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RPS (for Lincs Wind Farm Ltd)

Lincs Offshore Wind Farm

Review of Cable Installation Process - Jetting Option

Date: January 2011

Project Ref: R/3983/01

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Lincs Offshore Wind Farm
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1. Introduction

This note has been prepared to respond to specific consent conditions in the Lincs FEPA licence (Licence 33574/10/1) which requires the Licence Holder to submit details of predicted re-suspended sediment plumes in the case that jetting methods are requested as the most feasible option for burial of the export cable across the inter tidal zone. The pertinent licence conditions are given as:

9.46. The Licence Holder must make every effort to ensure that the export cable in the inter tidal zone is buried either by trenching or ploughing. If jetting is to be considered the written authorisation of the Licensing Authority should be sought ***four months prior*** *to works commencing. In requesting that jetting be permitted the Licence Holder must submit details of e.g. predicted resuspended sediment plumes, sensitive habitats and species and area affected so that the Licensing Authority in consultation with Cefas and Natural England can make an informed decision.*

9.47. If the use of jetting the export cable in the inter tidal zone is agreed, the Licence Holder will be required to carry out monitoring of suspended sediment concentrations within the area of jetting, and at a suitable control point outside the area. These monitoring reports must be forwarded to the Licensing Authority, Cefas, and Natural England within ***one month*** *of the completion of the jetting.*

2. Background

The Lincs Offshore Wind Farm is a consented project within the Greater Wash Strategic Area for Round 2. The application for consent was supported by an Environmental Statement (Centrica Energy, 2007) which includes consideration of issues relevant to the export cable route. The basis of such considerations in the Environmental Statement assumes a realistic worst case option drawing on information available to the project at the time.

The Lincs FEPA licence, received as part of the consent process, includes for the installation of two export cables from the offshore sub-station which will run approximately 40km to a landfall point on shore east of the mouth of the River Nene. The licence also requires that cable installation operations within the inter tidal zone are restricted to the period from 15 May to 31 August to avoid potential adverse effects on over-wintering birds.

The two export cables will be buried approximately 50m apart across the intertidal area which reduces to around 5m at the landfall. The majority of the cable will be buried to a depth of approximately between 1 to 3m, depending on ground conditions, with burial up to 5m along certain sections of the route.

The Cable Burial Management Plan (Subocean, 2010) has been developed post-consent, with reference to a burial assessment study (SEtech, 2009), and identifies the presently preferred methods for cable installation across the array and along the export cable route. Here, the export route has been sub-divided into “sea-defence”, “near-shore” and “main” sections.

The plan recommends the use of a cable plough (Spider-Plow) for the first 1.5km of the “near-shore” (pulled inshore from KP2.5 to KP1.0), followed by a jetting tool for the following 5.5km (pulled seaward from KP2.5 to KP8.0). It is noted here that a jetting tool can not operate in very shallow water depths, which is why the plough is the necessary method for the first 1.5km.

For reference, the “near-shore” is notionally the division from the sea-defence out to 8.0km offshore (KP8.0). The extent of the inter tidal zone falls within this division (Figure 1), with the extent for the low water mark (defined by mean low water springs) coinciding with KP4.0.

The consequence of identifying a jetting tool within the “near-shore” division (the inter tidal zone) requires the Licence Holder to evaluate the potential environmental concerns associated with use a jetting tool over and above existing consideration provided to date in the Environmental Statement. This note offers such an evaluation.

3. Baseline Evidence

The project has sought to undertake various baseline surveys to understand the character of the seabed across all areas of development, including the export cable route. It is noted that several key surveys have occurred since development of the Environmental Statement and now include further geophysical and geotechnical evidence along the export cable route.

It is noted, however, that there remains practical limitations in surveying across inter tidal zones since the shallow depths inherently restrict access to vessels, consequently the geophysical surveys do not extend much further inshore than KP2.5. The geotechnical surveys include various spot samples at regular intervals using a combination of CPT and vibrocore measurements and do extend along the full route of the export cable.

The project has not obtained any direct measurement of hydrodynamics across the inter tidal zone, however, previous modelling work used to support the development of the Lincs Environmental Statement included this area. This modelling work has been used to inform the present considerations, where necessary, and is supported by previous field investigations available from related sites.

4. Area of Interest

The specific area of interest to the licence condition relates to the section of the inter tidal zone where a jetting tool is planned for deployment. With regard to the extent of the inter tidal area shown in Figure 1, and the need to deploy a plough in the shallower water from KP2.5 to KP1.0, leads to the extent of interest being focussed between KP2.5 to KP4.0 only, a distance of 1.5km.

Based on a review of the available evidence the character of this area can be described as relatively shallow (depths vary from around +3 to +2m Chart Datum, in the offshore direction over the distance of 1.5km, suggesting a relatively flat profile (a gradient of around 1 in 1,500).

A secondary channel draining from the River Nene runs close to KP4.0 and here depths increase to +1.1m Chart Datum. N.B. the notation on water depth is offered here with positive values indicating depths above Chart Datum.

Water depths (quoted to Chart Datum) can vary above these values and during periods around high water local depths can increase by up to 5m on spring tides and 3m on neap tides for the deepest section. During periods of low water the areas remain dry. All tidal information is estimated here from tides measured at Kings Lynn.

A generalisation of the sediment composition for the wider unit KP1.0 to KP10.0 offers the following details (SEtech, 2009), drawn from an interpretation of the presently available baseline evidence (Table 1):

Table 1. Generalised description of sediments for KP1.0 to KP10.0 (based on SEtech, 2009)

Seabed Features	Shallow Geology (0 to 3m below seabed)	Dominant sediment type in cable trench
The seabed is locally undulating and shallow ranging between 2 - 6m in depth. Here, seabed sediments are indicated to comprise slightly gravelly sands with occasional patches of silt/clay. The River Nene cuts a channel between the banks with a number of small tributary channels. Information provided by the Port Authority suggests the main Nene river channel and its associated distributaries are mobile, however movement has been recorded as gradual in a easterly direction away from the route. A number of geophysical anomalies were identified by the geophysical survey within this section. Of these, a number were located on or near to the proposed route.	The geotechnical testing generally indicates the seabed to comprise loose to medium dense clay to slightly clayey sand. However, CPT4 located in the current Nene River Channel encountered a greater proportion of soft clay than surrounding shallow bank locations	Slightly clayey SAND with occasional very soft CLAY layers.

In general, it is anticipated that from the upper part of the unit KP1.0 to KP10.0 there is a seaward transition from a mud environment to a sand environment, and the overall tendency is a depositional environment for finer sediment fractions to create an accretional tidal flat.

Recent geophysical sidescan evidence (EMU, 2009; EGS, 2010) also suggests small bedform features (crest height of 0.4 to 0.6m and wavelength of between 10 to 12m orientated SE - NW) in the vicinity of the area of interest, reinforcing the presence of (mobile) sands (Figure 2).

Above KP1.0 there is a saltmarsh environment, which over the longer-term is dependent on deposition of fine sediments to maintain the profile of the tidal flat against future sea level rise.

For the discrete section KP2.5 to KP4.0 the geotechnical evidence reported by Fugro (2009) includes both vibrocore (VC2) and CPT (CPT04) data. These data are adjacent to the cable route and indicate an upper layer of sandy sediment with some clay laminae down a depth of around 0.9m (defined as clayey fine SAND with a few shell fragments). Beyond 0.9m the clay content increases, although sand is also still recorded down to a depth of 3m (defined as sandy (fine) CLAY).

Further particle analysis descriptions of the vibrocore data are summarised in Table 2.

Table 2. Summary of sediment fractions for VC2, from Fugro (2009)

Sample depth (m)	Soil type (%)			
	Fines (Clays and Silts)	Sand	Gravel	Cobbles
0 - 0.46	19	80 (containing 1% shell)	1 (containing 100% shell)	0
0.95 - 1.16	60	40	0	0

Particle sizes for these fractions are defined as follows:

- Fines < 0.06mm
- Sands >0.06mm to < 2mm
- Gravel >2mm

Further, from these reported particle size distribution results it appears the majority of the sand content is very fine sand (<0.150mm), and the majority of the fines (silts and clays) is between 0.006 to 0.04mm.

Subsequently, further geotechnical investigations local to the nearshore section of the export cable route have recently been reported in GeoMarine (2009). This work extends from the earlier geotechnical surveys and adds detail across the shore approach section of the export cable. Of specific interest here are the trial pits dug at locations KP2.0, KP2.5 and KP3.0 along the cable route.

The general character of the soils in these pits revealed a veneer of soft material (light brown silty sand) thinning in the offshore direction down to around 1.3 to 2m. Beneath this veneer the soils are suggested to become sandier over depth (brown, slightly silty fine to medium grained sand with some shell fragments). In addition, laminations of clay and silt were present throughout, and typically occurring below 2m with thicknesses of between 0.05 to 0.25m.

Samples from these pits have been analysed for particle size distributions, with details summarised in Table 3.

Table 3. Summary of sediment fractions, from Geomarine (2009)

Sample depth (m)	Soil type (%)			
	Fines (Clays and Silts)	Sand	Gravel	Cobbles
KP2.5				
0.10	17	82	1	0
1.20	12	88	0	0
2.00	11	89	0	0
KP3.0				
1.20	5	95	0	0
1.80	11	88	1	0

It is further noted that the sands present from these trial pits also tend to be predominantly sized in the range 0.150 to 0.212mm (fine sand) and 0.063 to 0.150mm (very fine sand).

The regional scale (1:250,000) description of sediment type (BGS, 1988) indicates muddy sand as the surficial sediment type (based on the Folk Scale) present across the area of interest; i.e. generalised as less than 1% gravel, between 50 to 90% sand and less than 50% mud. This description helps to support the assumption that the data from the geotechnical surveys is also representative of the wider area related to the area of interest.

5. Cable Installation

The following details related to cable installation are summarised from the Cable Burial Management Plan (Subocean, 2010).

Inshore of KP2.5 the planned method of installation is using a cable plough (Spider-Plow) which will be pulled towards KP1.0 and will aim for a burial depth of 2m.

From KP2.5 to KP8.0 the planned method of installation is using a jetting tool (Salamander Jet Sled) aiming for a burial depth of 3m. The burial depth increases to 5m from KP3.5 where the cable approaches the mobile sediment area of the Wisbech Channel and to ensure additional long-term coverage of the cables. The jetting tool is also pulled and has an estimated rate of advance of 100 to 200m/hr, subject to soil strengths over burial depths. The width of the trench is expected to be 0.4m to accommodate a cable with a diameter of 0.2m.

The jetting tool operates on a sled and forces water onto the seabed with a pumped flow of around 4,400m^3 per hour (1.22m^3/s) at typical pressures of 4 to 6bar. The high pressure is required to fluidise the seabed sediments, through water injection, to enable advance of the tool and lay of the cable at the designated burial depth. The water required by the tool is drawn from the area around the tow vessel where it is pressurised. The relative position of the area of interest within the inter tidal zone, coupled with the need for the tool to be able to draw on volumes of water, suggests that operations will need to be phased with periods of high water.

The design of the jetting tool includes groups of nozzles to force water along the forward and rear facing edges of its cutting sword. The fluidised sediment is therefore directed within the trench, but some sediment is also likely to be entrained into the water column to form a localised sediment plume which then may become subject to advection and dispersion from local ambient flows. However, it is also the case that the behaviour of the fluidised material is likely to create a high sediment concentration that behaves as a dense fluid, especially when the material contains high percentages of fines (silts and clays). The behaviour of the dense fluid which remains within the trench will favour direct settlement over the cable, albeit at a lower initial bulk density than the disturbed soils.

The degree of advection, dispersion, levels of raised sediment concentrations, and the final locations for the material to settle out of the water column is subject to many factors. These issues are discussed in further detail in the following sections. Ideally, the majority of sediment will settle out and backfill the excavated trench, however some of the fine sediments are more likely to disperse over the wider area.

6. Dimensions

Table 4 presents a schedule of primary dimensions involved in trenching through the area of interest to assist the estimation of the volumes of sediments likely to be released and sediment concentrations from the source of water injection. It is to be noted that there are two cable routes planned, separated by 50m. However, installation operations will be limited by the use of a single tool and therefore operations are expected to happen separately, and one after the other.

Table 4. Estimates of sediment release, per cable route.

Parameter	Value	
	Minimum	Maximum
Length of trench within area of interest (m)	1500	
Width of trench (m)	0.4	
Depth of trench between KP2.5 and KP3.0 (m)[1]		3
Depth of trench between KP3.0 and KP4.0 (m)		5
Volume of trench (KP2.5 to KP3.0) (m^3)	600	
Volume of trench (KP3.0 to KP4.0) (m^3)	2,000	
Total trench volume (m^3)	2,600	
Volume of installed cable (m^3)	47	
Relative volume of cable in trench volume (%)	1.8	
Bulk soil density for VC2 (minimum) (Mg/m^3)	1.68	1.79
Estimate of mass of sediment disturbed, KP2.5 to KP3.0 (Mg)	1,008	1,074
Estimate of mass of sediment disturbed, KP3.0 to KP4.0 (Mg)	3,360	3,580
Total sediment mass (Mg)	4,368	4,654
Rate of cable burial (m/hr)	100	200
Estimate for time to complete KP2.5 to KP3.0 (hr)	2.5	5
Estimate for time to complete KP3.0 to KP4.0 (hr)	5	10
Total time (hr)	7.5	15
Rate of sediment disturbance, KP2.5 to KP3.0 (kg/s)	56	120

[1] Burial depth are maximum target depths

Parameter	Value	
	Minimum	Maximum
Rate of sediment disturbance, KP3.0 to KP4.0 (kg/s)	93	199
Pumped injection rate (m^3/s)	1.22	
Assumed fluidised concentration at source, KP2.5 to KP3.0 (g/l)	46	98
Assumed fluidised concentration at source, KP3.0 to KP4.0 (g/l)	76	163

Further to the estimate of the total time to complete the installation between KP2.5 and KP4.0, per cable, it is important to note that the jetting tool requires a minimum depth of water to operate. As the site is, by definition, part of the intertidal then the available period of the tide which will offer sufficient water depths is likely to be restricted to a few hours around periods of high water.

In addition, the estimate of assumed fluidised concentration must also be taken as highly conservative (maximum upper bound) since additional mixing with water already in the trench will occur above the water volumes being pumped under pressure into the trench. Taking the assumption that the rate of advance will enable the equivalent water volume to mix with the fluidised sediment offers values of sediment concentration between 43 and 161g/l. These concentrations can be regarded at the level of fluid muds, however, not all the local material is silts and clays, and between 40 to 95% is sands (very fine and fine sands).

7. Factors Affecting Re-suspended Sediment

The source for re-suspended sediment is the advancing jetting tool located within the trench and the face of the soil profile over the burial depth. The pumped water will force a sediment into suspension to create a plume, but with coarser grains settling out relatively quickly, leaving finer grains prone to wider dispersion. Ideally, the majority of sediment remains available to settle out within the trench to form a backfill over the buried cable. However, the compaction of the backfill will be low and will have a much weaker bulk density than soils in the pre-trench condition.

Further, the volume of the cable within each trench (47m^3), albeit small in comparison, will naturally require displacement of an equivalent sediment volume. The net difference in backfill and pre-trenched sediment volumes will be the volume of sediments available for wider dispersion.

There are a number of factors that will influence the amount of sediment being re-suspended from the trench, the creation of a sediment plume and the spread of sediments across the wider area. These include:

- Location of the source of sediment (KP2.5 to KP4.0);
- Proportions of sediment for various sediment sizes;
- Fall velocity of the various sediment sizes;
- Local sediment concentrations; and
- Local hydrodynamics (flows and water depths).

7.1 Location of the Source of Sediment

The location of the source of sediment has been reviewed previously.

7.2 Proportions of Sediment for Various Sediment Sizes

The proportions of sediment sizes is a mix of fines (silts and clays) and sands (very fine and fine sands) which is also described previously and for upper and lower parts of the sediment profile. When jetted these proportions will quickly become mixed. For the purpose of this review the overall relative proportions are estimated variable in the range 4 to 60% for fines (average 19%), and 40 to 95% (average 81%) for sands.

7.3 Fall Velocities

Assuming a median grain size for fine sands as 0.180mm (between 0.212 and 0.150mm) enables an estimate for fall velocity of 0.017m/s. Similarly, for very fine sands and taking a value of 0.100mm (between 0.150 and 0.063mm) provides an estimate of 0.006m/s.

It is to be noted though that these estimates assume independence from any fluid mud process which may be associated with the fines (silts and clays).

The settling velocity for fines (silts and clays) is often regarded as a function of sediment concentration rather than grain size and where the density of the fluid creates the settling velocity. For very high concentrations (i.e. more sediment than water per unit volume) then hindered settling becomes an issue as the layer is already likely to be acting as a highly fluidised sediment where consolidation and compaction (removal of pore water / dewatering) of the fluidised sediment is the process rather than settling, as such.

The following expressions for fall velocity (w_f) are in common use (Mehta, 1986):

$w_f = 0.11c^{1.6}$ for $c < 2$g/l

$w_f = 0.37(1 - 0.01c)^5$ for $c > 2$g/l and < 100g/l

If the assumption is taken that concentrations at source apply (see above) and only around 19% of the sediments are fines (silts and clays), then the relative concentrations for fines are estimated to be in the range 8g/l to 31g/l, on average. Equivalent fall velocities for these concentrations are therefore estimated as 0.24m/s and 0.06m/s, respectively.

Assuming that the sediments were falling a distance of 1m provides an indication of the time taken to settle onto the bed. Table 5 summarises the range of fall velocities offered above and determines a timescale for settling over this example distance.

Table 5. Table of fall velocities and rates to fall 1m

Sediment type	Fall velocity (m/s)	Time to fall 1m (s)
Very fine sand (0.100mm)	0.006	166
Fine sand (0.180mm)	0.017	83
Fluid mud (8g/l)	0.240	4
Fluid mud (31g/l)	0.060	17
Fluid mud (0.2g/l)	0.008	120

7.4 Local Sediment Concentrations

Table 5 includes an assumed lower concentration fluid mud concentration of 0.2g/l. This value is based on the assumption that if any of the fluid mud is entrained away from the main fluid mud layer and then carried higher into the water column above the trench then it will quickly become diluted and have a much reduced concentration.

Previous investigation have suggested that ambient suspended sediment concentrations over inter tidal areas may be typically 0.2g/l, but also vary between 0.002 and 2g/l (Evans and Collins, 1975).

Any higher concentrations (>100g/l) that may form are likely to act as fluid mud layers and are not applicable to this calculation. Here dewatering, and consolidation of the sediment, is likely to occur at a rate of around 0.05mm/s to form a weak soil.

7.5 Local Hydrodynamics

Whilst it is not possible to provide any definitive account of the actual amounts of re-suspended sediment which will result from jetting it is possible to offer some further illustrative comment about the potential for wider dispersion. Such dispersion will be a function of local hydrodynamics (i.e. waves and tides).

Given that the operations are limited to the period 15 May to 31 August, and due to local sheltering from shallow offshore areas, it is assumed that waves are not a major process across the intertidal for this area. This assumption can be regarded as fair since the site is also regarded as a general deposition environment for fine sediments in the form of an accretional tidal flat, hence would provide conditions with minimal erosional influences.

Further, the Environment Agency has undertaken previous monitoring of waves within the shallow sub tidal zones around The Wash. The data from Brest Sands shows an average significant wave height of 0.1m during the equivalent period from May to August, noting this measure is applicable to a deeper water location.

The local tidal range determine from King's Lynn identifies a mean spring tide range of 5.8m and a mean neap tide range of 3.2m. During the periods around high water the site will become inundated by the tide and will be subject to periods of flood and ebb flows. Whilst the project has not obtained any direct metocean measurements across the inter tidal zone there has been earlier work which has sought to characterise the tidal characteristics over a similar accretional tidal flat in The Wash at Freiston (Ke and Collins, 2000). Here, a number of survey stations spanned the tidal flat from the saltmarsh, upper mudflat, *Arenicola* sandflat and to the lower sandflat. Measurements from the equivalent part of the inter tidal to the proposed Lincs cable route suggest instantaneous peak flows of no greater than 0.43m/s (flood) and 0.29m/s (ebb) and generally less than 0.2m/s, all recorded over a tide with a range of 4.5m.

In comparison to the measurements at Freiston, predicted conditions obtained locally to the area KP2.5 to KP4.0, as given from the model used to support the Lincs EIA, indicate an instantaneous flood peak flow of around 0.47m/s (to the south) and a peak ebb flow of around 0.27m/s (to the north) for a spring tide, and with values of 0.23 and 0.14m/s for a neap tide.

Slack waters occur around the high water period when flows reduce to around 0.1m/s on springs and less on neaps. The general close comparison between the model and adjacent measurements for an equivalent area help underpin the confidence applying these hydrodynamics conditions further.

The model also suggests that the site is covered by the tide from -4 to + 4 hours around the high water period (i.e. around 8 hours of each 12.4 hour tidal period. N.B. This time period is relevant when considered against the need to operate the jetting tool in submerged conditions. Depending on the degree of submergence required, the phasing of the tide is likely to place a logistical operating restriction on the jetting tool.

Further, the general pattern for flood dominance in the tide directed to the south indicates an important process mechanism for net transport of suspended sediments across the tidal flat and onto the adjacent saltmarsh, noting the flows are insufficient to carry coarse sediments. Here, the bedform evidence mentioned above also offers further evidence to support the orientation of this asymmetry.

7.6 Sediment Pathways

Based on the available hydrodynamic information reviewed above, the pathway for net sediment transport can be considered as south and towards the saltmarsh. This is suggested to offer a positive effect to such a receptor.

An illustration for the overall scale of tidal advection can be based on the period and rate of flows effective over the area. The advective excursion distance for flood flows from this position is around 5.1km to the south on spring tides, and 3.5km to the north on the ebb phase, equating to 1.6km net to the south for each tide. Equivalent values for neap tides would be 3.1km and 2.3km, respectively, with a net value of 0.8km to the south. N.B. these values are offered to illustrate the net direction of the sediment pathway rather than to indicate any absolute distance. Actual distances would be dependent on the change in flows away from the reference position which are suggested to weaken towards the shoreline and increase seaward.

From above, these overall scales can also be moderated to consider the passage of suspended sediment moving away from the jetting locations and in terms of the time available in the water column before the material settles out and based on fall velocities offered in Table 4.

Assuming sands were entrained into the water column by 1m above the trench (noting that the total depth is likely to be constrained by the tide), then the time taken for this material to settle back to the seabed is estimated between 59 to 166 seconds (i.e. up to 3 minutes, approximately). In this period the material would only be carried by up to 85m (to the south and for spring tides) away from the trench, and further if entrained higher into the water column, but also over shorter distances for lesser tides.

For fluid mud concentrations at 0.2mg/l, entrained above the trench by 1m, the equivalent time in the water column would be around 2 minutes and the maximum distance travelled in this period would be approximately 60m.

Successive tides may redistribute the material further and to the south along the identified sediment pathway, noting this is also along the cable route.

8. Summary of Potential Effects

In summary, the jetting process is designed to fluidise the sediments sufficient for a cable to be laid and the jetting tool to advance and with the aim of the majority of the fluidised sediments to form a backfill over the cable.

The composition of the fluidised sediment is likely to contain sediment sizes that would behave as particulates (sands) and as fluid muds (silts and clays).

Whilst the major part of the disturbed sediment is designed to remain in the trench there is likely to be locally raised levels of suspended sediments created by the process.

These locally raised levels of suspended sediment are expected to be short lived and constrained by the duration of the installation process (which creates the source of such material) and the time taken for the material settles out of the water column. It is suggested here that the duration of the installation process, estimated in hours, is far greater than the time taken for material to settle out, which is estimated as a few minutes.

The fate of any sediment entrained into the water column and above the trench would be subject to ambient hydrodynamic conditions. Here the dominant process is likely to be effects of the tide, whereas wave effects would be limited, and especially with the restrictions on the inter tidal zone for installation limited to the period between 15 May and 31 August.

Available evidence supports the description of a net southerly pathway for sediments which is towards an area of saltmarsh. The local morphology of the area is also understood to be an accretional tidal flat suggesting that deposition will also remain local.

Ambient suspended sediment concentrations in the area of proposed jetting are expected to be in the range 0.002 and 2g/l. The effects of jetting may well raise local suspended sediment concentrations for locations beyond the trench but at levels that are predicted to remain within this ambient range.

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Figures

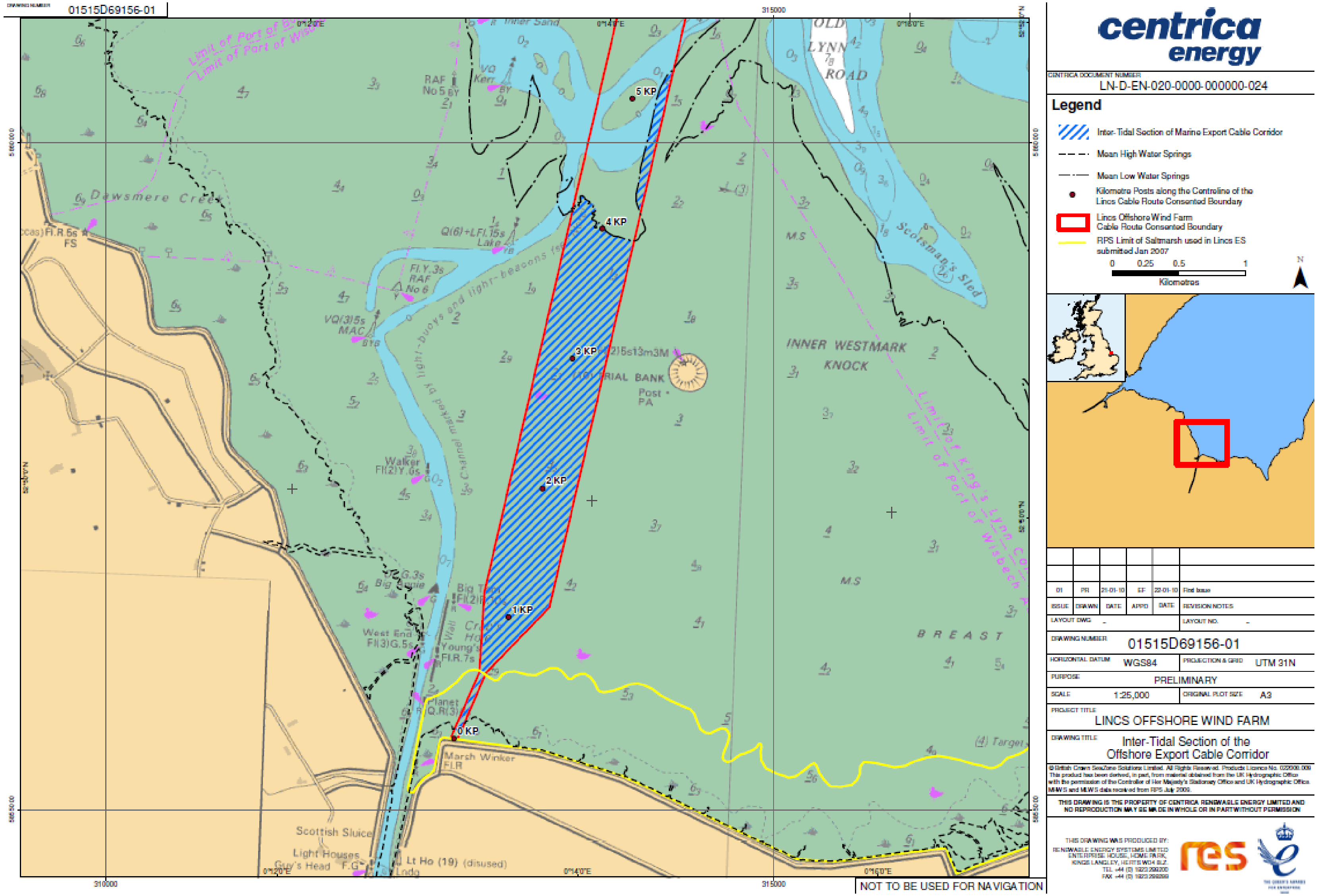

Figure 1. Area of Interest

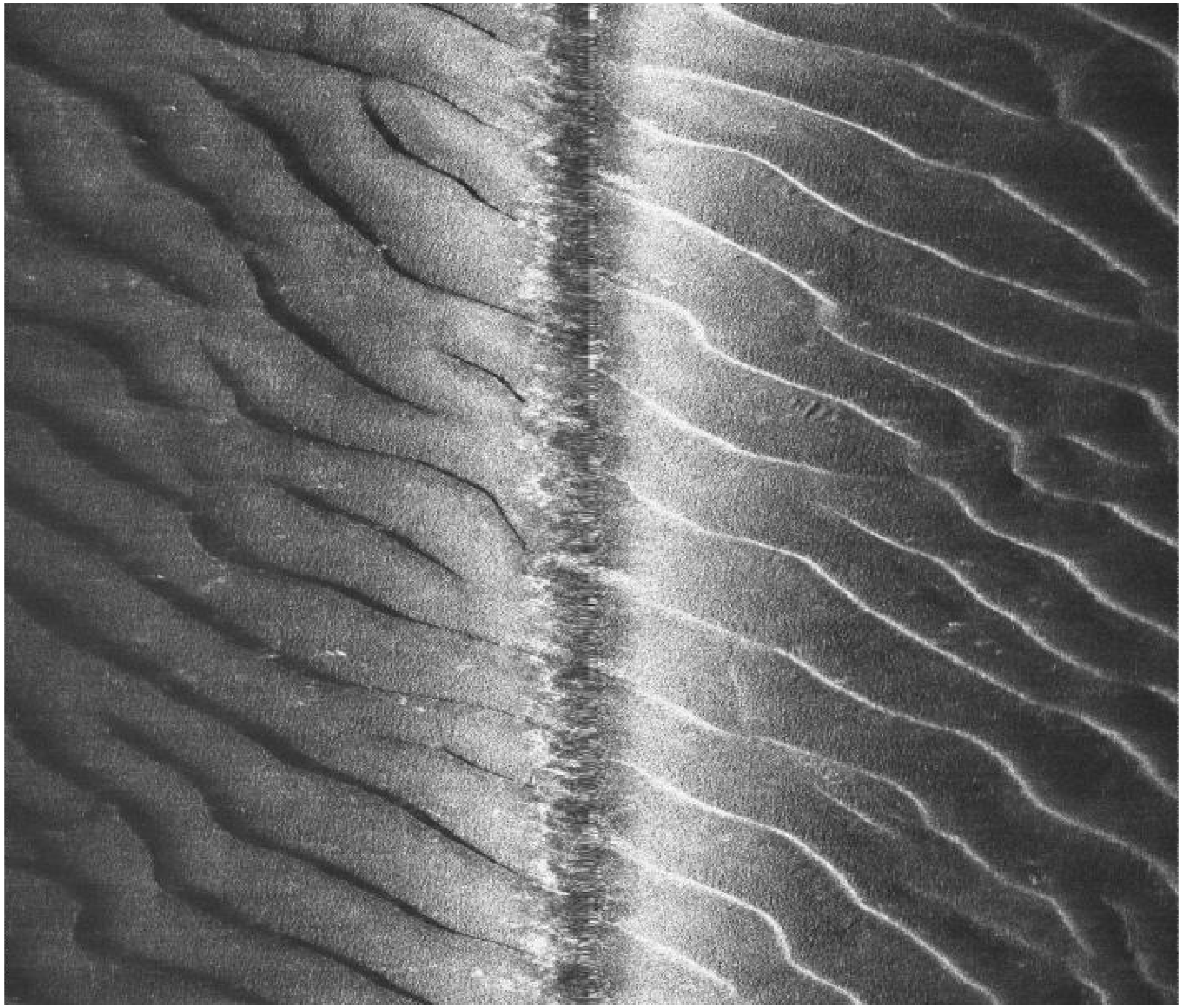

Figure 2. Mobile gravelly SAND to sandy GRAVEL with straight-crested megaripples, orientated SE-NW (EGS, 2010)


a. Trial Pit at KP2.5


b. Trial Pit at KP3.0

Figure 3. Photographs of the soil types within trial pits (from Geomarine, 2009)

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