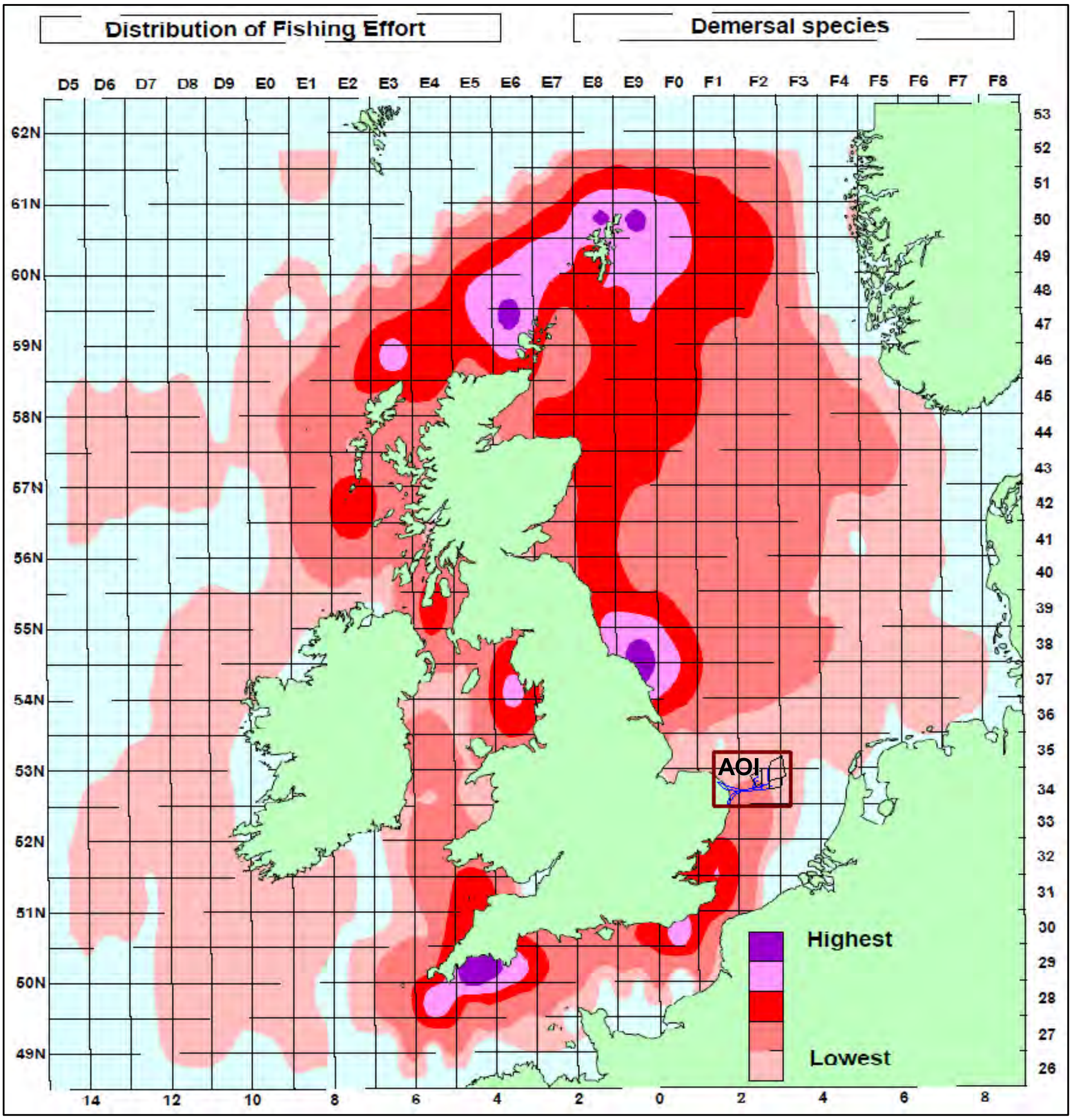


Figure 28 UK Demersal Fishing Effort in the North Sea - 1995 (UKOOA/SFF/NFFO)

The next method presented is shown in Figure 29 which is the beam trawling effort for UK vessels. This shows almost all the AOI covered by the second lowest category of effort, so UK vessels probably carry out a small amount of beam trawling inside the AOI.

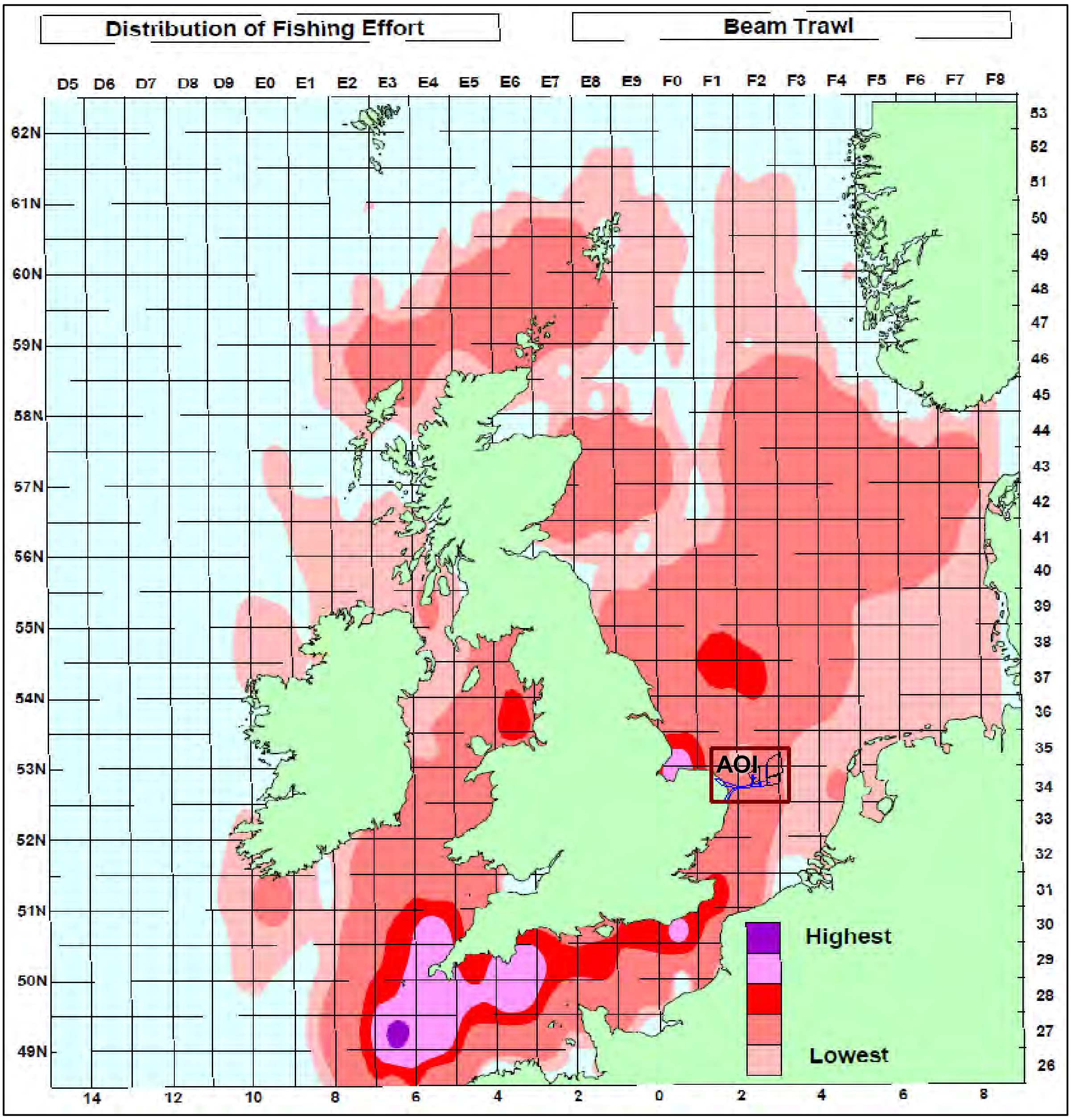


Figure 29 UK Beam Trawl Effort in the North Sea - 1995 (UKOOA/SFF/NFFO)

Beam trawling is also carried out by non UK vessels. Figure 30 is the beam trawling effort for Foreign (non-UK) vessels. This shows the AOI is covered by the 3 most intense categories of effort. So Dutch and Belgian vessels probably carry out a large amount of beam trawling inside the AOI. The most important of these as stated earlier is the Dutch fleet. This ties in well with observations from repair vessels repairing two BT cables in the AOI (see section 5.2.3) which mention beam trawlers sighted during repair operations.

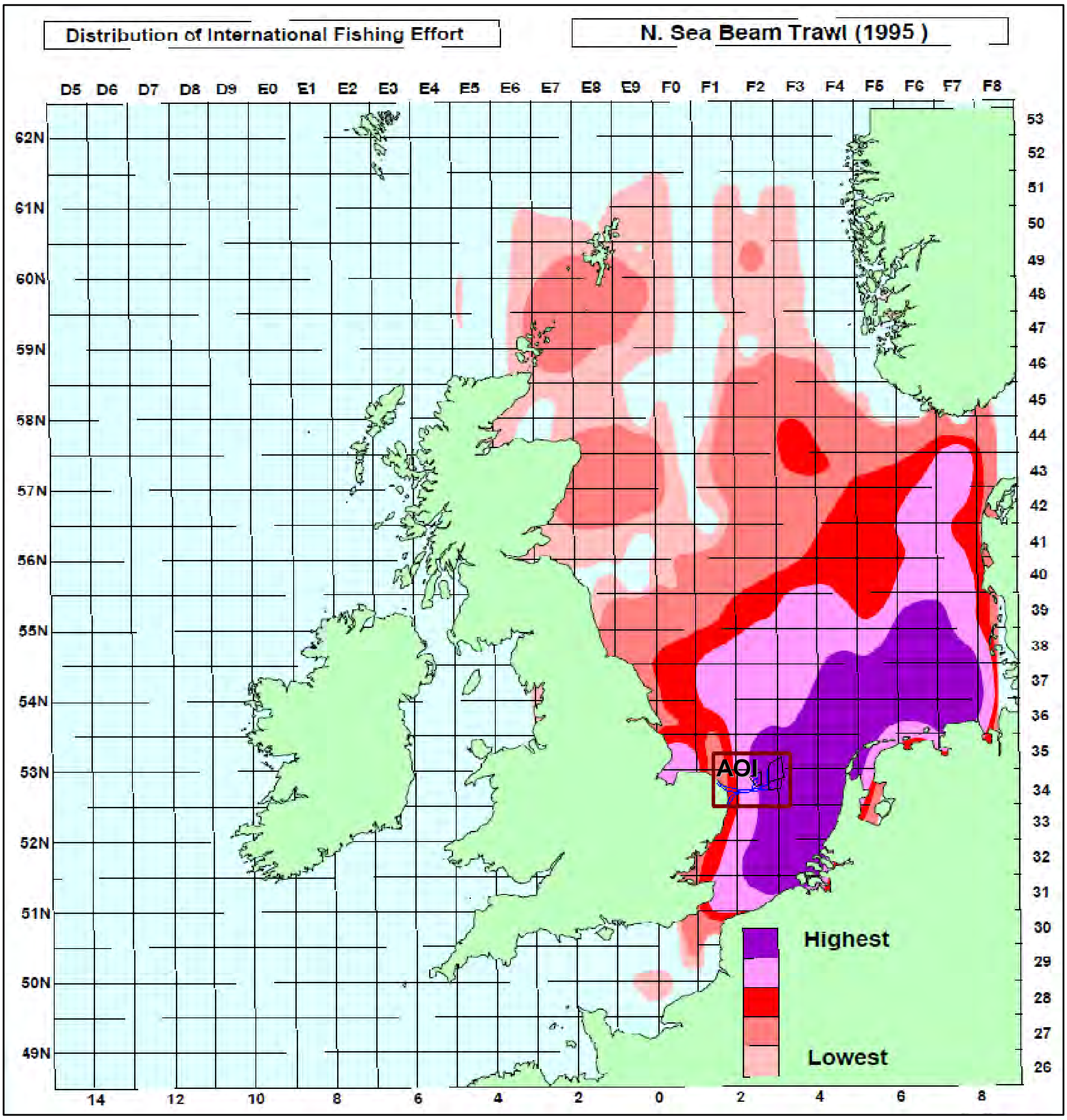


Figure 30 Foreign Beam Trawl Effort in the North Sea - 1995 (UKOOA/SFF/NFFO)

Shrimp trawling effort requires bottom contact fishing gear. The AOI is covered by a small portion of the lowest intensity category for shrimping as shown in Figure 31. Nephrops shrimps are generally found in softer muddy sediments and the AOI is covered mainly by sandy seabed sediments.

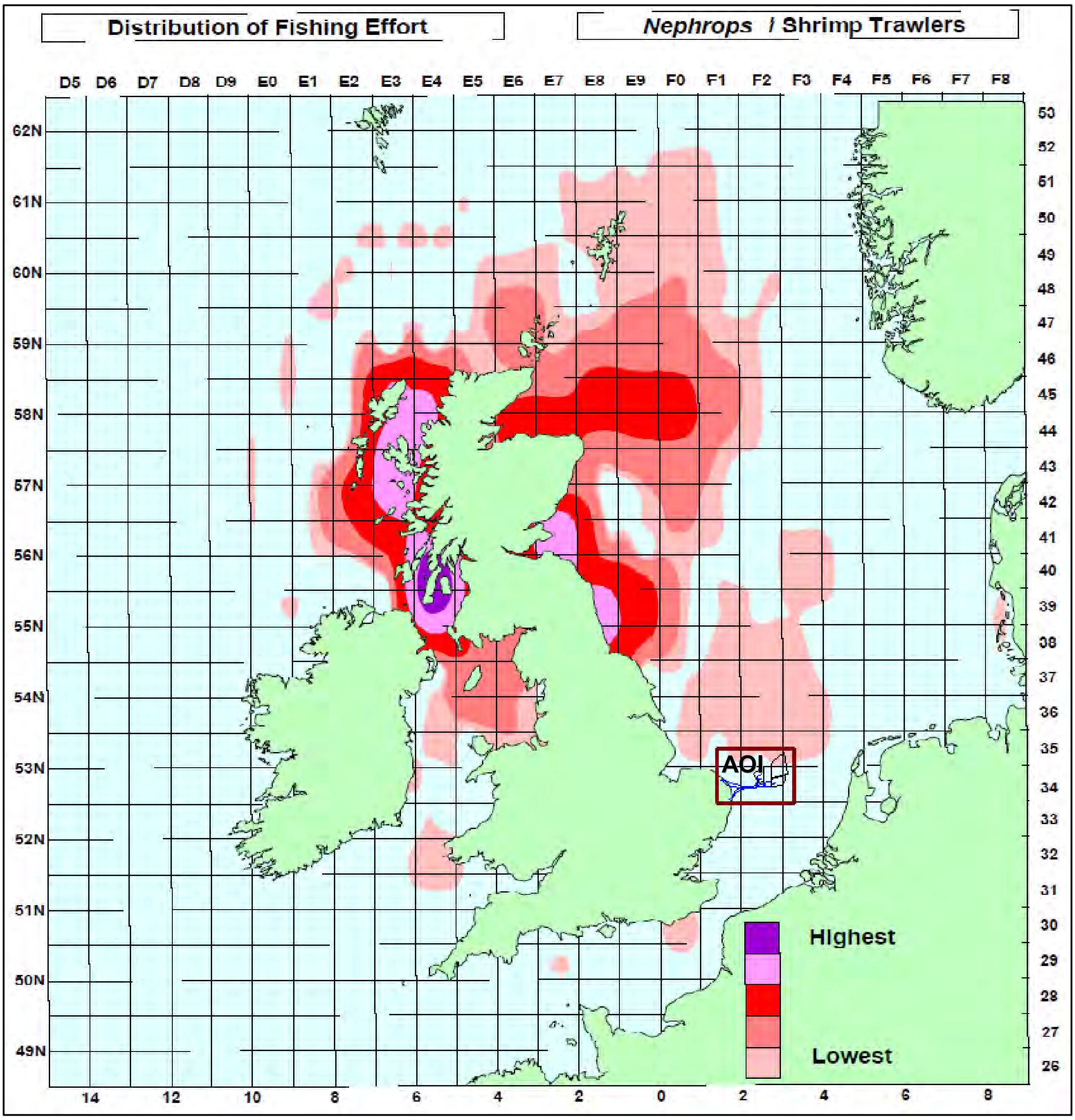


Figure 31 UK Nephrops/Shrimp Effort in the North Sea - 1995 (UKOOA/SFF/NFFO)

Figure 32 shows the distribution of pelagic and static fishing. Pelagic species are caught in mid water and therefore this fishery presents a low risk to the EAN Tranche-1 export cables.

Whilst the static gear (most commonly gill nets) is present with a high category of effort across the AOI, this type of fishery presents a low risk to the EAN Tranche-1 export cables. In inshore areas static fishing is commonly undertaken using small vessels <12m long and this may explain its apparent absence from the VMS data presented in Figure 25, Figure 26 and Figure 27.

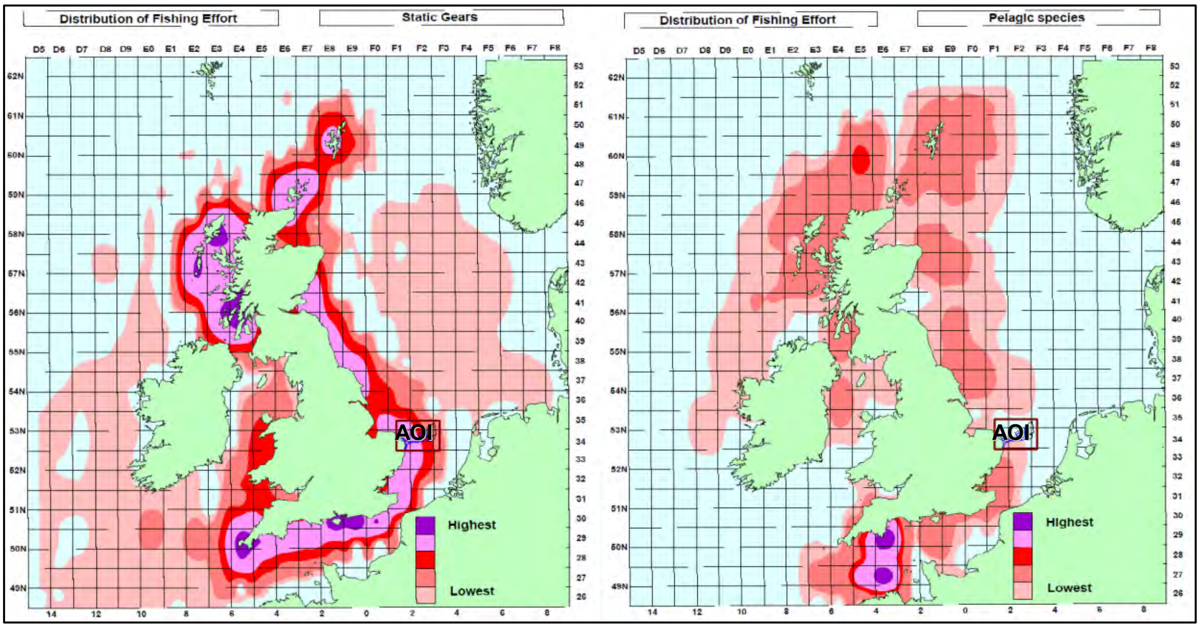


Figure 32 UK Pelagic and Static Effort in the North Sea - 1995 (UKOOA/SFF/NFFO)

4.3.11 Marine traffic and anchoring

Shipping traffic and other marine traffic can have an impact on cable security should vessels deploy an anchor in an emergency or through the presence of anchorages near cable landing points. Avoidance of major shipping routes is advisable but often not achievable.

Figure 34 shows marine traffic density through the EAN Tranche-1 AOI. The majority of this traffic represents coastal transit traffic. There are concentrations of activity east of Great Yarmouth which represent the aggregate dredging described in section 4.3.5. Also evident are the higher concentrations associated with the hydrocarbon industry in the northern part of Figure 34.

The ANATEC data supplied by Vattenfall was cropped to the AOI boundaries and then the AIS track lengths measured for each category of vessel. The total length of tracks inside the AOI was 117,951km. Of these the highest proportion of traffic was from General Cargo vessels (18%), with vessel associated with the hydrocarbon industry on the southern North Sea representing some of the next highest proportions. Much of this Hydrocarbon industry traffic is based out of Great Yarmouth. Figure 34 shows a summary of the vessel type sighted in the EAN Tranche-1 AOI with the smallest categories grouped together as ‘other’ (sailing, tall ship, military, wind farm support, motor boat and recreational).

Anchors are a direct threat to submarine cables especially large vessel anchors, despite burial of the cable. The average length of vessel from the ANATEC data within the AOI is 126.5m, therefore the anchors carried by the vessels transiting the area are of concern to cable security. The only anchorage charted in the region is just south of Great Yarmouth and not an influence on the export corridors.

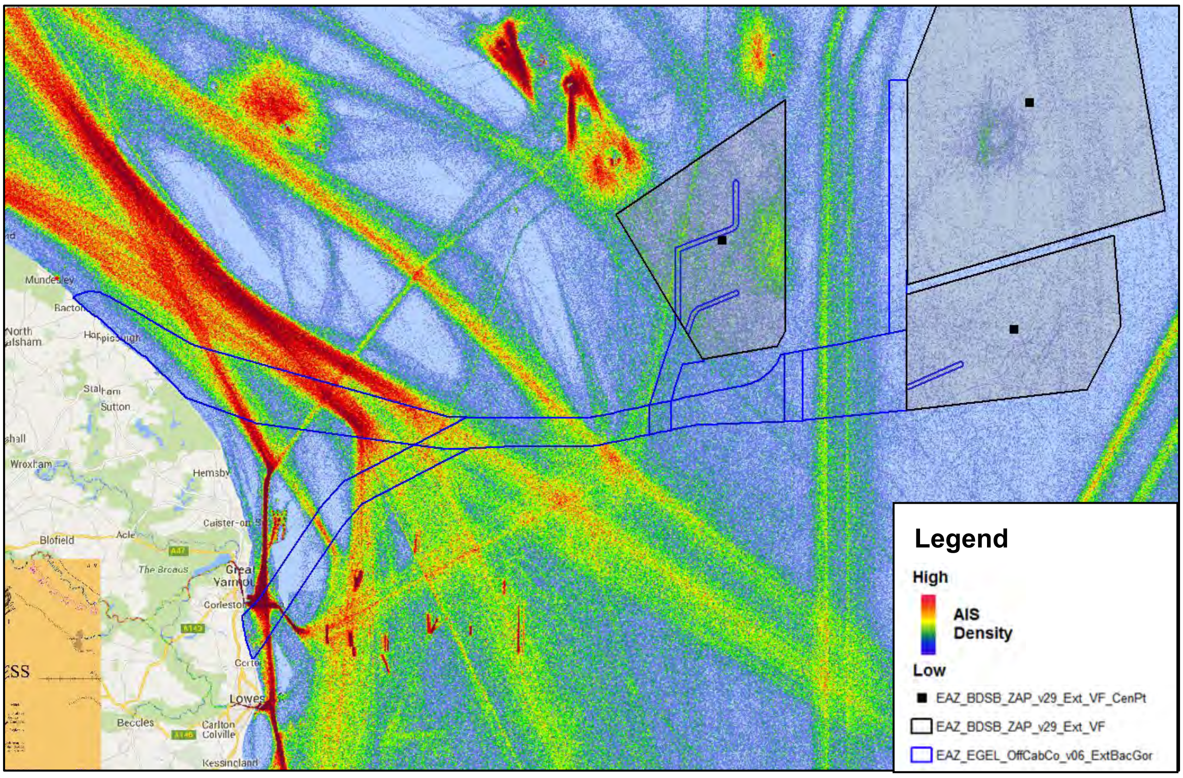


Figure 33 AIS Marine Traffic Density (marinetraffic)

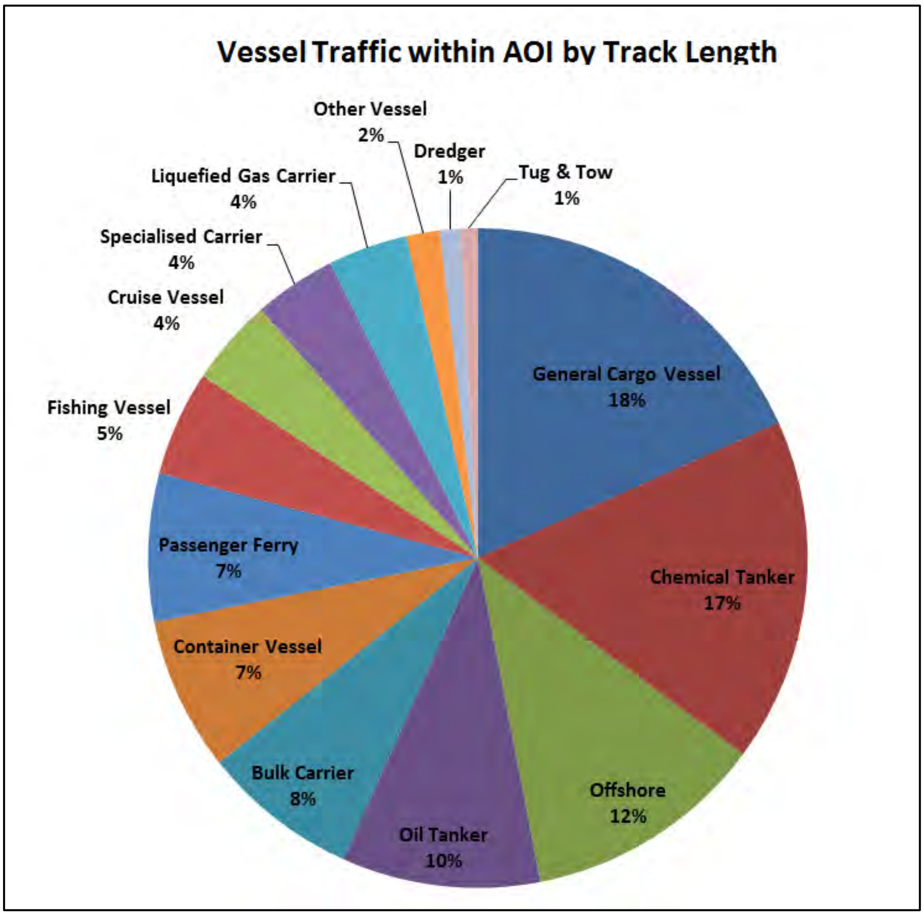


Figure 34 Vessel Traffic Categories (ANATEC AIS)

There have been a number of recorded cases in UK water where vessels underway have dragged their anchors and damaged submarine cables; in some incidents, damage has been caused to multiple cables in the same event. During one significant incident in 2008, a 58,000 ton tanker dragged its anchors for 300km and damaged 6 cables in water depths up to 180m off the coast of the Scilly Isles.

Finally the marine traffic, whilst not a major influence on the cable corridors may have an effect later route survey and installation operations, most notably as the corridors cross the major transit lanes closer to the Norfolk coast.

4.3.12 Unexploded Ordnance

The North Sea has been an area subject to frequent naval confrontations throughout history. Since the late 19th century these engagements have had the potential to leave unexploded ordnance (UXO) on the seabed in the form of high explosive shells, torpedoes and sea mines. Typical high explosives do not significantly degrade over time and in fact can become more sensitive to disturbance (PMSS, 2011). The most significant sources of UXO in the North Sea today are the result of the campaigns in World War 1 (WW1) and World War 2 (WW2). Other sources considered include modern firing ranges, sunken munitions ships and disposal grounds for unwanted ammunition.

During WW1 submarine warfare, particularly commerce raiding by the German 'U-boats', was widespread. The zones designated by the Germans for 'unrestricted submarine warfare' (USW) of this type in 1915 and 1917 are sketched in Figure 35. Torpedoes and other ammunition that missed its target could have wound up in the waters around the cable routes. Any UXO hazard from this source is expected to be low however due to the scattered nature of the engagements with usually low ammunition expenditure and the resulting low probability of encountering objects from this source. Any WW1-era U-boat wrecks are a potential source of drifting UXO from ammunition on board or munitions carried as cargo.

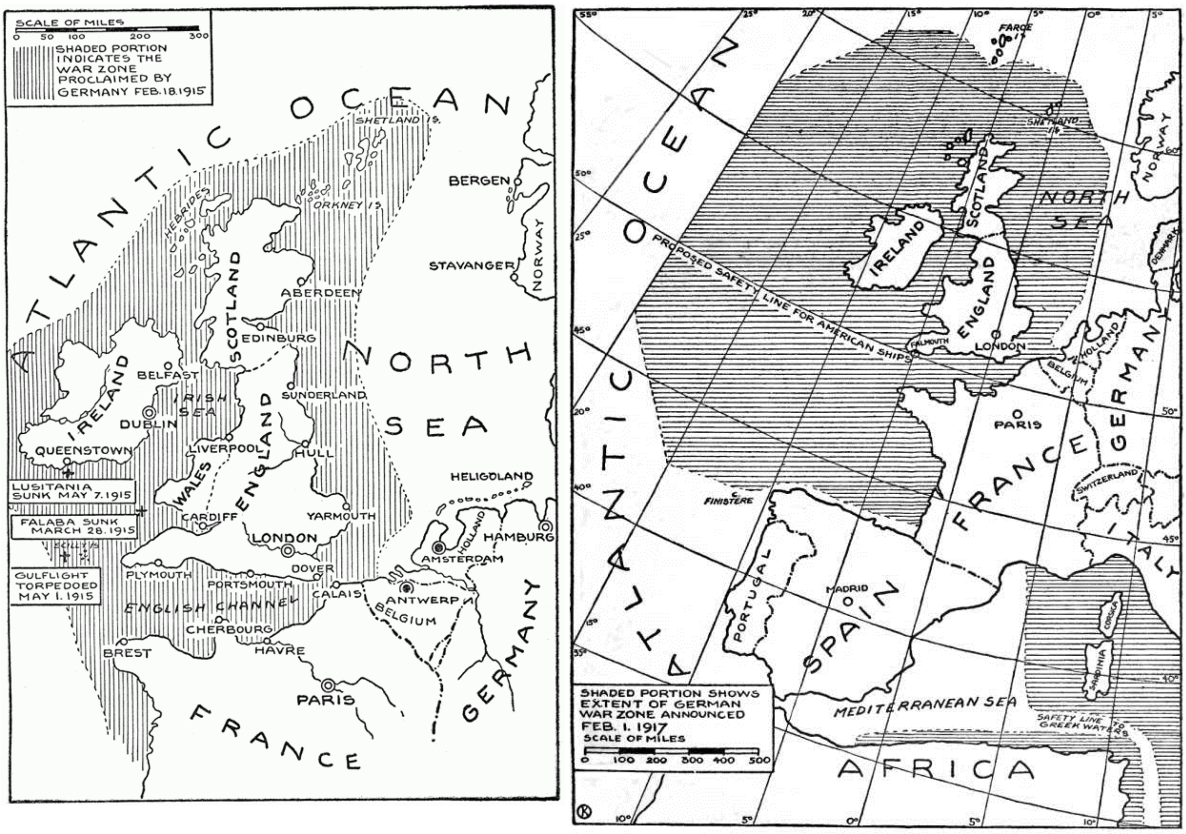


Figure 35 German USW Zones, 1915 and 1917. (The Story of the Great War Vol. VI)

Another threat to the cable from WW1-era explosives is from sea mines. Late in WW1 the USW described above was proving extremely effective in preventing supplies reaching the

UK. In order to protect the Atlantic shipping lanes several minefields were laid to restrict the movement of the U-boats. Of the mines deployed many detonated during deployment, broke free of moorings or were not successful for other reasons.

Minelaying operations came into prominence once again in WW2. The focus again was to prevent U-boats from having free access to the Atlantic. The British set up the East Coast Barrier, a mine barrage between twenty and fifty miles wide from Scotland to the Thames, leaving a narrow space between the barrage and the coast for navigation. The location of this mine barrier and other laid during WW2 can be seen in Figure 36.

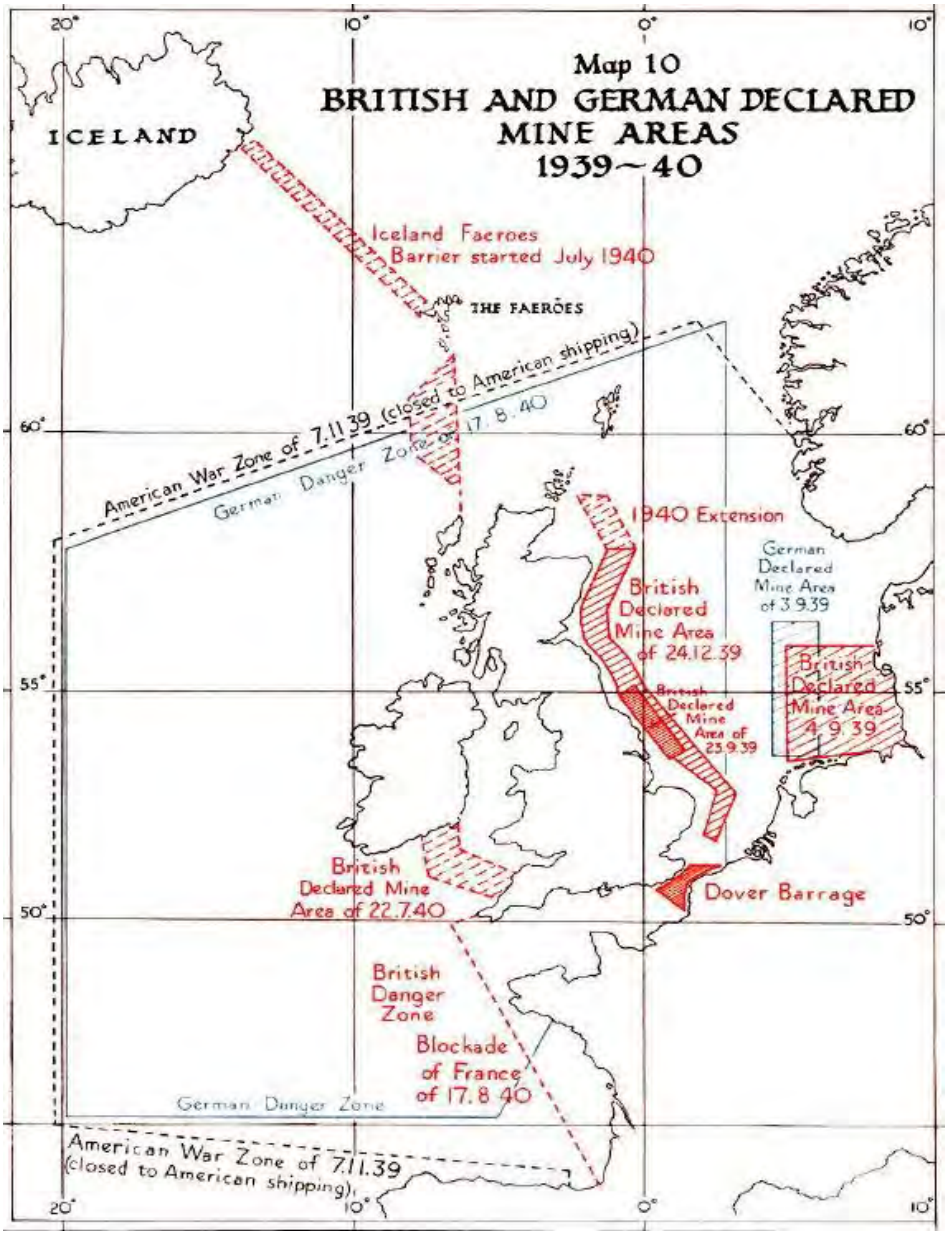
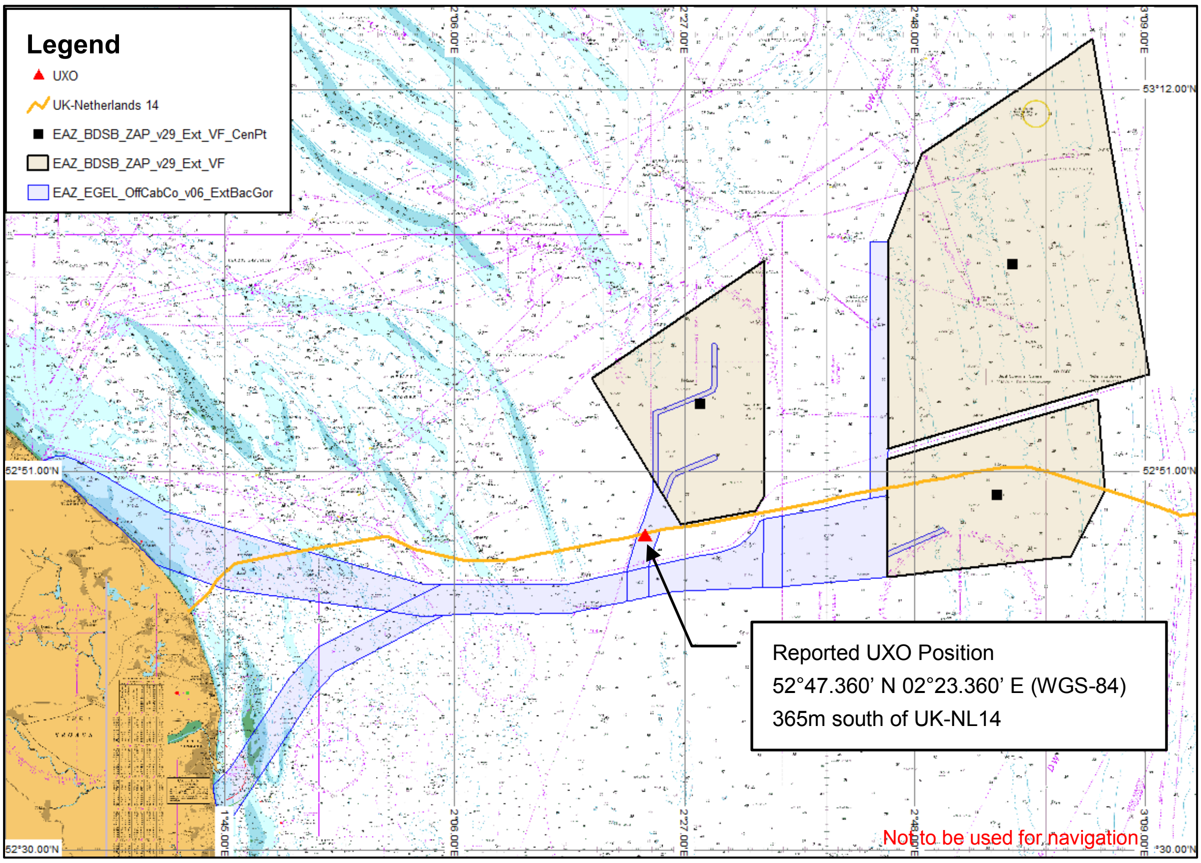


Figure 36 WW2 Mine Barriers (Roskill)

Anti-shipping mines were also used by the Germans, primarily deployed by air. These deserve special mention as many were constructed with aluminium casings to avoid being detected magnetically. This renders a magnetometer far less effective in finding them.

Since 1945 there have been no naval engagements in the North Sea. The potential for more recent UXO is therefore limited. There are no explosives dumping grounds or firing ranges charted close to the EAN Tranche-1 export corridors.

Of particular note is an entry in the UK-Netherlands 14 route position list. A UXO was found some 365m from the cable and remains at that location. It lies within the original Vattenfall corridors and the position is shown in Figure 37. The type or size of UXO is not recorded.



Reported UXO Position
52°47.360' N 02°23.360' E (WGS-84)
365m south of UK-NL14

Figure 37 Reported UXO Location (UK-Netherlands 14 RPL)

GMSL are not UXO experts and a detailed risk assessment by experts is advised for the EAN Tranche-1 project as it moves forward.

4.4 Resulting Corridors

After using the information presented in section 4.3 (Description of Constraints and Influences) a set of recommended export cable corridors for EAN Tranche-1 have been engineered. In total 4 corridors have been created these are designated as per Figure 38 and titled;

- **EAN T1 NORTH East**
- **EAN T1 NORTH West**
- **EAN T1 SOUTH East**
- **EAN T1 SOUTH West**

As per the CCA scope of work, the NORTH corridors allow for a cable landing between Bacton and Waxham, the SOUTH corridors allow for a cable landing between Hopton and Corton in Norfolk, England. An outline of a possible future corridor option is shown connecting to EAN Tranche-2 and demonstrates how these cables could also be accommodated.

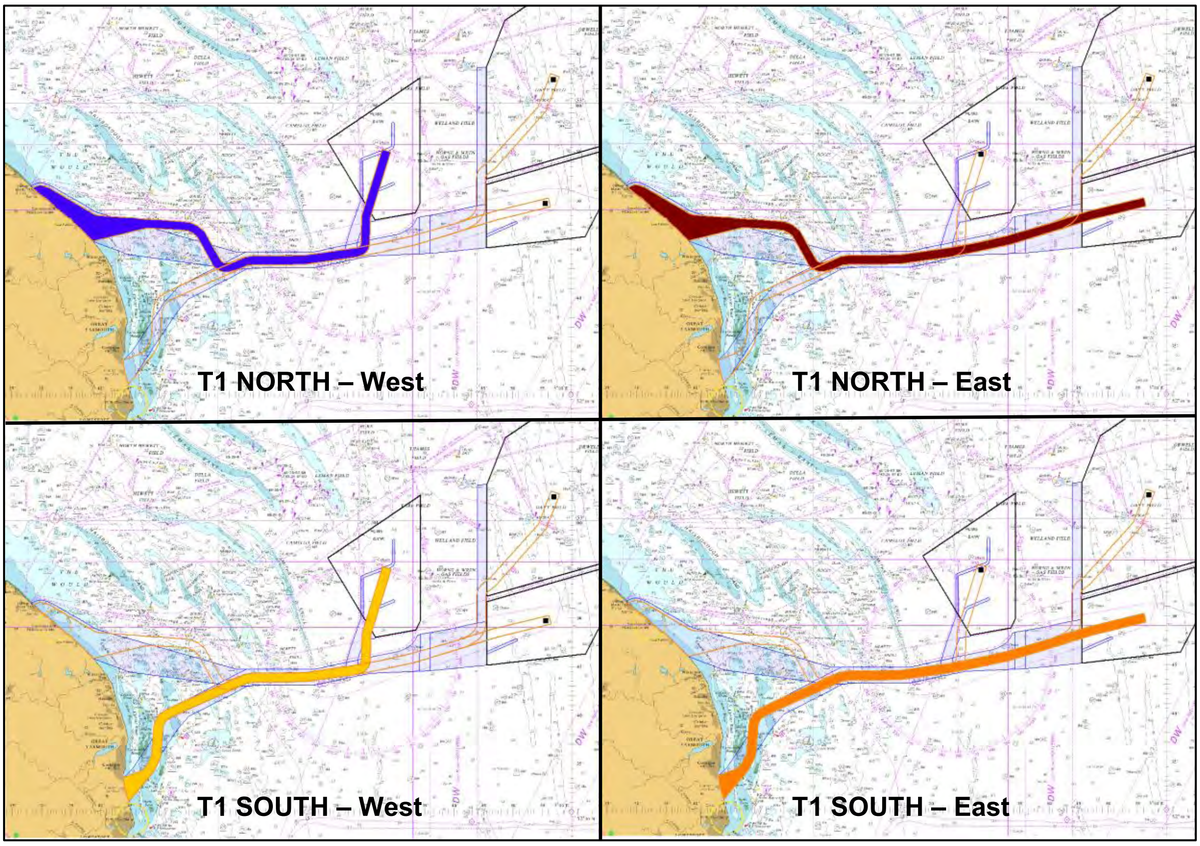


Figure 38 The 4 GMSL EAN Tranche-1 Export Cable Corridors

Key characteristics of the four route corridors are summarised in Table 8 below:

Corridor	Total Length	No. Pipeline Crossings	No. IS Cable Crossings	No. OOS Cable Crossings	Significant Seabed Features Crossed
T1 NORTH – East	99km	1	2	7	Newarp Banks
T1 NORTH – West	81km	2	3	7	
T1 SOUTH – East	94km	1	1	1	Corton Sand Barley Picle Middle Cross Sand Newarp Banks
T1 SOUTH – West	76km	2	2	1	

Table 8: Route Summary Table

The main criteria GMSL used as the main influences on the corridors were as per Table 9 below.

GMSL Export Corridor Engineering Design Criteria	
1	Avoid seabed areas <15m deep to maximise the possible installation solution options and minimise project costs
2	Where corridors must cross shoals <15m deep, minimise the crossing distance and maximise the water depth across the corridor where possible
3	Avoid Pipelines and cables by at least 500m when in close proximity

4	Where crossings of in-service cables or pipelines are necessary make the crossing angle as close to 90° as possible
5	Avoid all aggregate extraction areas by at least 500m
6	Avoid all existing OWF arrays and export cable routes
7	Corridor widths are based on a worst case assumption of 1710m (see section 3.4)
8	Corridors should expand near to shore in order to accommodate all possible landing points as defined by Vattenfall.
9	Avoid clusters of wreckage and seabed obstructions where this does not have an undue effect on route length

Table 9 GMSL EAN Tranche-1 Export Corridor Engineering Design Criteria

For each corridor the engineering and design decisions are described in more detail below. Descriptions all start from shore and finish at the assumed central locations for the eastern and western areas.

4.4.1 EAN T1 NORTH East

This corridor starts by accommodating all possible landing points between Bacton, the most north western limit and Waxham, the most south eastern limit of the NORTH corridor. Close to the landing the corridor's main constraint is the Bacton to Zeebruge gas pipeline. In order to limit the amount of pipeline crossings and to cross at a good angle this pipe acts as the northern boundary for the corridor, with the edge of the GMSL corridor being 505m from the pipe. The southern boundary from Waxham avoids the outside edge of Winterton Shoal, which is shallower than 15m. The corridor then crosses the northern edge of Newarp Banks, where it cannot avoid crossing the 15m charted water depth. The least depth inside the corridor on the UKHO chart is 12.2m.

The corridor then turns to the south outside of Newarp Banks and crosses the UK-Netherlands 14 fibre optic cable at an angle which should allow for a 60° crossing. The corridor then proceeds 7km southeast before turning to the east ready to cross the Bacton to Zeebruge gas pipeline and heads east towards the eastern array zone. The Bacton to Zeebruge pipeline crossings should achieve at least an 85° crossing angle.

The corridor proceeds eastwards with the northern boundary influenced by the BBL Balgzand to Bacton gas pipeline which lies to the north and is orientated east-west. The corridor remains at over 800m from the pipeline. The corridor also avoids crossing the 15m charted water depth of Hearty Knoll Sandbank, passing to the south of this seabed feature.

19.0km east of the Bacton to Zeebruge pipeline crossing, the corridor crosses the NorthSeaCom 1 segment 3 fibre optic cable. The crossings should achieve at least an 65° crossing angle.

Continuing east the corridor remains south of the BBL Balgzand to Bacton gas pipeline and after 28.5km reaches the T1 East zone boundary and 11.5km later reaches the assumed central location of the T1 East zone.

All turns in the corridor have a minimum inside turning radii of at least 600m, this should allow a cable plough (which has the most limited rate of turn for a burial tool considered) to achieve the necessary final export routes.

4.4.2 EAN T1 NORTH West

This corridor is identical to the EAN T1 NORTH East cable corridor until after the crossing of the NorthSeaCom 1 cable. Following the NorthSeaCom 1 crossing the corridor turns north and crosses BBL Balgzand to Bacton gas pipeline. The crossings should achieve at least an 80° crossing angle. 3.0km further north the UK-Netherlands 14 fibre optic cable is crossed. Here the crossings should also achieve at least an 80° crossing angle.

Continuing north the corridor reaches the T1 West zone boundary after 2.5km and 11.0km later reaches the assumed central location of the T1 West zone.

All turns in the corridor have a minimum inside turning radii of at least 600m, this should allow a cable plough (which has the most limited rate of turn for a burial tool considered) to achieve the necessary final export routes.

4.4.3 EAN T1 SOUTH East

This corridor starts by accommodating all possible landing points between Gorleston-on-Sea/Hopton, the most northern limit and Corton the most southern limit of the SOUTH corridor.

The landing zone for the SOUTH corridor starts at the northern limit, just south of Great Yarmouth Port and extends to Corton, just north of Lowestoft.

There are two major constraints on the SOUTH corridor. To the north is Scroby Sands offshore windfarm and this offshore development is avoided entirely to prevent unnecessary interaction. To the southeast are large established aggregate extraction areas. Crossing these would place the export cables at a high risk of damage and would most likely raise objections from the aggregate industry, so this has also been avoided entirely.

As a result of these two constraints the corridor endeavours to pass over the shallow sandbanks and troughs in the most advantageous way to the installation. Maximising the water depth at all times so that the portions of the route where water depths are <15m are as short as possible and so that sandbanks are crossed at high angles of incidence.

The northern boundary from Gorleston-on-Sea crosses Gorleston Road to reach Corton Sand sandbank. It avoids the largest intertidal zone as charted on Corton Sand, but does cross some extremely shoal areas and the chart here notes changing depths on the sandbank. The southern boundary from Hopton crosses to the southern end of Corton Sand, a corridor further southeast would have placed the corridor within 500m of a licenced extraction zone, and so whilst being less than ideal, the corridor crosses Corton Sand. The corridor passes over an area with <15m water depths, for 5km over the sandbank. As it passes over Corton Sand it also turns further to the north to utilise Barley Picle, the trough between Corton Sand and Middle and South Cross Sands. Here the corridor passes to the west of the Scroby Sands OWF and then turns to the northeast to cross Middle Cross Sand.

Middle Cross Sand is another shoal sandbank area with a least charted depth of 5.4m. The distance over which the corridor crosses the sandbank is minimised. The length of corridor which is <15m deep is 1.5km. The chart features a caution over changing depths here. The crossing point for Middle Cross Sand also avoids a cluster of wrecks at the southern end of the sandbank. There sufficient numbers of wrecks to pose a potential issue for future cable routing, and so this area is avoided.

The corridor continues 7.0km from Middle Cross Sand before it reaches a sandbank which is part of the Newarp Banks group. The distance over which the corridor crosses this sandbank is minimised. The length of corridor which is <15m deep is 500m. The least charted depth is 10.6m. From this final sandbank crossing the corridor proceeds 6.4km to cross the Bacton to Zeebruge gas pipeline and then heads east towards the eastern array zone. The Bacton to Zeebruge pipeline crossings should achieve at least an 85° crossing angle.

The corridor proceeds eastwards with the northern boundary influenced by the BBL Balgzand to Bacton gas pipeline which lies to the north and is orientated east-west. The corridor remains at over 800m from the pipeline. The corridor also avoids crossing the 15m charted water depth of Hearty Knoll Sandbank, passing to the south of this seabed feature.

19km east of the Bacton to Zeebruge pipeline crossing, the corridor crosses the NorthSeaCom 1 segment 3 fibre optic cable. The crossings should achieve at least an 65° crossing angle.

Continuing east the corridor remains south of the BBL Balgzand to Bacton gas pipeline and after 28.5km reaches the T1 East zone boundary and 11.5km later reaches the assumed central location of the T1 East zone.

All turns in the corridor have a minimum inside turning radii of at least 600m, this should allow a cable plough (which has the most limited rate of turn for a burial tool considered) to achieve the necessary final export routes.

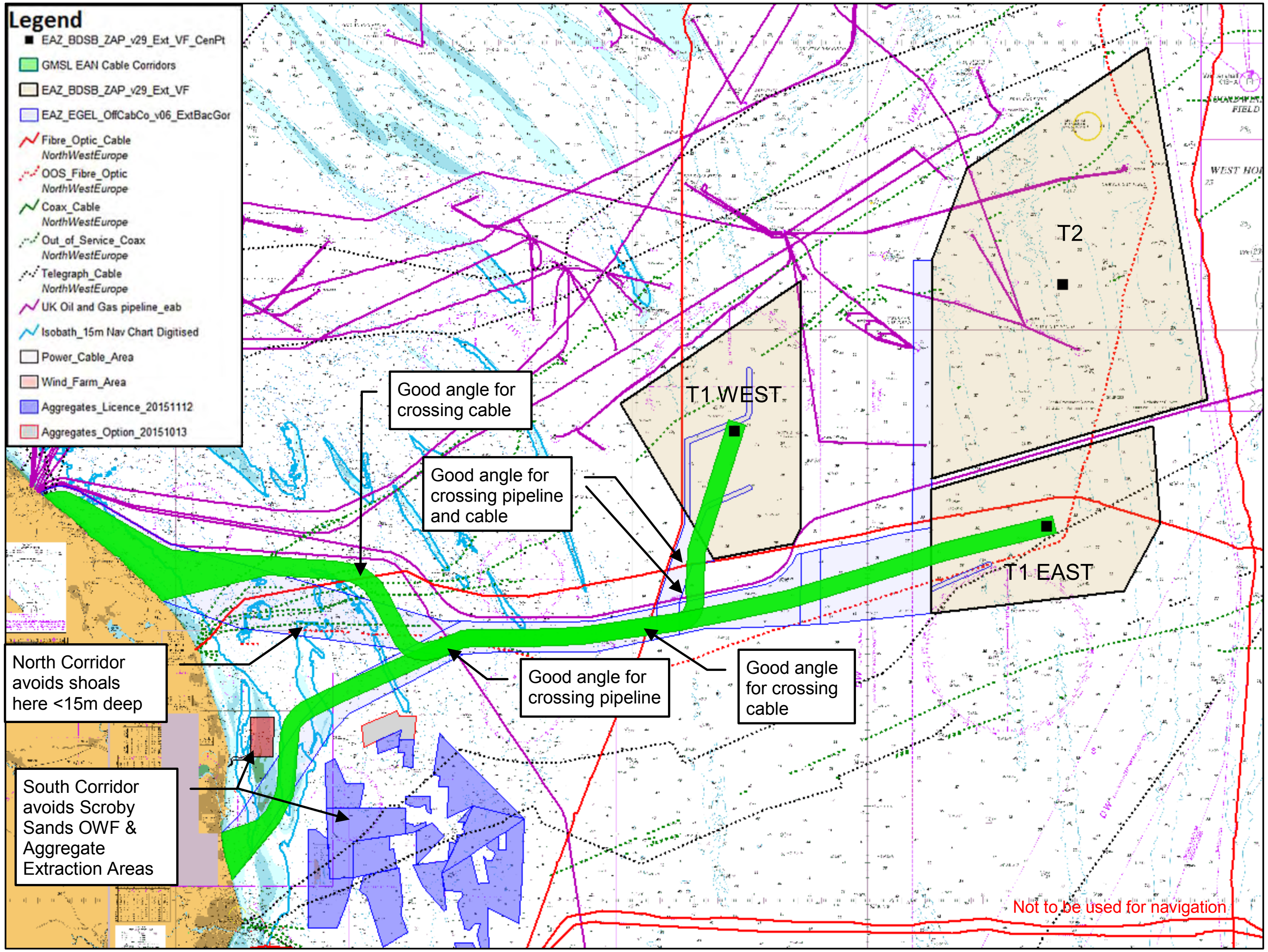
4.4.4 EAN T1 SOUTH West

This corridor is identical to the EAN T1 SOUTH East cable corridor until after the crossing of the NorthSeaCom 1 cable. Following the NorthSeaCom 1 crossing the corridor turns north and crosses BBL Balgzand to Bacton gas pipeline. The crossings should achieve at least an 80° crossing angle. 3.0km further north the UK-Netherlands 14 fibre optic cable is crossed. Here the crossings should also achieve at least an 80° crossing angle.

Continuing north the corridor reaches the T1 West zone boundary after 2.5km and 11.0km later reaches the assumed central location of the T1 West zone.

All turns in the corridor have a minimum inside turning radii of at least 600m, this should allow a cable plough (which has the most limited rate of turn for a burial tool considered) to achieve the necessary final export routes.

The major design influences for all 4 corridors have been illustrated in Figure 39, which has routing annotations marked on the figure for some significant corridor routeing decisions.



Good angle for crossing cable

Good angle for crossing pipeline and cable

North Corridor avoids shoals here <15m deep

Good angle for crossing pipeline

Good angle for crossing cable

South Corridor avoids Scroby Sands OWF & Aggregate Extraction Areas

Not to be used for navigation

Figure 39 EAN Tranche-1 GMSL Export Cable Corridors and Major Design Influences

5.0 EXPORT CABLE CORRIDOR THREAT ASSESSMENT

5.1 Introduction

This section takes the information presented earlier in the report on the marine activities carried out in the EAN Tranche-1 AOI and makes an assessment of the threat posed to the export cable corridors.

5.2 Lessons from Previous Cables in the Project Area

5.2.1 Introduction

In the EAN Tranche 1 project area are numerous existing submarine cables. These are listed in Table 5 and their locations shown in Figure 11 (Section 4.3.4).

Two of these cables are of particular interest as the cable survey, installation and maintenance records were made available to this study in order to gain as much knowledge of local cable security issues as possible. The maintenance authority for both cables is BT and permission to use the cable records for both cables was granted by Glenn Lipsham at BT Subsea Cable Systems.

These two cables are;

- UK-Germany 5

  A fibre optic telecommunication cable installed in 1991 and retired in 2006. It links Norden in Germany to Winterton in England. The cable was installed by Cable and Wireless Marine (now GMSL) and is owned by a consortium consisting of BT, Deutsche Telekom, Tele Danmark, Telia, Telenor and Telecom Finland. The cable manufacturer was OCC.

- UK-Netherlands 14

  A fibre optic telecommunication cable which was installed in 1996 and is still in service. It links Egmond in the Netherlands to Winterton in England. The cable is owned by a consortium consisting of BT, Vodafone and KPN. The cable manufacturer and installer was Pirelli.

The faults for UK-Germany 5 and UK-Netherlands 14 within the AOI are listed in Table 10 and their locations shown in Figure 40. It is apparent from Figure 40 that the faults lie in two clusters and these are displayed inside the red dashed boundaries and described as the eastern and western clusters in this report.

The reference numbers for each fault in the first column of Table 10 are used to label and identify each fault shown in Figure 40 for continuity. These reference numbers are also used within this section when individual faults are being discussed.

No	System Name	Fault Number	Fault Occurred	Water Depth (m)	Pre Repair Armour Type	Seabed Type	Seabed Slope	Cause of Fault
1	UK-Germany 5	5	11/01/1996	40	SINGLE ARMOUR LIGHT (SAL)	SAND	UNKNOWN	UNKNOWN
2	UK-Germany 5	6	11/07/1996	35	ROCK ARMOUR (RA)	SAND	UNKNOWN	FISHING - TRAWLING
3	UK-Germany 5	7	09/09/1996	35	ROCK ARMOUR (RA)	SAND	UNKNOWN	FISHING - TRAWLING
4	UK-Germany 5	8	29/12/1996	29	ROCK ARMOUR (RA)	SAND	SAND WAVES	ANCHOR
5	UK-Germany 5	9	14/05/1997	29	ROCK ARMOUR (RA)	SAND	SAND WAVES	ANCHOR
6	UK-Germany 5	10	09/06/1997	29	ROCK ARMOUR (RA)	SAND	SAND WAVES	FISHING - TRAWLING
7	UK-Germany 5	11	09/02/2000	38.5	ROCK ARMOUR (RA)	SAND	SAND WAVES	FISHING - TRAWLING
8	UK-Germany 5	12	06/02/2002	35	SINGLE ARMOUR LIGHT (SAL)	SAND	SAND WAVES	FISHING - TRAWLING
9	UK-Germany 5	13	04/12/2002	38	SINGLE ARMOUR LIGHT (SAL)	SAND	SAND WAVES	UNKNOWN
10	UK-Germany 5	14	06/01/2003	38	SINGLE ARMOUR LIGHT (SAL)	SAND	SAND WAVES	UNKNOWN
11	UK-Germany 5	15	18/06/2003	33	ROCK ARMOUR (RA)	SAND	SAND WAVES	FISHING - TRAWLING
12	UK-Germany 5	16	10/09/2003	36	ROCK ARMOUR (RA)	SAND	SAND WAVES	OTHER 3RD PARTY
13	UK-Germany 5	17	16/09/2003	35	ROCK ARMOUR (RA)	SAND	SAND WAVES	OTHER 3RD PARTY
14	UK-Germany 5	18	10/12/2003	30	SINGLE ARMOUR LIGHT (SAL)	SAND	SAND WAVES	UNKNOWN
15	UK-Germany 5	19	23/06/2004	36	SINGLE ARMOUR LIGHT (SAL)	SAND	SAND WAVES	FISHING - TRAWLING
16	UK-Germany 5	20	19/08/2004	36	SINGLE ARMOUR LIGHT (SAL)	SAND	SAND WAVES	FISHING - TRAWLING
17	UK-Netherlands 14	1	19/07/2002	42	ROCK ARMOUR (RA)	SAND	SAND WAVES	FISHING - TRAWLING
18	UK-Netherlands 14	4	31/05/2011	48	ROCK ARMOUR (RA)	SAND	SAND WAVES	FISHING - TRAWLING
19	UK-Netherlands 14	5	31/05/2011	27	SINGLE ARMOUR (SA)	SAND	SAND WAVES	FISHING - TRAWLING
20	UK-Netherlands 14	7	15/02/2012	36	SINGLE ARMOUR (SA)	SAND	SAND WAVES	FISHING - TRAWLING
21	UK-Netherlands 14	8	10/05/2013	34	SINGLE ARMOUR (SA)	CHALK	SAND WAVES	FISHING - TRAWLING
22	UK-Netherlands 14	10	18/07/2013	38	SINGLE ARMOUR (SA)	SAND	SAND WAVES	FISHING - TRAWLING
23	UK-Netherlands 14	11	06/02/2014	40	SINGLE ARMOUR (SA)	SAND	SAND WAVES	ANCHOR
24	UK-Netherlands 14	14	29/07/2014	30	SINGLE ARMOUR (SA)	SAND	SAND WAVES	UNKNOWN
25	UK-Netherlands 14	15	15/06/2015	27	SINGLE ARMOUR (SA)	SAND	SAND WAVES	UNKNOWN

Table 10 Cable Fault Data

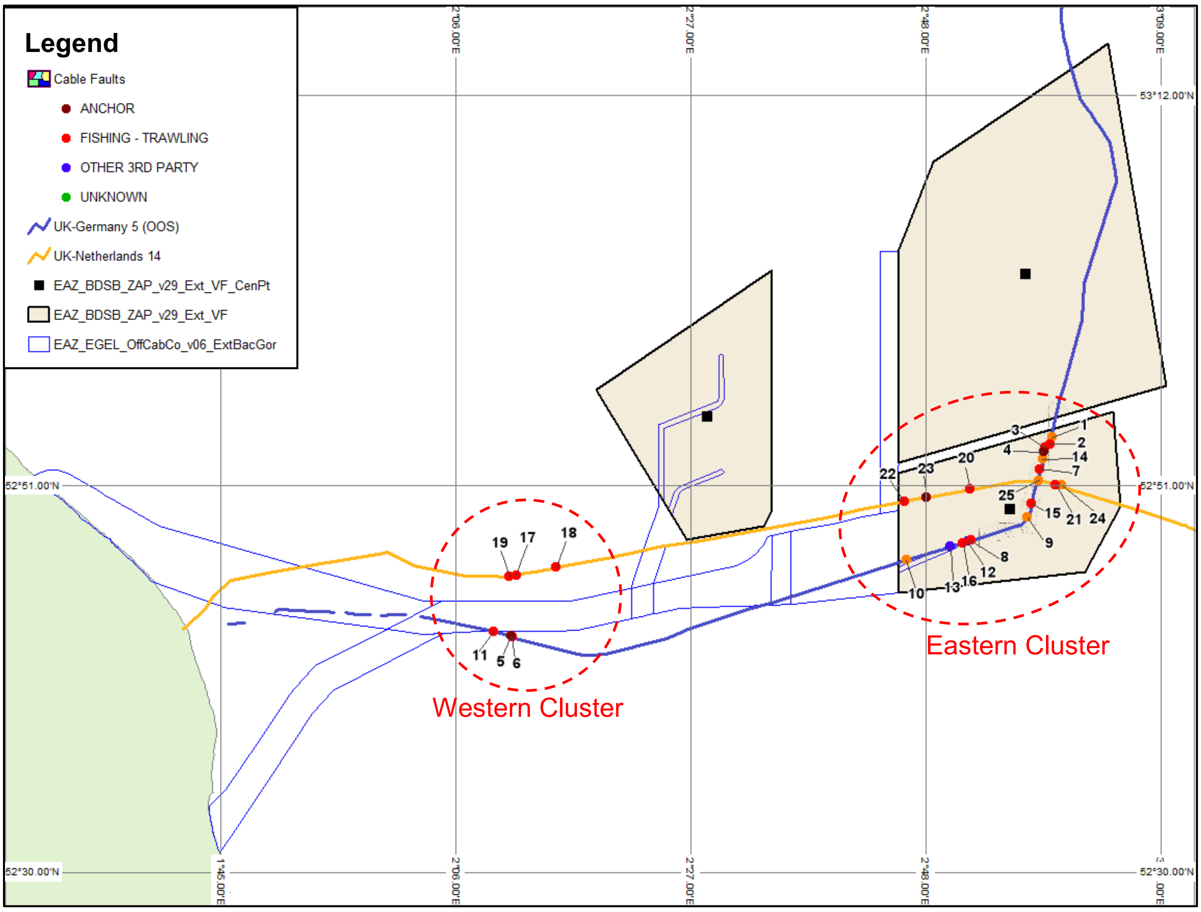


Figure 40 Cable Fault Locations

5.2.2 Fault Rates

Within the project AOI the 2 BT cables have suffered 25 faults. 16 of these have occurred on UK-Germany 5 and 9 have occurred on UK-Netherlands 14. The fault rates for each cable within the AOI therefore have been;

- UK-Germany 5: 16 faults over a 16 year in service period = 1.00 per year
- UK-Netherlands 14: 9 faults over a 20 year period (to date) = 0.45 per year

Whilst these rates provide overall fault rates for each system, a more detailed look at the temporal distribution of the combined faults shows a slightly different picture. Figure 41 shows the number of faults that have occurred in each year and the in-service periods for each cable.

For UK-Germany 5 the cable did not suffer a fault in its first 5 years of service and then had two years (1996-97) where a spike of 4 and 2 faults occurred. Between 2000 and 2004 faults occurred on both cables, but majority were on UK-Germany 5. The final two years of UK-Germany 5 were fault free within the AOI, however it is likely a fault occurred somewhere on the system in 2005-2006, acting as the trigger for BT to retire the system.

For UK-Netherlands 14 in the first 15 years of service only 1 fault occurred in the AOI, this being in 2002. The remainder have all fallen in the period 2011 to 2015, with a fault rate of 1 to 2 faults per year during this period.

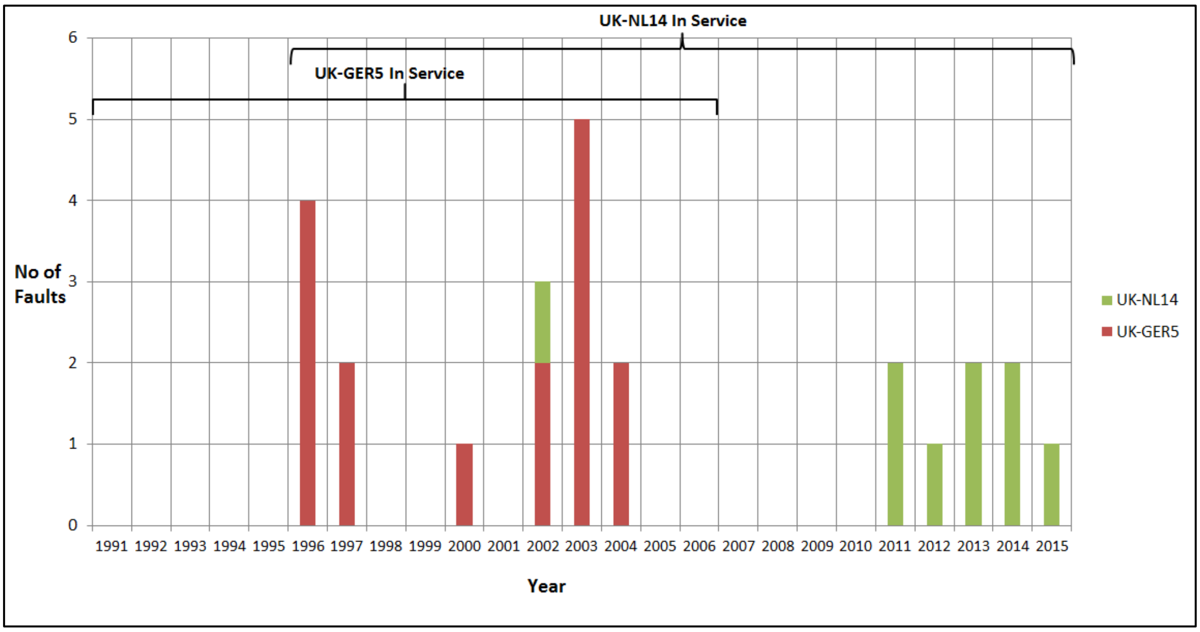


Figure 41 BT Cable Temporal Fault Distribution

The reasons for the variability in temporal fault distribution are not obvious. There are several possibilities which may help to explain the variation, indeed it may be a combination of factors.

As discussed below in section 5.2.3 in detail, fishing is the most likely cause of the majority of the faults. Spatial distribution of fishing effort varies year on year and the higher fault frequency periods could be due to higher rates of fishing effort in the vicinity of these two cables in those years. Similarly the fish species and fishing gear being utilised to catch these fish can evolve and the adoption of new gear or allocation of larger quotas for certain species may have an influence.

Another contributing factor may be variation in the depth of cable burial due to the migration of seabed sediments in close proximity to the routes. In shallow waters such as this, the reworking of seabed sediments can be the result of severe storm events and the weather history for the AOI could correlate with higher fault frequency periods.

Exploration of these factors has not been possible within the scope of this study, but they remain potential areas where further investigation may identify the reasons for the higher fault frequency periods. Section 5.2.6 below has tried to find any common factors affecting the cables at the fault locations. The objective being to identify the conditions in which future cables may be vulnerable to cable faults.

5.2.3 Fault Causes

When telecommunication cables are repaired a report is prepared to document the entire marine operation. These commonly include a fault record sheet which records information on the fault. One of the most important pieces of information recorded is the fault cause. All the fault records for the 2 BT cables in the AOI have been studied by GMSL and each repair operation report checked for consistency with the fault record sheets.

The suspected causes of faults as recorded by the repair vessels are shown in Figure 42. The largest proportion of faults is attributed to trawl fishing at 56%. The next is unknown at 20% and then comes anchors at 12% tied with other 3rd parties at 12%.

Having reviewed all the operational repair reports for only 5 of the 14 cases where fishing is identified there is some evidence in the reports to back up the suspicion of trawling as the root cause for these faults. Of course, evidence of fishing (e.g. active trawlers in the region, SSS trawl scars on the seabed, abandoned fishing gear on the cable, typical physical damage to the cable consistent with GMSL's experience of fishing faults) may have been observed during the repairs but was just not recorded in the report and so it is difficult to assess the confidence level accurately.

The faults recorded as the result of anchor damage did not document any firm evidence of the root cause. In all 3 cases where anchors were attributed, the fault was a complete cable break, with evidence of very high tensions (cable armour wire deformation shape at the broken ends). On all 3 occasions, trawlers were not observed in the vicinity – this is significant the repair vessels are typically on the repair site within a few days of the cable fault occurring and fishing activity can often still be happening when the vessel arrives. This does support an anchor cause, but in GMSL's opinion the anchor faults are not definitive.

The 5 'unknown' faults had no features or circumstances which led to the cause being identifiable. They did not feature complete breaks or obvious evidence of external aggression, otherwise they would have been classified as Other 3rd Party.

The cables were found exposed on almost all repairs. The cable was either at the seabed surface or brought to the surface when damaged. This suggests at least 20 are due to external aggression, with the remaining 5 less certain and listed as an 'unknown' cause. None of the UK-GER5 or UK-NL14 faults in the AOI were caused by cable plant failure (joint or repeater) or geohazards (seabed instability).

The full set of BT cable fault records for the 2 cables within the AOI are provided in Table 10.

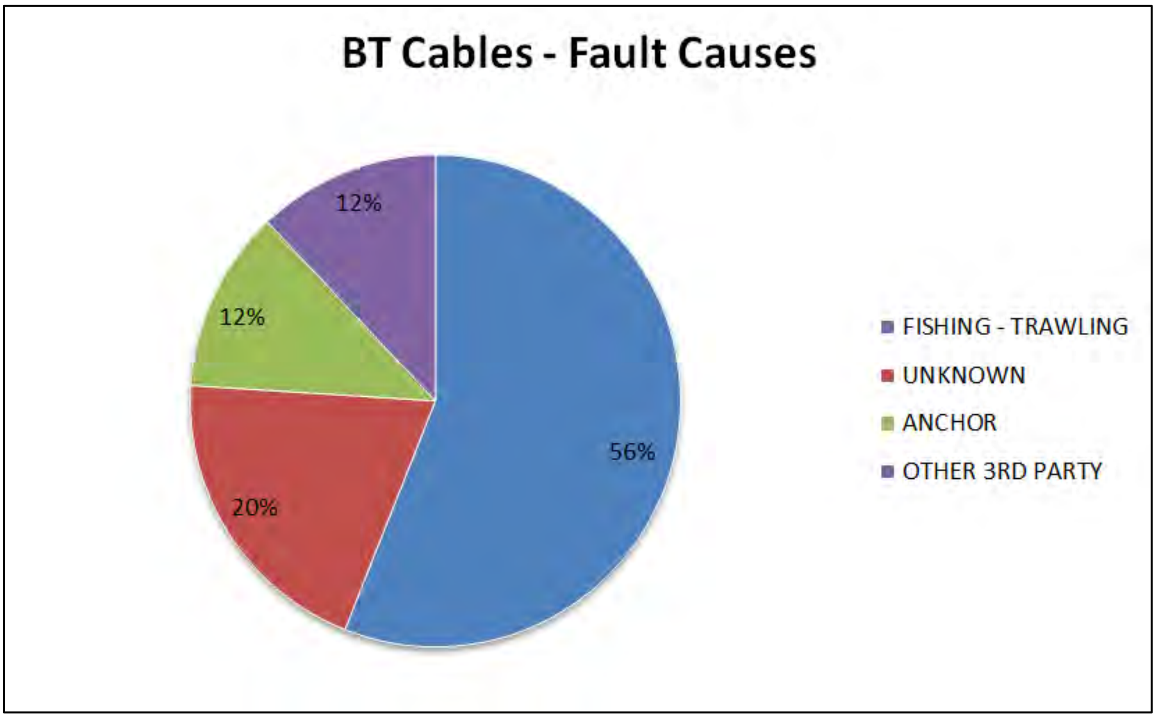


Figure 42 BT Cable Fault Causes

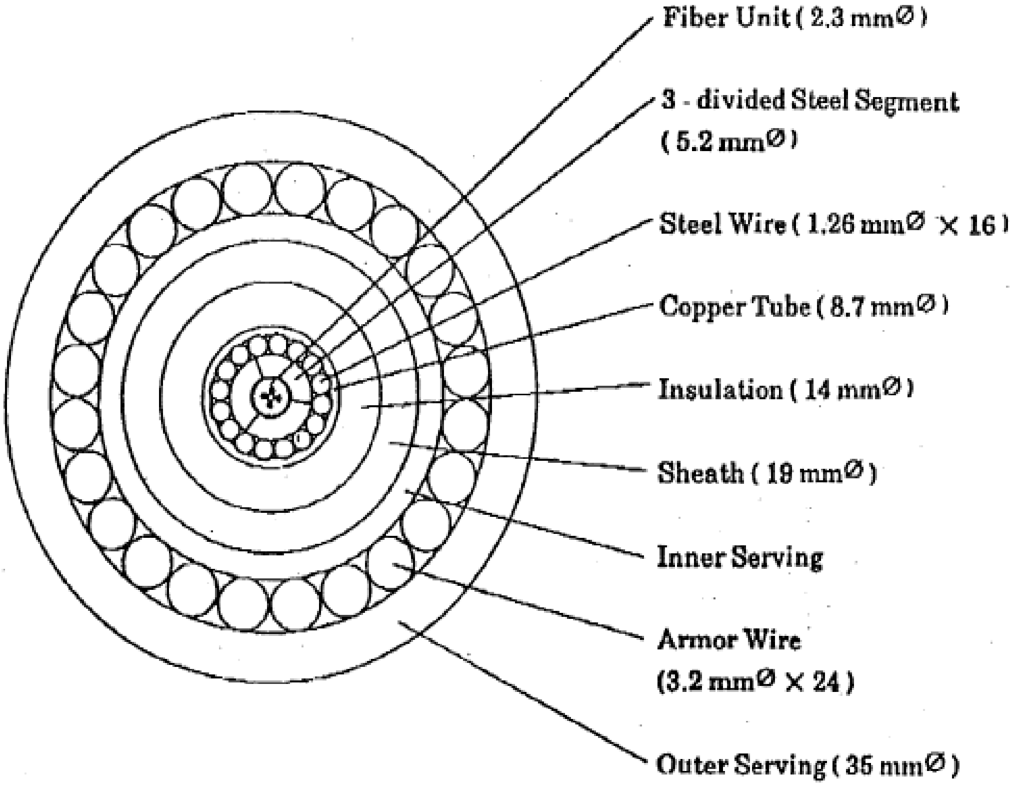
5.2.4 Cable Types

In order to appreciate the physical size and properties of the BT cables, the mechanical cable properties are provided in this section. Reference to Table 10 provides information on the types of cables at all 25 of the BT cable fault locations. Both systems feature a Rock Armour variant and these typically feature an outer layer of armour wires with a shorter pitch which are specifically designed to resist physical impact, crushing and penetration of the cable by fishing gear, due to the difference in pitch of the armour layers.

UK-Germany 5

The system features just two armour variants for this OCC manufactured cable. Both of them are present in the areas where the cable fault have occurred. The two types are

Single Armour Light (SAL) and Rock Armour (RA). The SAL mechanical properties are presented in Figure 43 and the RA mechanical properties are presented in Figure 44.

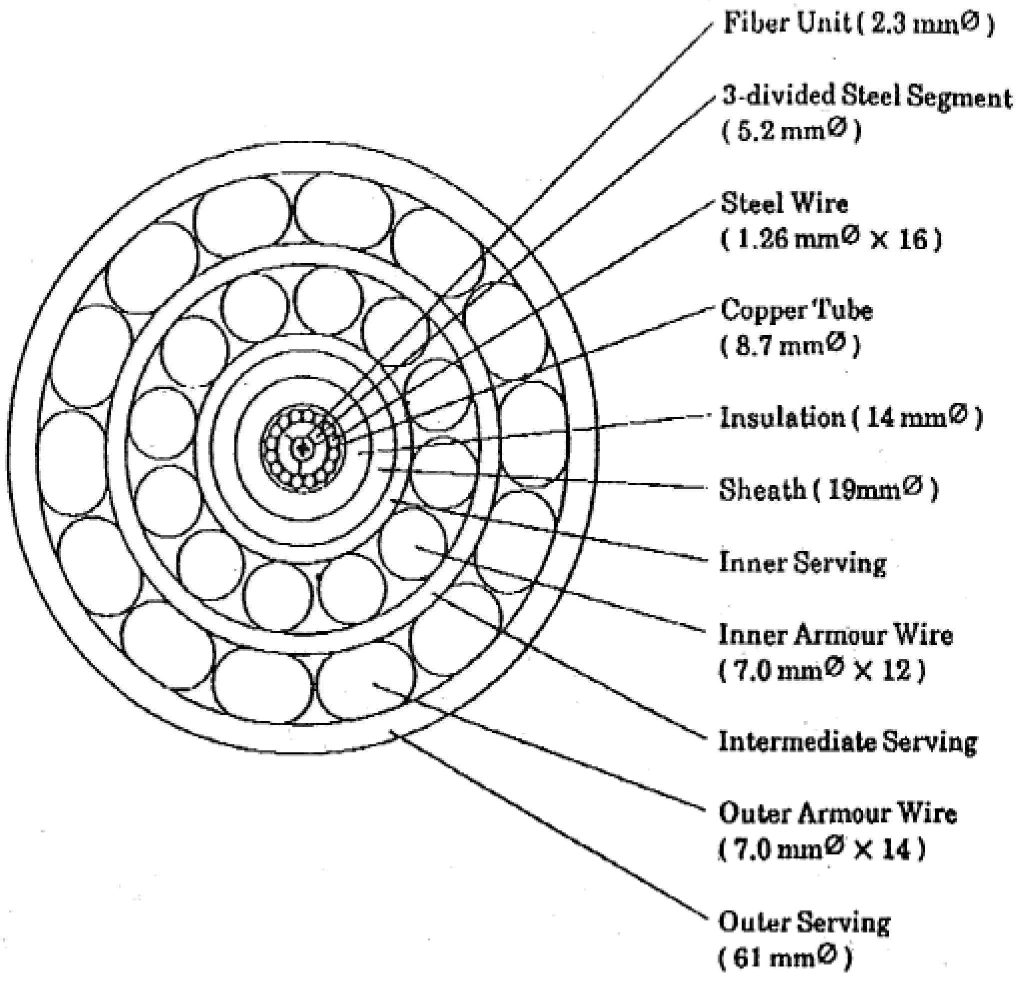


Cable Characteristic

Outer Diameter	Nominal 35 mm
Breaking Load	16 ton or more
Weight in Air	Approx. 2.5 ton / km
Weight in Water	Approx. 1.7 ton / km

Fig. 3 Type SAL Cable

Figure 43 OCC OS1.8G SAL Cable Properties (UK-GER5)



<u>Cable Characteristic</u>

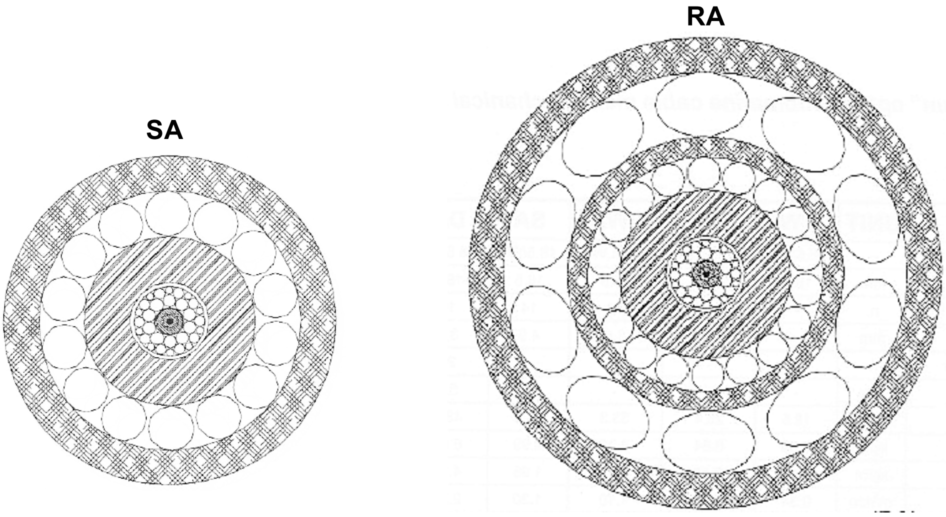
Outer Diameter	Nominal 61 mm
Breaking Load	31 ton or more
Weight in Air	Approx. 11.4 ton / km
Weight in Water	Approx. 9.0 ton / km

Fig. 4 Type RA Cable

Figure 44 OCC OS1.8G RA Cable Properties (UK-GER5)

UK-Netherlands 14

The system features three armour variants for this Pirelli manufactured 18.5mm cable. Only two of these occur in the fault areas. These are Single Armour (SA) and Rock Armour (RA). The mechanical properties for both types are provided in Figure 45.



Item	Unit	Pirelli 18.5mm Single Armour (SA)	Pirelli 18.5mm Rock Armour (RA)
Polyethylene Sheath Diameter	mm	18.5	18.5
Steel Wires in 1st Armour Layer	n.	14	18
Diameter of Wires	mm	4.9	3.6
Steel Wires in 2nd Armour Layer	n.	-	10
Diameter of Wires	mm	-	7
Overall Diameter (nominal)	mm	35.9	50.5
Weight in Air (approx.)	kg/m	2.99	7.17
Weight in Water (approx.)	kg/m	1.95	5.11
Storage Factor	m^3/km	1.30	2.70
NPTS	kN	80	60
NOTS	kN	180	140
NTTS	kN	260	200
NUTS	kN	380	290
FBL	kN	380	290
CBL	kN	380	290
Modulus	km	15.2	5.1
Minimum Bend Radius (loaded)	mm	1500	1500
Minimum Coiling Radius	mm	1500	1500
Hydrostatic Pressure Resistance	MPa	70	70
Typical Laying Depth	m	1500	200

Figure 45 Pirelli 18.5mm Cable Properties (UK-NL14)

5.2.5 Installation Methods and Performance

Both the UK-Germany 5 and UK-Netherlands 14 cable systems were primarily installed from cable lay vessels and buried using cable ploughs. Post lay burial by ROV trenching was carried out at cable crossings and areas where plough burial was interrupted. Cable burial was completed over the entire length of both systems. Fuller details are provided for each system below;

UK-Germany 5
Installation vessel: Northern Installer (Currently named Texas)
103m Long, DP vessel, Cable Lay Vessel (now working as a DSV)
Draft 5.0m

Cable Plough: C&WM SMD Plough (*max share size assumed to be 1.0m*)
Post Lay Burial ROV: BT Trencher (onboard CS Monarch)

UK-Netherlands 14
Installation vessel: Giulio Verne
133m Long, DP2, Cable Lay Vessel
Min Draft 5.19m Max Draft 8.5m

Cable Plough: Pirelli Plough P2 – 9000 kg, max burial 1.2m, max tension 50T
Post Lay Burial: Pirelli SF4 jetting system, max burial 2.0m (modified Perry Scorpion)

The UK-Germany 5 installation records are not as detailed as UK-Netherlands 14. The following information is taken from the UK-NL14 Cable & Wireless Marine Installation report and may be a valuable reference to aid the planning for the future installation of the EAN Tranche-1 cables.

A Burial Assessment was carried out for the UK-NL14 sandwave areas across the Newarp Banks, Haisborough Gat and just south of the Winterton Ridge. This consisted of pulling a smaller burial assessment plough through the area along the route and monitoring tow tensions. Tensions reached a peak of 25 tons over a 2km section, with an average range of 5 to 15 tons.

Sea currents during the UK-NL14 installation were nearly always found to be perpendicular to the direction of lay. Approaching the English coast the intensity of the tidal currents increased and the Giulio Verne could not carry on continuously with the lay and burial operations. This was the case even with support from a tug. During peak tidal flows the vessel had to suspend cable laying and turn to place the bow into the oncoming current.

East of 002° 20’ E the currents experienced by the Giulio Verne were up to 3 knots, which the vessel was able to manage with the help of a tug. Approaching the East coast of England during a spring tide the currents reached 4.2 knots. Some of the post lay burial operations were also hindered by the tidal currents, with work taking place during periods of reduced current flow. The post lay burial tool also had to be recovered from the seabed due to instability issues at times of peak tidal currents. The seabed energy information presented in section 4.3.7 corroborates this finding and it suggests future cable installations may have similar problems in the higher tidal current areas.

Plough performance during the installation achieved a burial depth of between 60cm to 70 cm at an average progress rate of 1000m/h. Max plough pitch was 64° and max roll was 54°. Tow tensions were generally lower than experienced during the burial assessment.

5.2.6 Common Conditions and Discussion

From experience and the cable fault information gathered, the most probable cause of the majority of the faults on UK-GER5 and UK-NL14 are the result of a reduction of cable burial in a mobile sandwave seabed environment, combined with either significant fishing activity at the same location or a marine traffic lane crossing the route, with resulting higher probability of a plough drag incident. To assess the validity of this theory we have studied these two aspects in more detail.

Looking first at fishing activity combined with the presence of mobile sandwaves, Figure 47 shows how the places where trawling (as seen in section 4.3.10 this is most likely to be beam trawling) and sandwave crests co-exist, match the presence of the cables faults in the eastern and western fault clusters. The sandwave crest data comes from the EMU survey data from 2013 (supplied by Vattenfall). This does not cover the entire EAN-Tranche-1 zone but was collected in a grid pattern, hence the striped patterning of the crest data.

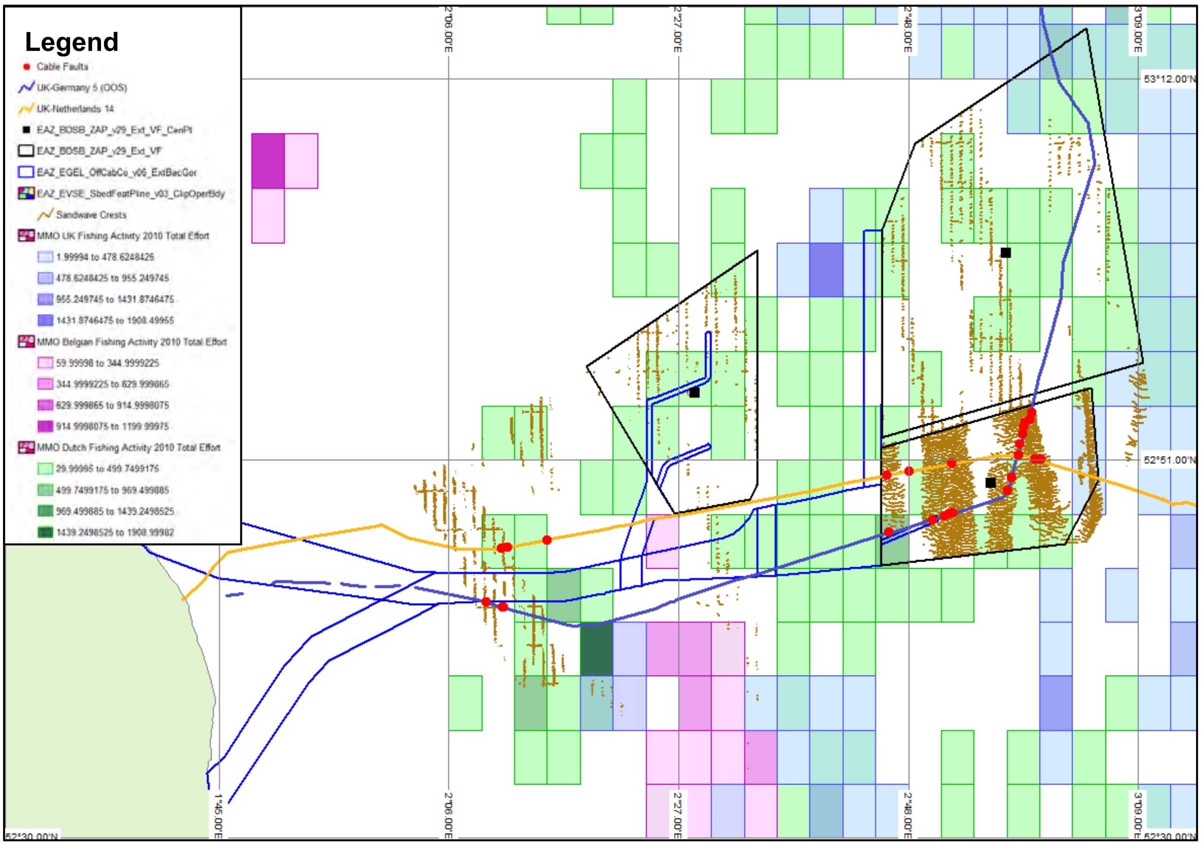


Figure 46 Fishing and Mobile Sandwaves Fault Cause Comparision

This strongly suggests it is the presence of mobile sandwaves and fishing which has led to the numerous cable faults on UK-GER5 and UK-NL14. Both cables enjoyed a 'honeymoon period' for numerous years after their installations where they suffered were no faults, but presumably the cable depth of burial cover gradually reduced in the mobile sandwave areas and eventually came within the penetration reach of the trawl gear. There are only 4 faults which lie outside the sandwave areas, with 3 of these lying on the flank of a sandbank.

Looking at Figure 47, we can compare where marine traffic lanes occur with mobile sandwaves. Here we find that they only co-exist over the western cluster of faults. So whilst anchors are not the main cause of faults, they may have contributed to the faults in the western cluster.

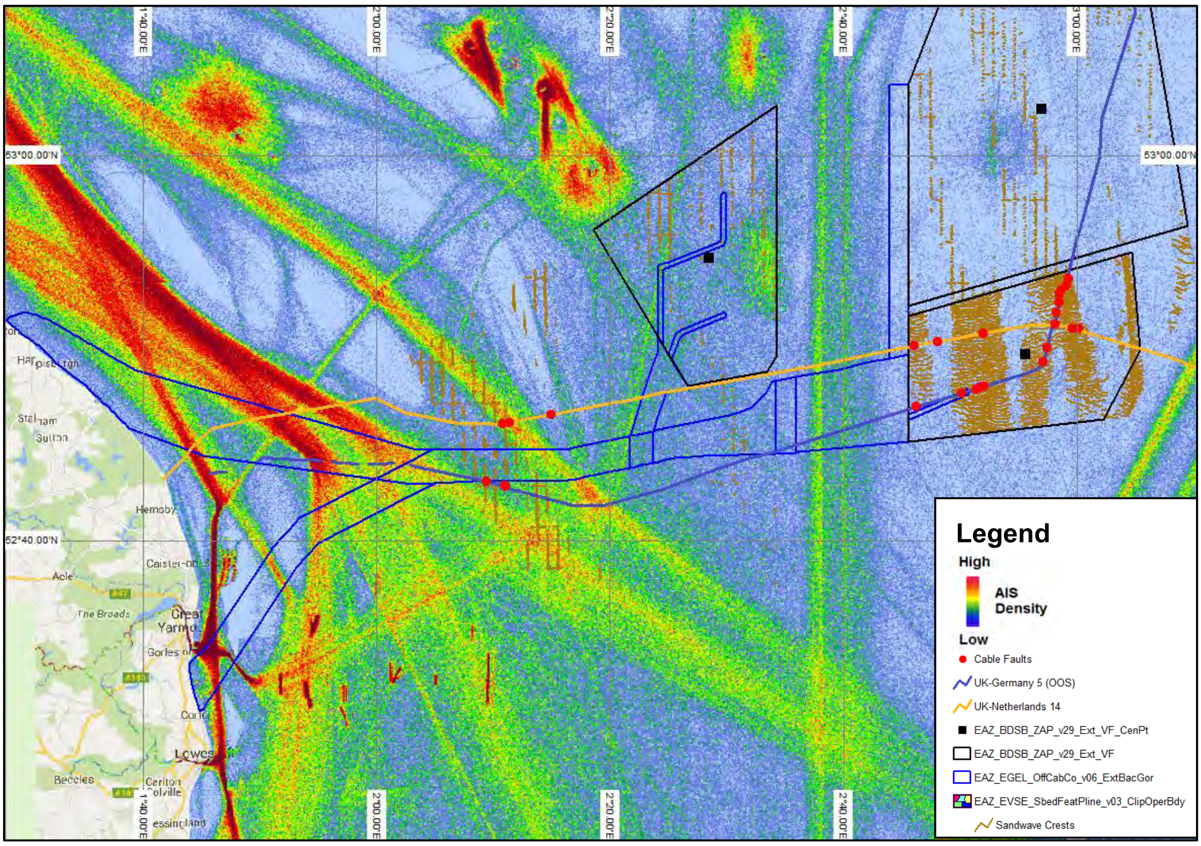


Figure 47 Fishing and Marine Traffic Lanes Fault Cause Comparision

The fault causes discussed from the fault records do provide some evidence of trawl fishing as the root cause, but it is less than conclusive, however combined with this analysis of the common conditions, GMSL are confident that their fault cause theory is correct. The primary cause is beam trawling (mainly by the Dutch fleet) where this occurs in mobile sandwave areas. There is also good reason to suspect the western cluster may have had anchor drag faults due to the presence of the marine traffic lanes and mobile sandwaves.

At all the 25 fault locations GMSL have investigated and recorded the conditions related to the seabed characteristics, the presence of fishing activity (based on the 2010 MMO gridded VMS data), the presence of a marine traffic lane (based on 2014 AIS data from marinetraffic) and the proximity to trawl scars and exposed cable found during the 2013 EMU survey. Where sandwaves occur at the locations (21 out of 25 cases) the amplitudes, wavelengths and angle of incidence between the sandwave crests and the cable route have been recorded. The sandwaves are typically between 1.5m to 7m amplitude (height) and have wavelengths between 150m and 350m. The average angle of incidence is 45° and ranges between 4° and 89°, so it appears this is not particularly significant. All the information on the conditions at the seabed are presented in Table 11.

Fault Number	Cluster	Reported Cause	Seabed Characteristics (from original survey charting)				Observations from EMU Survey 2013	Fishing Present? (2010 VMS)	Marine Traffic Lane? (2014 AIS)
			Sandwaves Present?	Ht (m)	Local λ (m)	Cable Angle With Crest (deg)			
1	East	UNKNOWN	YES	1.5	230-320	63°	Trawl scars within 1km. No nearby cable exposures	YES	NO
2	East	TRAWLING	YES	2.5	120-220	64°	Trawl scars within 1.5km. No nearby cable exposures	YES	NO
3	East	TRAWLING	YES	3.0	250-270	73°	Trawl scars within 1.1km. No nearby cable exposures	YES	NO
4	East	ANCHOR	YES	3.0	200-230	77°	Trawl scars within 1km. No nearby cable exposures	YES	NO
5	West	ANCHOR	NO (flank of sandbank)	-	-	-	No nearby trawl scars or cable exposures	YES	YES
6	West	TRAWLING	NO (flank of sandbank)	-	-	-	No nearby trawl scars or cable exposures	YES	YES
7	East	TRAWLING	YES	5.0	270-350	51°	Trawl scars within 0.4km. Cable exposure within 0.5km.	YES	NO
8	East	TRAWLING	YES	3.0	190-200	42°	Trawl scars within 1.5km. No nearby cable exposures	YES	NO
9	East	UNKNOWN	YES	2.5	200-250	57°	Trawl scars within 1.0km. No nearby cable exposures	YES	NO
10	East	UNKNOWN	YES	1.0	500	32°	No nearby trawl scars or cable exposures	YES	NO
11	West	TRAWLING	YES	5.5	120-160	70°	No nearby trawl scars or cable exposures	YES	YES
12	East	OTHER 3RD PARTY	YES	2.5	260-300	4° (near others @ 43°)	Trawl scars within 1km. No nearby cable exposures	YES	NO
13	East	OTHER 3RD PARTY	YES	3.0	260-280	44°	Trawl scars within 0.9km. No nearby cable exposures	YES	NO
14	East	UNKNOWN	YES	3.5	210-270	89°	Trawl scars within 0.8km. Cable exposure within 1.5km.	YES	NO
15	East	TRAWLING	YES	1.5	300-350	58°	Trawl scars within 50m. Cable exposure within 370m.	YES	NO
16	East	TRAWLING	YES	2.5	280-350	26°	Trawl scars within 0.6km. No nearby cable exposures.	YES	NO
17	West	TRAWLING	YES	2.0	30-80	13°	No nearby trawl scars or cable exposures	YES	YES
18	West	TRAWLING	NO (flank of sandbank)	-	-	-	No nearby trawl scars or cable exposures	YES	NO
19	West	TRAWLING	YES	7.0	200	67°	No nearby trawl scars or cable exposures	YES	YES
20	East	TRAWLING	YES	3.0	200-260	32°	Trawl scars within 60m. No nearby cable exposures	YES	NO
21	East	TRAWLING	YES	5.0	220-260	24°	Trawl scars within 1.5km. No nearby cable exposures	YES	NO
22	East	TRAWLING	YES	3.0	260-360	25°	No nearby trawl scars or cable exposures	YES	NO
23	East	ANCHOR	NO (megaripples)	0.2	12-14	-	No nearby trawl scars or cable exposures	YES	NO
24	East	UNKNOWN	YES	5.0	220-260	24°	Trawl scars within 1.0km. No nearby cable exposures	YES	NO
25	East	UNKNOWN	YES	3.5	230-320	23°	Trawl scars within 0.7km. Cable exposure within 0.2km.	YES	NO

Table 11 Cable Fault Key Characteristics

5.3 Assessment of Threat Sources

5.3.1 Fishing

The most frequent cause of faulting on submarine cable systems is fishing activity. Of more than 4800 cable faults recorded by GMSL worldwide, over 40% were caused by fishing.

Fishing faults are most commonly caused by mobile gear such as bottom trawls, beam trawls and dredges. During the process of bottom trawling, parts of the fishing gear are in close contact with the seabed. The gear has the potential to sink or dig into the seabed if the soils are particularly loose or soft. The mechanism of penetration may be considered as either static, by penetration under the fishing gears self-weight or dynamic.

A wide range of observational and theoretical studies into the penetration of trawling gear into the seabed is available and are summarised by Linnane et al (2000). Table 12 replicates the summary produced by Linnane.

These data indicate that the depth of penetration of trawl beams or otter boards is typically limited to 0.1m in sands and harder clays, and up to 0.3m in loose sands and soft clays. For static fisheries, pots and nets are typically anchored with small anchors weighing between 10kg to 15kg, principally to allow ease of handling from small vessels. Penetration of this gear into the seabed is also unlikely to exceed a maximum of 0.2m.

Figure 48 is a photograph of a cable fault on the UK-Netherlands 14 cable attributed to fishing gear, which occurred in May 2011 inside the AOI.

Figure 48 Cable Fault Caused by Fishing Gear (UK-NL14, Repair 4, May 2011)

Limited penetration of fishing gear is a logical conclusion given that greater penetration will result in increased wear on gear and increased drag on the seabed which will increase fuel usage and reduce trawling speed; essentially, fishermen try to avoid this.

From this information it seems reasonable to assume that the worst case scenario for beam trawl, or trawl board penetration could be set at 0.3m. If a factor of safety is then applied of 100%, it can be assumed that cables buried to 0.6m below the seabed surface should be safe from most forms of fishing activity.

The issue for the EAN Tranche-1 export cables will most likely not be achieving this depth of cover during installation (both UK-GER5 and UK-NL 14 achieved greater than 0.6m on average), but retaining this depth of cover in areas of high seabed mobility.

Penetration Depth	Reference	Gear type	Substratum
100-150 mm	Arntz and Weber, 1970	Otter boards	muddy fine sand
a thin layer of top substrate	Bridger, 1970	Otter trawl ticklers	sand
80-100 mm	Margetts and Bridger, 1971	Beam trawls	muddy sand
100-200 mm	Houghton et al., 1971	Beam trawls	sand
0-27 mm	Bridger, 1972	Beam trawls	mud
rather limited	de Clerck and Hovart, 1972	Beam trawls	rough ground
few centimetres	Caddy, 1973	Otter boards	sandy sediment
10-30 mm	de Groot, 1984	Beam trawls	mud, sand
200 mm	Khandriche, et al., 1986	Otter board	mud
a few centimetres	Blom, 1990	Beam trawls	sand
= 60 mm	Bergman et al., 1990	Beam trawls	fine to medium hard sand
5-200 mm 20-50 mm	Krost et al, 1990	Otter board rollers on foot rope	mud, sand
200 mm	Laane et al., 1990	Beam trawls	mud, sand
20-300 mm	Rauck, 1988	Beam trawls	mud, sand
5-170 mm	Rumohr (in Krost et al, 1990)	Otter board	mud, sand
40-70 mm	Laban and Lindeboom, 1991	Beam trawls	fine sand
50-60 mm	BEON, 1991	Beam trawls	fine sand
few cm. - 300 mm	Jones, 1992	Otterboards	deepest in soft mud
20-40 mm	Santbrink and Bergman, 1994	Beam trawls	fine to medium sand sediment
15-70 mm	de Groot, 1995	Beam trawls	substratum dependant
~ 140 mm	Lindeboom and de Groot (edit.), 1998	Otterboards in the Irish Sea	mud

Table 12 Fishing Gear Penetration (Linnane)

The distribution for the fishing threat is best shown by Figure 48 in the preceding section of this report, where the 2010 fishing activity of the 3 active fishing nations is shown. It can be seen that fishing is prevalent east of 002° 5’ E and the main threat is from the Dutch beam trawling fleet.

Beam trawls are designed to catch flatfish and must maintain good bottom contact to be able to disturb the flatfish that tend to hide by burying in the surface sediments. Offshore beam trawlers range in size from 35 to 50 m.

European beam trawl vessels tow two 4 to 12-meter wide beam trawls equipped with heavy chain mats weighing up to 3.5 to 7.5 mt each for a total gear weight of 7-15 mt. A beam trawl is composed of a rigid beam to maintain the horizontal opening of the net held off the seabed by shoes at each end. The net is attached to the beam. Figure 49 shows the construction of an beam trawl. On “clean” grounds only tickler chains are rigged, but chain matrices (stone mats) and flip-up ropes are added to allow rough grounds to be exploited by the larger vessels (unlikely to feature in the AOI).

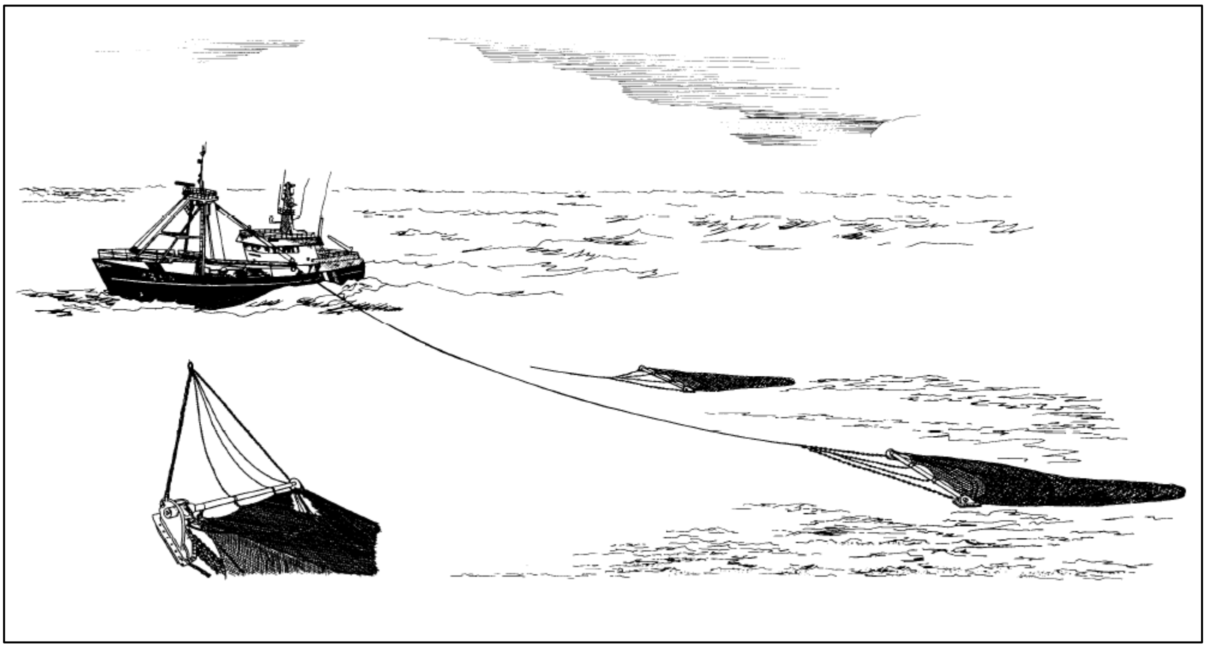


Figure 49 Beam Trawling

5.3.2 Marine Traffic and Anchors

Anchors are particularly damaging to cable systems because of their strength and the depth to which they can penetrate the seabed. As seen in section 4.3.11 the risk to the EAN Tranche-1 export cables from anchors is mainly posed by anchors from merchant vessels and offshore industry vessels. Intentional deployment directly over the cable would be a rare occurrence, as professional mariners will consult charts to avoid seabed infrastructure, including cables before deciding on an anchorage.

More likely is a dragged anchor incident as a result of a vessel in an emergency, when their propulsion system is not working and they lose control of their position keeping. In emergency circumstances like these the anchor may be deployed to prevent a more serious marine incident developing. In such circumstances if the weather is poor or the currents are strong locally the anchor may be dragged over the seabed.

Another more likely scenario is an anchor dragged in error whilst underway as previously mentioned in section 4.3.11.

To try to ascertain level of risk this poses to the cable and to assess the burial depth at which the cable may be safe from their anchors, some further analysis has been undertaken.

The largest length of vessel from the ANATEC data provided by Vattenfall was the Guthorm Maersk, a container ship, 367m long and with a 116K tonnes DWT. The 90th percentile of the range of vessel lengths was 225m, and a representative vessel from the ANATEC dataset for such a length would be the Amira, a bulk carrier with a 74K tonnes DWT. Using a generalised graph of vessel DWT to anchor size (Figure 50), this estimates the anchor size for this vessel would be circa 12,000 kg.

As an anchor is pulled across the seabed, the flukes pivot and engage into the seabed soil. In most seabed soils, the flukes will open and bite into the seabed, but not penetrate deeply due to the resistance of penetration of the flukes, palm and shank. In some hard soils, the flukes may not be able to penetrate at all, while in very soft soils there may be a tendency for the anchor to penetrate to depth as it is dragged.

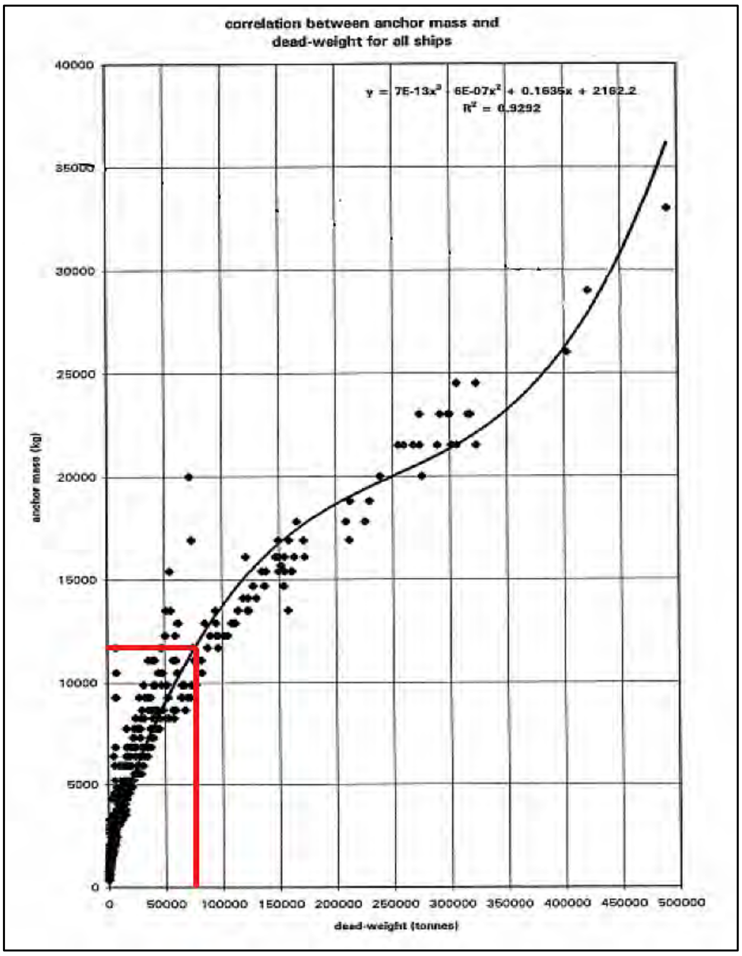
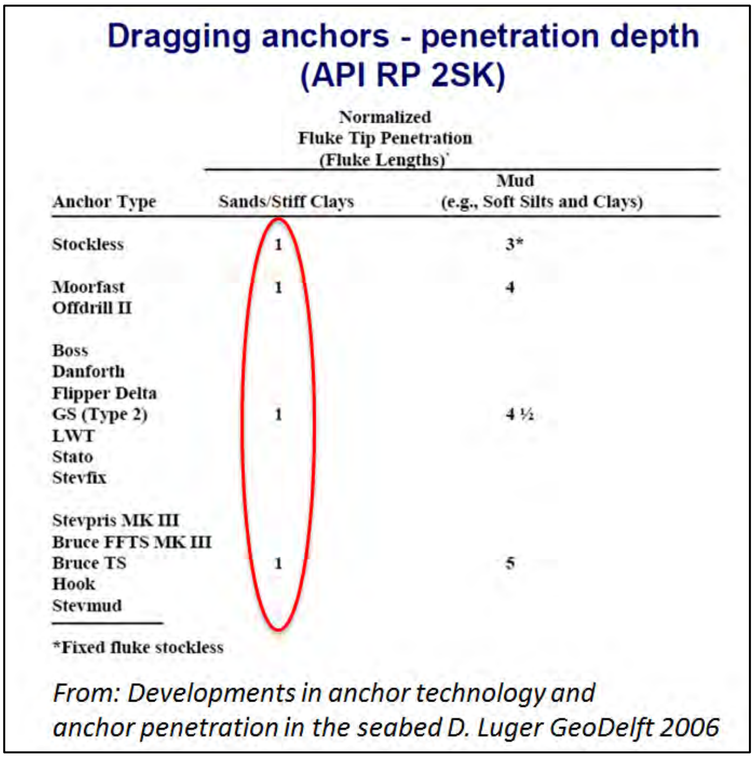


Figure 50 Anchor Mass v Vessel DWT

By looking at various manufacturers catalogues the fluke length of a typical 12,000 kg stockless anchor is approximately 2m. To determine how far such an anchor will penetrate the seabed in the AOI a table taken from work by D Luger is presented as Figure 51. This suggests in the sands and clays found in the AOI the maximum penetration depth will be 1 x fluke length.



Dragging anchors - penetration depth (API RP 2SK)

	Normalized Fluke Tip Penetration (Fluke Lengths)'	
Anchor Type	Sands/Stiff Clays	Mud (e.g., Soft Silts and Clays)
Stockless	1	3*
Moorfast Offdrill II	1	4
Boss Danforth Flipper Delta GS (Type 2) LWT Stato Stevfix	1	4 ½
Stevpris MK III Bruce FFTS MK III Bruce TS Hook Stevmud	1	5

*Fixed fluke stockless

From: Developments in anchor technology and anchor penetration in the seabed D. Luger GeoDelft 2006

Figure 51 Anchor Penetration Depths

So the maximum estimated penetration depth for 90% of the anchors expected to be found on the vessels crossing the EAN Tranche-1 export corridors is 2.0m.

An important consideration when assessing the potential risk from ships anchors is the depth of water in which the threat exists of an anchor engaging a cable. At one extreme, larger vessels will navigate through very shallow water (unless as the result of an incident) and due to the finite length of anchor chain used on vessels, as water depth increases beyond 50m, the risk lessens. Along the EAN Tranche-1 export corridors the seabed depth does not exceed 48m. In seabed areas shallower than 5m, many of the larger merchant vessels will not be a threat.

Clearly the probability of an anchor incident will increase in the high vessel traffic lanes. Chart 2210-3 in Appendix 7.2 shows the GMSL proposed export corridors and AIS marine traffic density.

5.3.3 Seabed Characteristics

The seabed bedforms found across the AOI do not in themselves pose a threat to the export cables. However they have been found to be extremely influential to the security of future cables when the mobility of the sandwaves reduces the burial depth of cover and associated protection. This reduction in protection presents the cable at greater risk from the fishing and anchoring risks described in sections 5.3.1 and 5.3.2. The reduction in cable burial can even lead to the cable being exposed or in suspension at the surface. Evidence of exactly this situation was captured in the EMU 2013 survey over the EAN Tranche-1 East zone. The UK-GER5 and UK-NL14 cable was found with exposures. These can be seen in Figure 52. These portions of the cables were reported as being successfully burial to >0.6m during their respective installations by plough.

This situation will happen if the amplitude of the sandwaves is greater than the depth of burial of the cable. An indication of whether a particular sandwave is active is an asymmetrical cross-section, which can normally be determined from bathymetry survey data.

Seabed sandwaves and megaripples can also limit the success of cable burial during the installation. Typical power cable ploughs are around 15m in length and are pulled by the cable lay ship. The depth to which the cable is buried is regulated by the height of the front skids on the plough. Over larger scale features, such as sandwaves and sandbanks, the length of the plough is relatively short in comparison with the wavelength of the bedform. The main factor to consider is the change in the tow force as the plough is pulled up one side of the sandwave and then down the other. The slope effect may vary the tow force by between 10 and 15 tonnes. More significant is the interaction of the plough as it crosses megaripples with a wavelength close to it's own length. The relationship of the relative seabed and plough dimension can combine with a lay tension that tends to pull the cable out of the seabed. The result can be the cable is exposed on the flank of the megaripple.

Because of the localised steep gradients in areas of sandwaves, the stability of a plough (and therefore the cable product) may also be at risk.

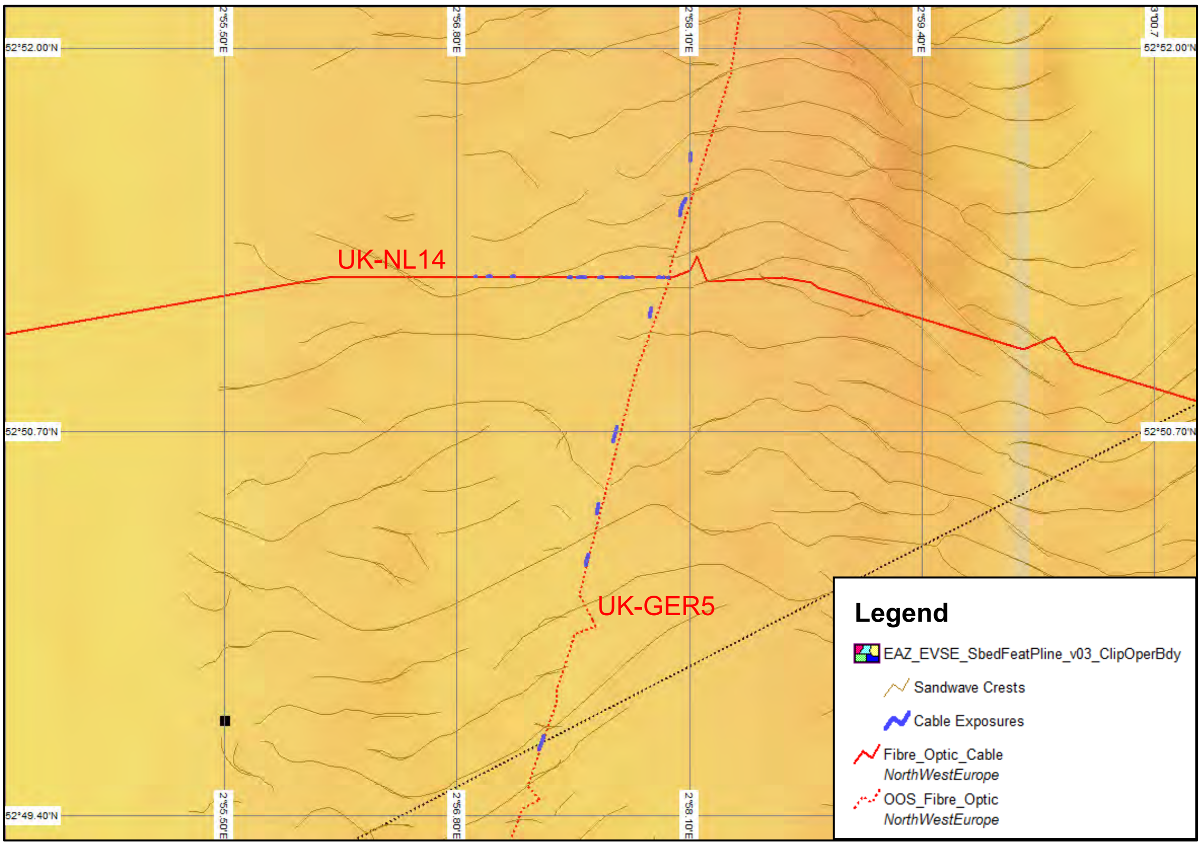


Figure 52 UK-GER5 and UK-NL14 Cable Exposures (EMU 2013)

A further important practical aspect of the seabed characteristics along the EAN Tranche-1 cable corridors is the depth of water in the inshore areas. Once clear of the shore end approaches the northern GMSL corridor partly clips a charted depth contour of 15m on just one occasion. The least charted depth at this point is 12.2m, which is potentially still within the capabilities of a large CLV. The Southern GMSL corridor however is hampered by numerous sandbank shoal areas between the coast and the crossing with the Bacton to Zeebruge pipeline, a distance of approximately 25km.

The significance of this, is that it will limit the installation solution for the southern corridor far more than the northern one. The southern corridor may require a very shallow drafted vessel to be able to clear the sandbank areas. Over Corton Sand, at one point the charted depth is between -0.1 and 0.5m across the whole corridor. Such a shallow drafted vessel is unlikely to have the carrying capacity to hold all the export cable onboard. Therefore the export cable may require a marine powercable joint and separate shallow and deeper water installation spreads. Indeed once the cable design is known it would be prudent to calculate if a vessel capable of the installation over this portion of the southern route is available in the market. A more complicated installation solution will inevitably drive up the installation cost. The cost and complication makes the northern corridor a far more attractive solution for the export cables.

5.3.4 MetOcean Characteristics

The Metocean characteristics are mainly an issue for the installation and maintenance of the future export cables. The information from the UKSeaMap 2010 project regarding seabed energy levels is probably the most telling. In the highest energy areas the installation vessels will require powerful positioning systems to be able to maintain their position and the high tidal current flows will most likely interrupt cable lay operations, as they did the UK-GER5 and UK-NL14 projects. The same conditions will pose a similar risk to any future O&M works on the export cables.

5.3.5 Seabed Infrastructure

All the seabed infrastructure such as the pipelines and telecoms cables which must be crossed by the EAN Tranche-1 corridors present a risk to the export cables. The physical obstruction each of these represents necessitates the export cable to cross and is likely to prevent the target burial depths being achieved at these locations. They will also require some form of cable protection system to avoid direct interaction between the export power cable and pipe/cable. This can take the form of high impact resistant polyurethane (PU) or polyethylene (PE) cable protection shells, concrete matressing, rock dumping or concrete bridging or a combination of these. The burial status of the infrastructure being crossed will affect the crossing design and it is known that UK-Netherlands 14 was buried during its installation. The burial status of the pipelines is not known, but as they are large diameter export pipes, they are likely to be surface laid.

Once installed the cable crossing engineering designs must be able to withstand trawl fishing gear at crossing locations as they are all within or near the active fishing areas identified in section 4.3.10.

5.3.6 UXO

The risk to the export cables from UXO is related to installation and maintenance operations. The probability of a UXO incident is estimated to be very low during these activities; however the impact of a UXO incident on the project could be dramatic.

It is worth noting that difficulty of detecting UXO across the AOI is increased by the mobility of the seabed. The deeper any UXO below the seabed surface the harder it will be to detect during a UXO survey and the seabed mobility and time period taken between survey activities and installation means some UXO which were deeply buried at the time of the survey are exposed during the installation.

The identification of the UXO found near the UK-NL14 cable and reported in Figure 37, shows the risk is real on this project and should be respected.

GMSL recommend a full UXO risk assessment should be conducted by an independent specialist. Based on previous experience on windfarm projects GMSL would expect the ALARP (As Low as Reasonably Practicable) principle to guide the risk management process.

5.4 Cable Protection

Taking the various threats to export cables identified and described in sections 5.2 and 5.3 this section looks at the depth of burial likely to be required to mitigate against the identified risks. A summary is provided of the tools and measures that may be required to ensure the security of the cables and their limitations.

5.4.1 Cable Burial

Cable burial is the most practically and cost effective method of protecting submarine cables. Burial was successful in protecting both UK-GER5 and UK-NL14 telecoms cables in the AOI, for a minimum of the first 5 years of service and it has been the reduction in burial depth at some critical locations along those cable routes which has resulted in the fault rates now seen.

The most sensible approach to cable burial is to set the target burial depth according to the level of the threat and the seabed environment. If we look at the threats they are basically from fishing and anchors. A from fishing threat is ubiquitous across the AOI but it varies dramatically in the level of risk to cables depending on the location. Inshore across the Norfolk sandbanks is an inshore potting and static gear fishery, with limited risk to the cables. East of the major sandbanks closer to shore around 002 deg 4' E is a much more serious threat from beam trawlers and this extends across the rest of the AOI.

A low level of risk exists from large vessel anchors across most of export cable corridors but the probability of an anchor incident is increased in the major vessel traffic lanes which cross the corridors.

The most important issue is the mobile sediments and their ability to change the burial depth post installation. In order to tackle this issue the seabed mobility in the export corridors should be studied further.

At a later point in the project when the export routes have been determined, if a seabed mobility study is undertaken it should be possible to determine (or at least estimate with some objectivity) the seabed levels which are stable and immobile along the routes. It should also be possible to therefore provide a design depth below the crests and the troughs of the bedforms along the cable routes within the corridors.

Once these depths have been identified suitable burial tools can be determined for burial of the cable. In some areas this may not require anything more than the ploughs and jetting ROVs described in the following section. Where the depth of burial exceeds the capabilities of the tools described in mobile sandwave areas then sandwave presweeping may be a solution.

Presweeping can be achieved either by dredging or by using a mass flow excavation tool. The presweeping creates a corridor through which a cable plough can pass to bury the cable. This gives two advantages. It can ensure the design depths below the crests and the troughs are achieved and can reduce the risk of destabilisation of the plough by reducing the gradients on the flanks of the sandwaves. The presweeping must be timed so that the cable laying is carried out before the mobile sediments on the seafloor start to re-establish the profile of the sandwaves. Such sandwave presweeping was used on the Britned HVDC interconnector project. Figure 53 is an image of the seabed topology showing the preswept sandwave crests and cable route.

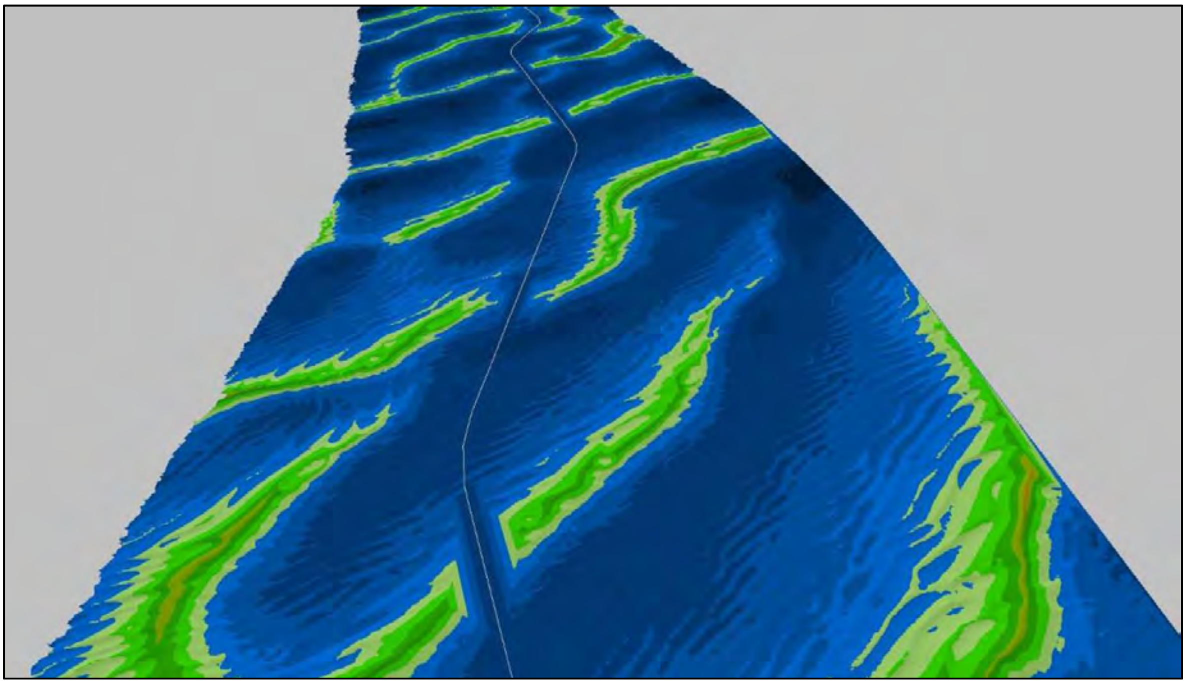


Figure 53 BritNed Presweept Sandwaves and Cable Bathymetry (Primo Marine)

Presweeping can be carried out by trailing suction hopper dredgers or by mass flow excavation tools.

5.4.2 Preliminary burial depth recommendations

Based on the threat assessments related to fishing and anchors in this report, as a general target GMSL recommend a depth of 1.0m across the whole of the export corridor. This should be increased to 2.5m where the cable crosses high vessel traffic lanes to protect against the anchor threat. Crucially these depths need to be achieved below the mobile sediment layer. Therefore determining the volume of mobile sediment where the final routes cross sandwave areas will be critical to ensure cable security.

1.0m exceeds the penetration estimates for trawl fishing gear and 2.5m exceeds the depth of the majority of the estimated largest vessel's anchor penetration.

At a later stage in the project GMSL recommend that a detailed probabilistic power cable burial risk assessment is carried out for the export cable routes, using the principles set out on the carbon trusts report - *Cable Burial Risk Assessment Methodology, Guidance for the Preparation of Cable Burial Depth of Lowering Specification* (Feb 2015)

5.4.3 Burial Tools

GMSL believe the cable burial tools most suited to the EAN Tranche-1 export corridors are cable ploughs and jetting ROVs. The shallow seabed sediment geology shown by the BGS information in Figure 22 is a mixture of Sand, Gravelly Sand and Sandy Gravel with some fractions of mud in places. As the surface seabed sediments section (4.3.9) states –

Sandy Holocene deposits largely overlie the Brown Bank Formation, which is composed more of silts and clays with a sandier basal layer. In some area the Twente Formation may lie between the two, though as this formation is largely composed of sand it is difficult to distinguish from the Holocene sands in sub-bottom profiler data and is usually only between 4 and 5m thickness. The Holocene layer is of highly variable thickness and in many areas, particularly between sandbanks, the older sediments may be exposed.

All of these sediment types are expected to be within the capability of existing cable burial equipment used by the submarine cable industry (ploughs and jetting ROV's). The Brown Bank Formation may be partially consolidated (Rijsdijk, Passchier, Weerts, Laban, van Leeuwen, & Ebbing, 2005) *in which case it has the potential to be an obstacle to jet trenching.*

The selection of burial tools will ultimately be decided at a later stage of the project but cable ploughs offer the advantage of simultaneous lay and protection. Their performance can however suffer when faced by sandwaves which have a wavelength similar to the plough length and this may occur at numerous points along the export corridors. The difficult sandwave conditions cannot be entirely avoided due to the prevalence of sandwaves and megaripples across the AOI.

The performance of ROV jetting tools are not affected by sandwave features as much as ploughs are, but they are not able to simultaneously protect the cable at the time of the lay, so leaving the cable exposed at the surface for a period before burial takes place. ROV jetting tools are often limited by the depth of water and cannot be used in very shallow depths (approx. <10m) as a minimum head of water is required to safely operate the water pumps. Here ploughs can have an advantage in as they can be used in very shallow water, even being landed on a beach at high tide and pulled offshore with the cable engaged.

Some ploughs also have a jetting capability, which can be particularly useful to improve performance in non-cohesive soils (loose sand). Here though the shallow depth limitations for jetting operations become a limiting factor once again for the plough in jetting mode.

Some examples of typical submarine power cable ploughs are the IHC Engineering Business Sea Stallion 4 and the SMD HD3. Both are shown in Figure 54. The plough shares on such ploughs have a capability in softer grounds of achieving a 3m max trench depth. This is partly due to the very high pull capacities of 150te.

Figure 54 Example Power Cable Ploughs

Cable jetting ROV performance is determined by the pump power, water pressures, flow rates, jetting swords, nozzle configurations and the use of such features as eductors and cable depressors. There are numerous large powerful cable jetting ROV's on the market and two examples would be the Canyon T750 and SMD Q1000, shown in Figure 55. These are cable of jetting to 2-3m in suitable soil strengths (approx 100Kpa). Their progress speeds are typically not as quick as a plough, but numerous burial passes are possible.

Figure 55 Example Power Cable Jetting ROVs

5.4.4 Other Protection Measures

In addition to cable burial other protection measures may be required at particular points along the final export routes.

At cable crossings high impact resistant polyurethane (PU) or polyethylene (PE) cable protection shells for the cable, concrete matressing, rock dumping, concrete bridging or a combination of these measures may be required to protect the crossed pipe or cable and the power cable.

Near to shore at the proposed HDD exit points the cable may require similar additional protection measures, particularly if the HDD exit engineering design is not able to keep the cable buried as it exits the duct.

As well as additional physical protection measures, non-physical measures can improve a cables security. Ensuring the final export cables are accurately positioned on UKHO charts will help raise awareness of the cables location to mariners, thus minimising the risk of cable damage.

Good cable route engineering at a later stage may help to mitigate the effect of sandwaves on the system. It is recommended that all sandwave area are identified and recorded during the marine survey, along with their slopes and heights. The route engineer should then attempt the follow the objectives for the cable routes below where practically possible.

- Reduce the number of sandwaves to be crossed
- Avoid the more mobile sections within sandwave areas
- Avoid crests and route through troughs
- Optimise crossing angles where presweeping is required (from a profile construction point of view)

6.0 FUTURE SURVEY RECOMMENDATIONS

GMSL recommend earlier in this report conducting a separate seabed mobility study with an emphasis on identifying the layer below the seabed which is immobile.

There is also a recommendation to conduct a detailed UXO risk assessment.

Both these will require geophysical marine surveys along the proposed GMSL export corridors. GMSL believe these marine surveys are best conducted separately.

Cable Route Survey

A general cable route survey should be carried out across the whole corridor width. The results of this survey would provide Vattenfall with enough information to confirm the route feasibility, cable separation, cable burial risk assessment and to feed into any environmental assessments and archaeological studies (presuming the AC/DC technology choice, cable design and number of cables is determined by this point).

The cable route survey should identify the following;

- All seabed obstacles and features – scars, cables, pipelines, surface sediment boundaries.
- Wreckage (established wreck and as yet unfound)
- Seabed bathymetry - providing input into the seabed mobility study, seabed bedforms, slopes and water depths to assist with installation solution options
- Magnetic contacts along the survey lines – with a purpose of establishing as found pipeline and cable routes and ferrous wreckage. It is not as a UXO survey
- Sub bottom dataset along the survey lines – to help with determining the subsurface geological unit thicknesses and assist the seabed mobility study, building on the information already acquired inside the EA North zone

This would be typically be achieved by the use of the following key survey equipment;

- Side Scan Sonar
- Multibeam Echosounder
- Magnetometer
- Sub Bottom Profiler
- DGPS Positioning System

The survey should cover the whole GMSL export corridor width and extend from the potential HDD exit point to the assumed central locations or if later established the Offshore Substations.

An additional benefit of the cable route survey is the ability to map areas where bottom fishing has occurred. This is achieved by interpretation of SSS records.

Evidence of past bottom trawl fishing activities can be preserved on the seabed as ‘scars’. In non-cohesive granular soils (e.g. sand or gravel with no silt or clay content) it is possible that scarring evidence will be only temporary as the sediments are modified by the storm events and sediment deposition and erosion. This can be seen in some of the 2013 EMU survey results and should be an objective of the cable route survey.

UXO Survey

In turn the results of the cable route survey would ultimately lead onto a dedicated UXO survey campaign along the export cable routes, with potentially a narrower corridor for each cable of 100m, reducing the cost of the typically more survey line intensive UXO survey specifications.

The detailed UXO survey specification should be determined by the potential UXO risk and guided by a qualified UXO consultant.

The seabed mobility study may be aided by historical bathymetry datasets and therefore the survey extracts from the UK-GER5 and UK-NL14 surveys along with the EA EMU 2013 survey should be offered to the company that undertakes this work.

7.0 APPENDICES

7.1 Bibliography

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7.2 Charts

Four charts have been created for the EAN Tranche-1 export corridors and are included here as an Appendix. The table below provides details for each chart.

Chart	Description	Revision
2210-1	Overview of export corridors and navigation charts (A0)	1
2210-2	Engineering constraints and influences (A0)	1
2210-3	Marine Vessel Traffic (A2)	1
2210-4	Regional Bathymetry (A2)	1

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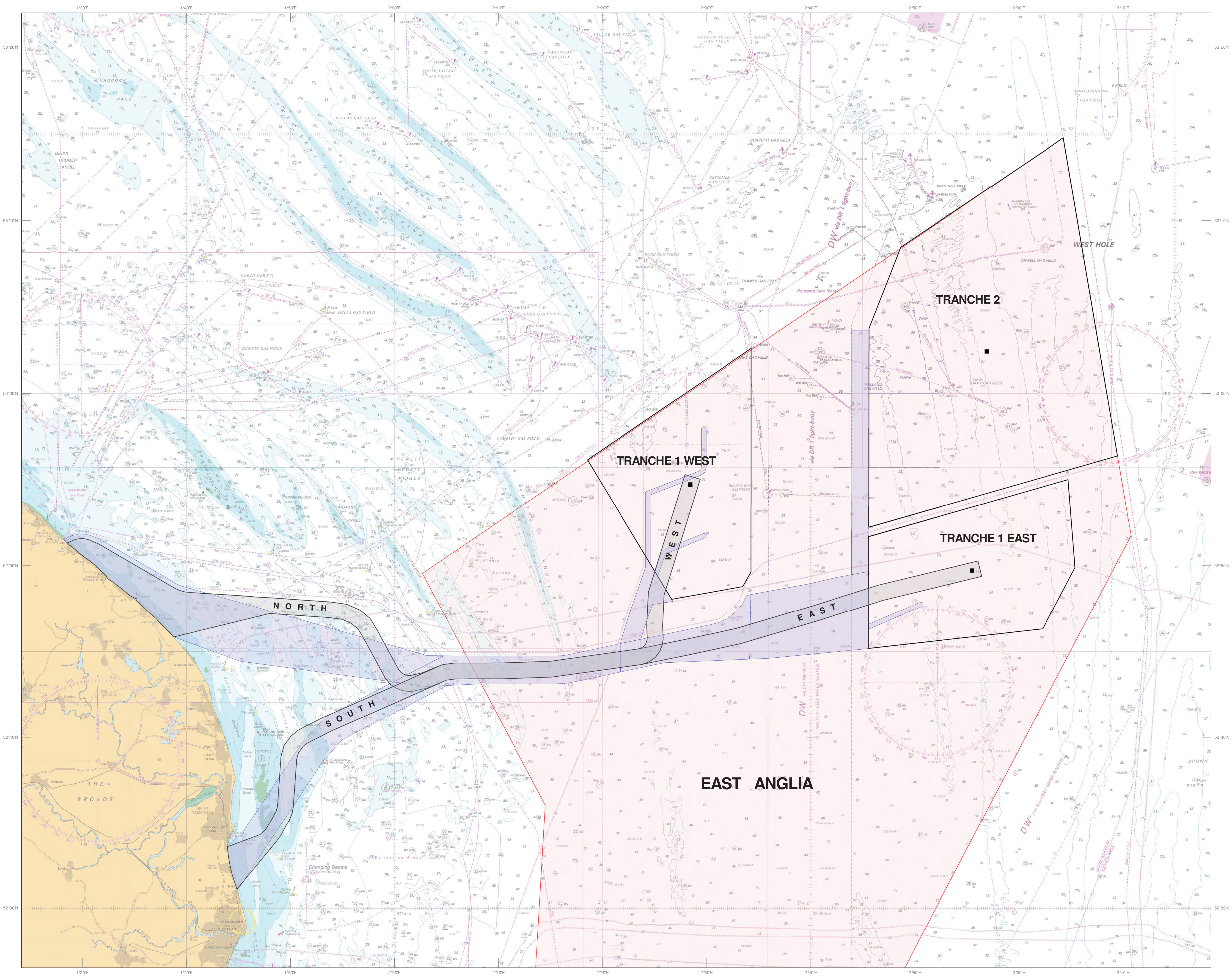

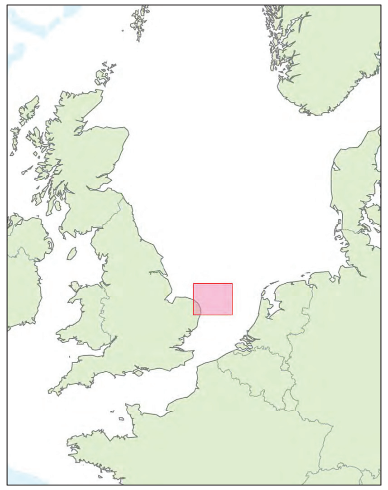

LEGEND

Windfarm Areas:

- ■ Windfarm Assumed Central Location
- ▨ GMSL Proposed Cable Corridors
- ▨ Original Vattenfall Proposed Cable Corridors (EAZ_EGEL_OffCabCo_v06_ExtBacGor)
- ☐ Proposed Windfarm Zones
- 🟥 East Anglia Windfarm Area

Source:-

1.GMSL Databases
2.Vattenfall
3. Admiralty Charts 1503, 1504, 1631 and 1632

NOTE:-

This chart has been created on the Global Marine Systems Limited Computer Mapping System and is intended for general reference only and NOT FOR NAVIGATION PURPOSES.

CHART HISTORY

Rev.	AMENDMENT	UPD	CKD	Date
0	Original	SB	BP	Jan 2016

NATURAL SCALE 1 : 134,500 at 52° N

0 5 10 15 20
Kilometres

SPHEROID & DATUM : WGS84

PROJECTION : MERCATOR

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EAN TRANCHE 1

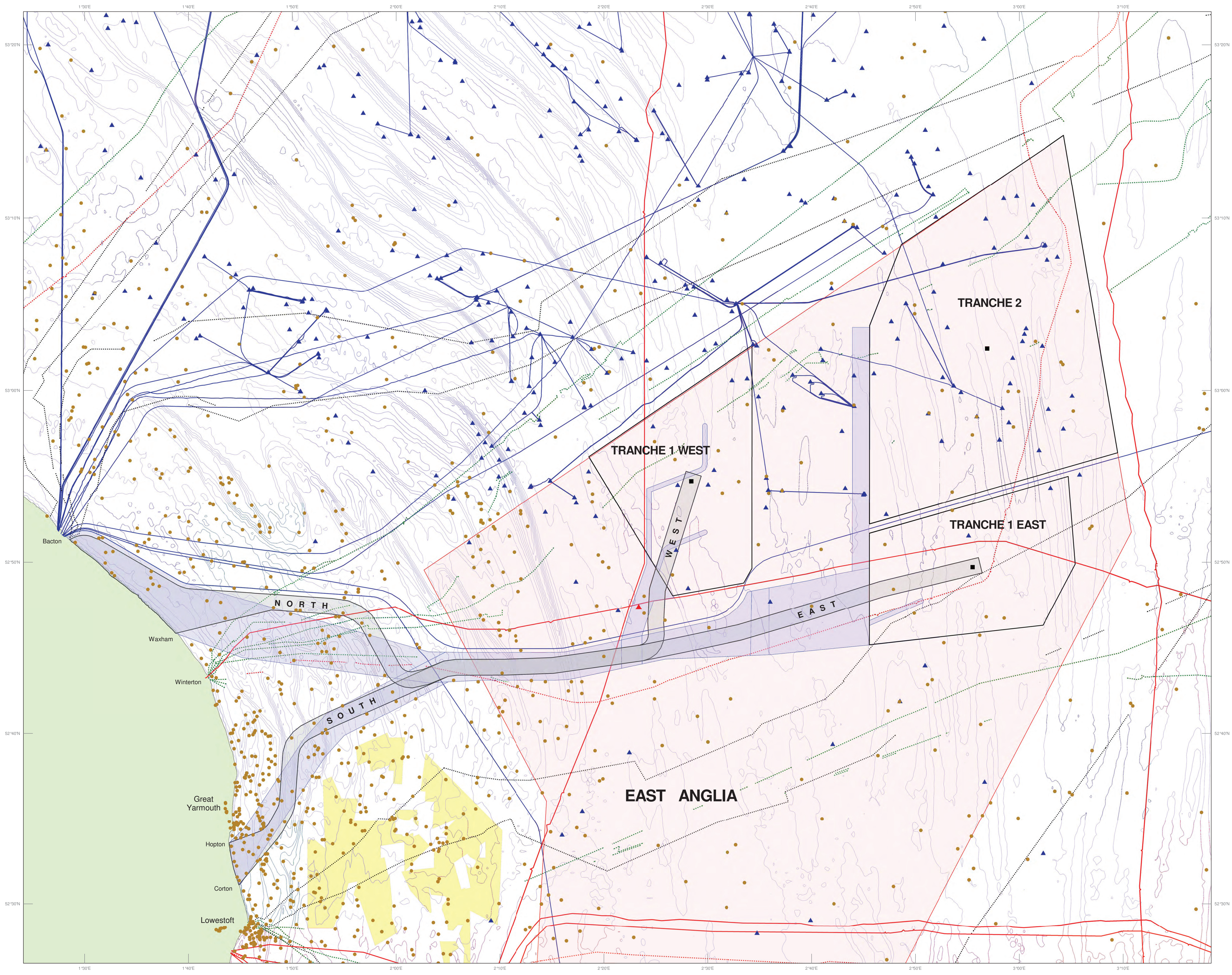
CHART:

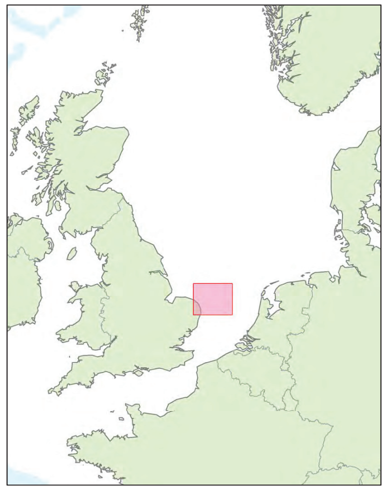
CABLE CONSTRUCTABILITY ASSEEESSMENT

CHART NO. 2210 - 1

Revision: 1 Date: January 2016
Original chart size A0 1189 x 841 mm

Produced by Charting Services
Global Marine Systems Limited, Chelmsford





LEGEND

Windfarm Areas:

■	Windfarm Assumed Central Location
▨	GMSL Proposed Cable Corridors
▨	Original Vattenfall Proposed Cable Corridors (EAZ_EGEL_OffCabCo_v06_ExtBacGor)
☐	Proposed Windfarm Zones
🟥	East Anglia Windfarm Area

Cables and Pipelines

—	Fibre Optic Cable
······	Fibre Optic Cable (Out of Service)
······	Coax Cable (Out of Sevrvice)
······	Telegraph Cable (Out of Service)
—	Oil and Gas Pipelines

Hazards

●	Wrecks and Obstructions
▲	Unexploded Ordnance
▲	Wells
—	5m Contours
🟨	Dredging Areas

Source:-

1. GMSL Databases
2. Vattenfall
3. SeaZones Wrecks Database
4. EMODNET
5. UK Oil and GAS
6. The Crown Estate

NOTE:-
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EAN TRANCHE 1

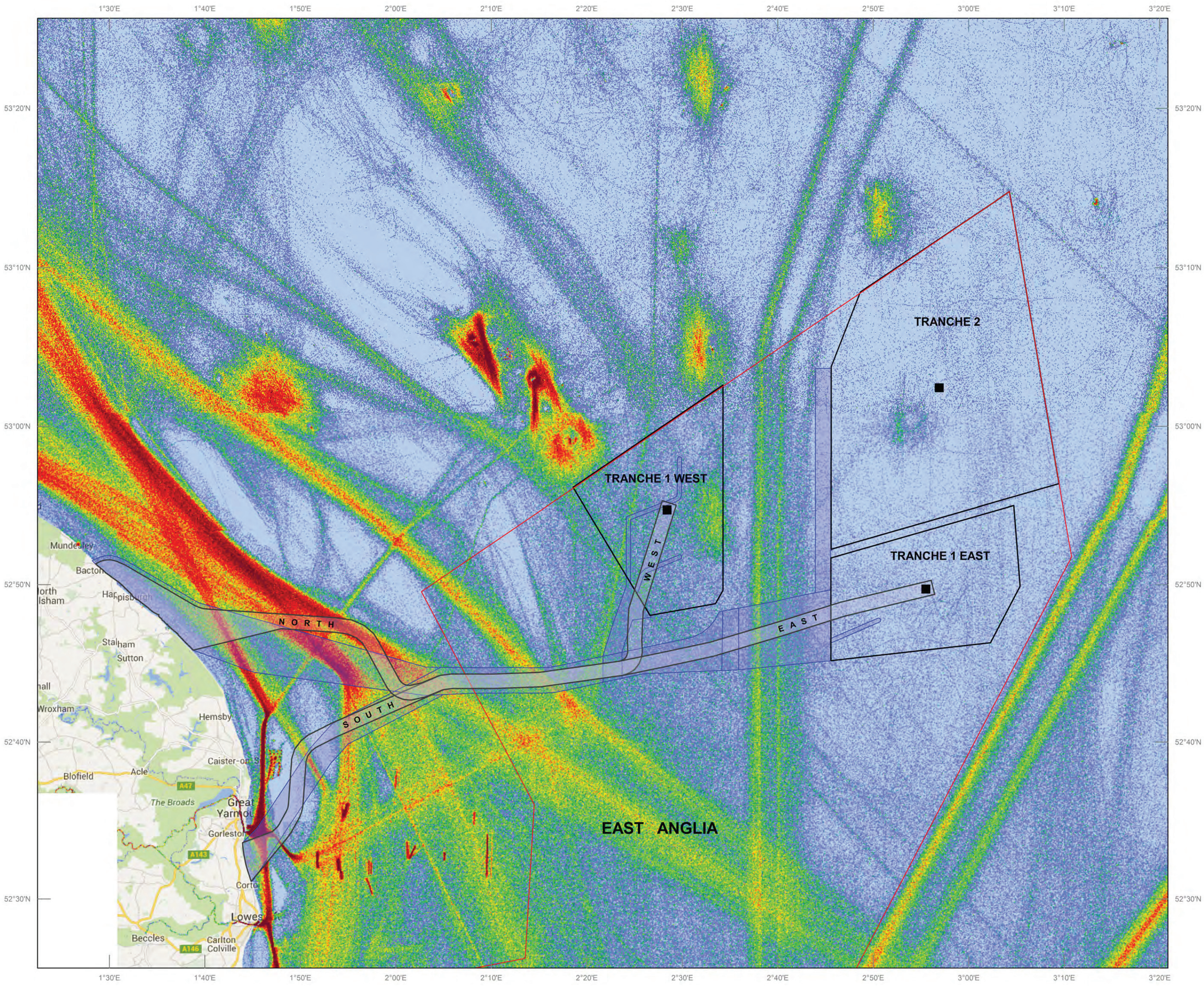
CHART:

ENGINEERING CONSTRAINTS

CHART NO. 2210 - 2

Revision: 1 Date: January 2016
Original chart size A0 1189 x 841 mm

Produced by Charting Services
Global Marine Systems Limited, Chelmsford



LEGEND

Windfarm Areas:

■ Windfarm Assumed Central Location

▭ GMSL Proposed Cable Corridors

▭ Original Vattenfall Proposed Cable Corridors (EAZ_EGEL_OffCabCo_v06_ExtBacGor)

▭ Proposed Windfarm Zones

▭ East Anglia Windfarm Area

Source:-

1. GMSL Databases
2. Vattenfall
4. Marine Traffic

NOTE:-

This chart has been created on the Global Marine Systems Limited Computer Mapping System and is intended for general reference only and NOT FOR NAVIGATION PURPOSES.

CHART HISTORY

Rev.	AMENDMENT	UPD	CKD	Date
0	Original	SB	BP	Jan 2016

NATURAL SCALE 1 : 303,600 at 52° N

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Kilometres

SPHEROID & DATUM : WGS84

PROJECTION : MERCATOR

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EAN TRANCHE 1

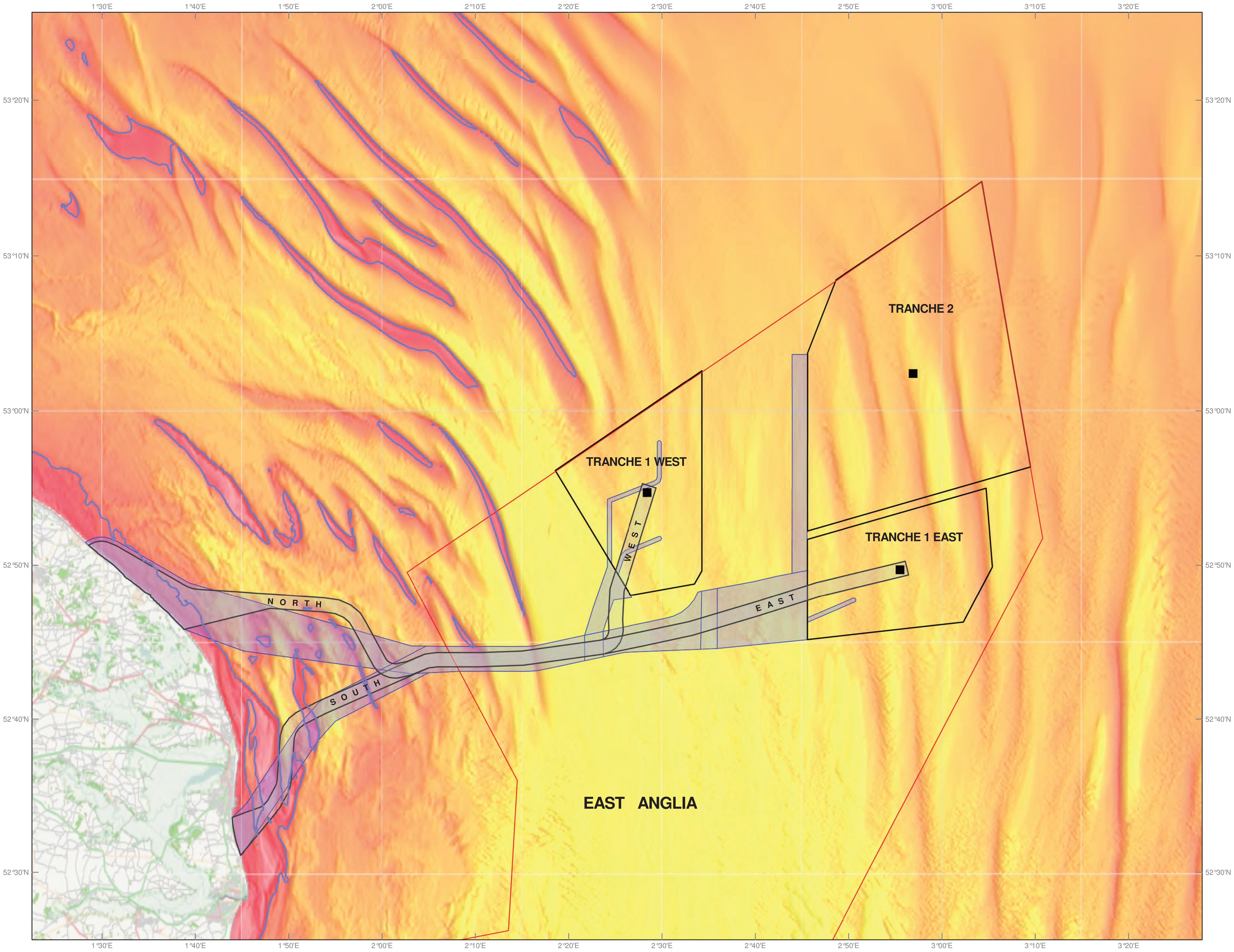
CHART:

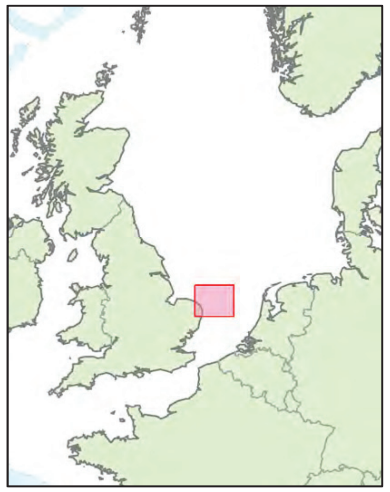
MARINE TRAFFIC

CHART NO. 2210 - 3

Revision: 1 Date: January 2016
Original chart size A2 594 x 420 mm

Produced by Charting Services
Global Marine Systems Limited, Chelmsford





LEGEND

Windfarm Areas:

■ Windfarm Assumed Central Location

▨ GMSL Proposed Cable Corridors

▨ Original Vattenfall Proposed Cable Corridors (EAZ_EGEL_OffCabCo_v06_ExtBacGor)

☐ Proposed Windfarm Zones

☐ East Anglia Windfarm Area

Bathymetry:

— 15m Contour

Source:-

1. GMSL Databases
2. Vattenfall
4. EMODNET

NOTE:-

This chart has been created on the Global Marine Systems Limited Computer Mapping System and is intended for general reference only and NOT FOR NAVIGATION PURPOSES.

CHART HISTORY

Rev.	AMENDMENT	UPD	CKD	Date
0	Original	SB	BP	Jan 2016

NATURAL SCALE 1 : 303,600 at 52° N

0 5 10 15 20
Kilometres

SPHEROID & DATUM : WGS84

PROJECTION : MERCATOR

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EAN TRANCHE 1

CHART:

REGIONAL BATHYMETRY

CHART NO. 2210 - 4

Revision: 1 Date: January 2016
Original chart size A2 594 x 420 mm

Produced by Charting Services
Global Marine Systems Limited, Chelmsford