Norfolk Boreas Offshore Wind Farm

Appendix 4.1

Initial HDD Feasibility Report

As produced for Norfolk Vanguard

Environmental Statement

Volume 3

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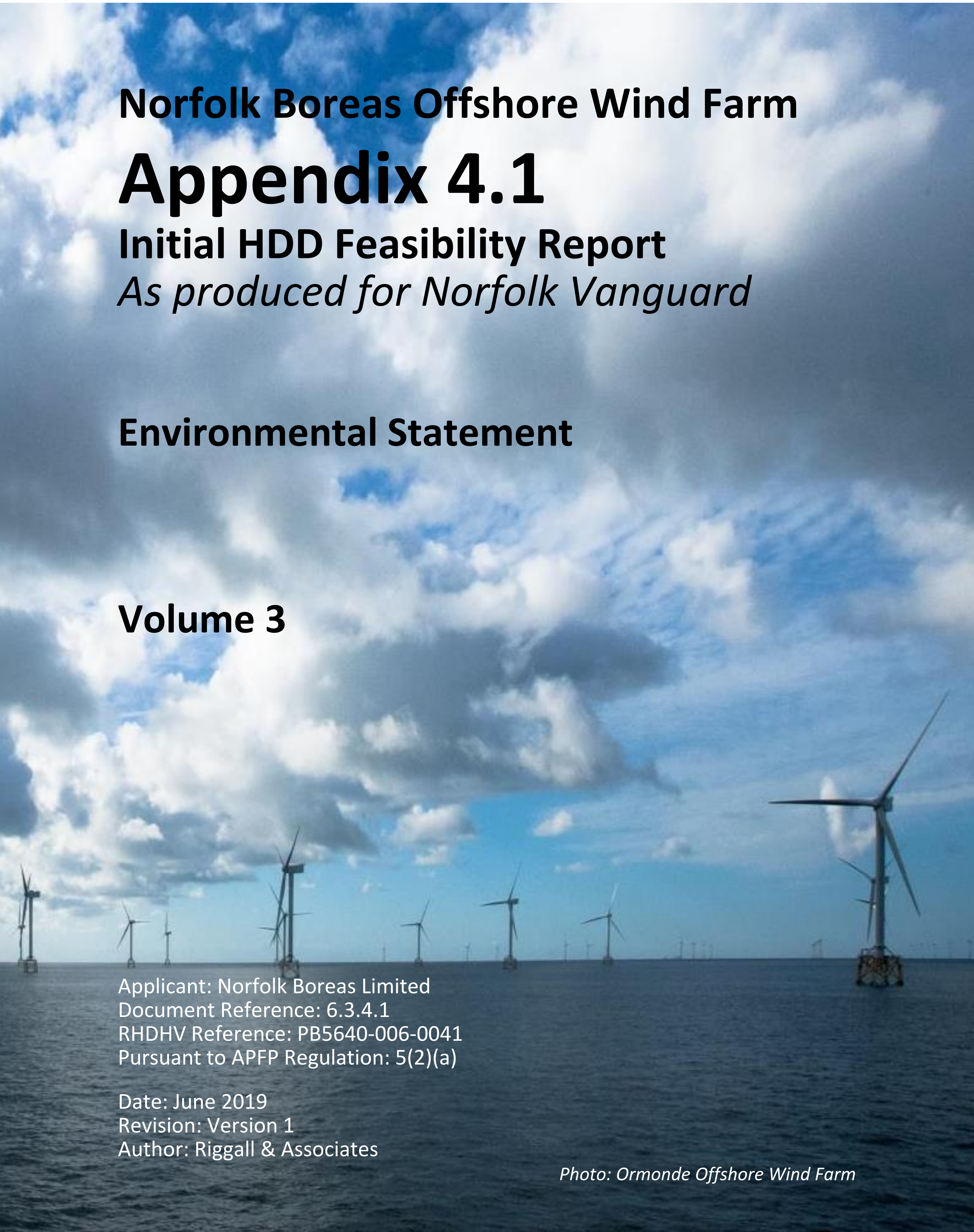

Photo: Ormonde Offshore Wind Farm

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Riggall & Associates Ltd.

HDD FEASIBILITY REPORT

Cable Landfalls for East Anglia North Tranche 1 (EAN) U.K.

Client: Vattenfall Wind Power Ltd

Date of Issue: 26th February 2016

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1. INTRODUCTION

1.1. Overview

Vattenfall Wind Power Ltd. ("Vattenfall") has sought expert opinion on the feasibility of Horizontal Directional Drilling (HDD) for proposed landfalls of offshore cables from the East Anglia North Trance 1 project (EAN). This report assesses possible HDD locations and feasibility based on a site visit and desk study using publicly available information.

1.2. Scope of Work

Riggall and Associates have been invited by Vattenfall to examine documents related to the project. The aim of this report is to apply our knowledge and expertise in HDD, geotechnical engineering and geology in assessing possible HDD locations and review the feasibility of the HDD's at those locations.

Tim Riggall has a combination of theoretical knowledge, a BSc in Geology and MSc in Geotechnical Engineering, and practical experience, 8 years in geology followed by 15 years in HDD. His career in HDD has progressed from guidance and design of HDD pilot drilling through modelling of drilling forces and downhole fluid pressures to project evaluation and troubleshooting. Tim has guided pilot holes on over 120 HDD's and intersections in a wide range of ground conditions throughout the world. He has consulted on over 50 projects worldwide with a particular focus on management of downhole fluid pressures to avoid ground formation damage and surface breakout.

1.3. Reference Documents

The following documents and information sources have been reviewed:

Filename / Source	**Title / Description**	**Doc No. and Issue**	**Author**
EAN Tranche 1 HDD feasibility study.docx	EAN Tranche 1 – HDD Feasibility Scope of Works	Date: 3/11/2015	Vattenfall
OS Explorer Maps 1:25,000	Accessed through online subscription	Accessed 14/1/2016	Ordnance Survey
Google Aerial Mapping	Aerial mapping	Accessed 14/1/2016	Google
BGS Geology of Britain Viewer	http://mapapps.bgs.ac.uk/geologyofbritain/home.html 1:50 000 mapping of superficial and bedrock	Accessed 15/1/2016	British Geological Survey
BGS Borehole Logs	Publically available borehole logs. Borehole numbers are given in Section 3.2	Accessed 15/1/2016	British Geological Survey
Happisburgh - Geological Guide for the Geology and Stratification.pdf	http://www.happisburgh.ukfossils.co.uk/geology-guide.asp	Accessed 18/1/2016	UK Fossils Network
Corton - Geological Guide for the Geology and Stratification.pdf	http://www.corton.ukfossils.co.uk/geology-guide.asp	Accessed 18/1/2016	UK Fossils Network

Filename / Source	**Title / Description**	**Doc No. and Issue**	**Author**
Pakefield - Geological Guide for the Geology and Stratification.pdf	http://www.pakefield.ukfossils.co.uk/Pakefield-Fossils-Geology/geology-guide.htm	Accessed 18/1/2016	UK Fossils Network
Shoreline_management_plan Kelling-Lowestoft.pdf	Kelling to Lowestoft Ness Shoreline Management Plan	Final Report 3/1//2010 Adopted August 2012	AECOM Limited
Shoreline_management_plan Lowestoft-Benacre Ness.pdf	Suffolk SMP2 Sub-cell 3c Policy Development Zone 1 – Lowestoft Ness to Benacre Ness	January 2010 Version 9	Suffolk Coastal District Council / Waveney District Council / Environment Agency
NE Norfolk and N Suffolk coastal trends report 2013.pdf	Coastal Trends Report North East Norfolk and North Suffolk (Kelling Hard to Lowestoft Ness)	RP033/N/2013 June 2013	Environment Agency
Coastal Trends Report Suffolk (Lowestoft to Languard Point, Felixstowe) 2011 RP022S2011.pdf	Coastal Trends Report Suffolk (Lowestoft to Languard Point, Felixstowe)	RP022/S/2011 February 2011	Environment Agency

Table 1. Reference Documents reviewed for the Study. Additional references are listed in Section 16.

In addition to these documents a number of other resources have been accessed in compiling the report and these are listed in the References, Section 16.

For this study Vattenfall have stated that the assumed duct size is 500mm OD SDR11 HDPE.

1.4. Quality of Information

The available mapping information, both onshore and offshore, is at a scale suitable for this study but unsuitable for preliminary design stages or later. Lidar data or topographical surveys will be required for the chosen land and beach sites. A bathymetric survey will be required for the near shore and offshore areas.

The quality of geological information is reasonable for this level of study but unsuitable for preliminary design stages or later. The available BGS borehole data is generally of low quality due to the majority of boreholes being for drilled water bores between 1900 and 1960. The logs give very brief and general terms for the strata encountered. Very few boreholes detail the density or stiffness of the soils and fewer still contain SPT values or other test results. Ground investigation boreholes and possibly geophysics will be required to better inform the geology at the chosen location/s.

The documents related to Coastal Erosion are of high quality. Further assessment of the impact of coastal erosion at the chosen site/s might involve a specialist in the field examining and interpreting the available data.

2. LOCATION OF SITES

The site visit assessed 13 sites within three different areas defined in the scope of works:
Area 1: Bacton to Winterton, Sites 1 to 7
Area 2: Gorleston to Corton, Sites 8 to 10
Area 3: Pakefield to Kessingland, Sites 11 to 13

VATTENFALL EAN SITE VIST ITINERARY 19-20 JANUARY 2016				
LOCATION	**OS GRID REF**	**LOCATION**	**ACCESS**	**VISIT DATE**
Site 1	TG 35668 33110	Keswick	At location	18/01/2016
Site 2	TG 37486 31781	Happisburgh North	Parking at Happisburgh Lookout Station, Beach Road, TG 38438 30928	18/01/2016
Site 3	TG 38819 30559	Happisburgh South	Parking at Happisburgh Lookout Station, Beach Road, TG 38438 30929	18/01/2016
Site 4	TG 40898 29151	Eccles-on-Sea	Parking and beach access at Beach Rd, TG 41133 28869	18/01/2016
Site 5	TG 44018 26599	Waxham	Parking and beach access at Church Rd, TG 44125 26289	18/01/2016
Site 6	TG 46413 24157	Horsey Gap	At location	18/01/2016
Site 7	TG 48578 21769	Winterton Ness	Parking at Winterton-on-Sea, TG 49854 19772	18/01/2016
Site 8	TG 52958 01116	Gorleston South	Parking for beach access at Gorleston Cliffs, TG 53061 02204	19/01/2016
Site 9	TM 53743 99265	Hopton South	Beach access from Beach Road, TM 53588 99695	19/01/2016
Site 10	TM 54254 97923	Corton North	Park at St Bart's Church, TM 53794 98058	19/01/2016
Site 11	TM 53708 89205	Pakefield South	Parking at Morrisons	19/01/2016
Site 12	TM 53588 88263	Heath Farm	Parking at Oaklands Terrace, TM 52950 87805. Footpath along Cliff	19/01/2016
Site 13	TM 53559 87048	Kessingland North	As above	19/01/2016

Table 2. Location of sites examined on the site visit.

Subsequent to the site visit mapping files were received from Vattenfall showing that the onshore extent of Area 1 is from Bacton to Mill Lane, Sea Palling. This removes Sites 6 and 7 from the required study area. Assessment of Sites 6 and 7 are included in this Report for completeness but they have low potential for HDD landfalls because environmental designations.

The general location of the sites is shown in Figure 1 to Figure 4. Indicative HDD alignments at each site are shown in Appendix A.

At both Sites 3 and 4 there were two separate locations that could conceptually host a HDD alignment; consequently these have been designated as Sites 3a, 3b, 4a and 4b.

Figure 1. General Location of Sites 1-5 in Area 1.

Figure 2. General Location of Sites 5-7 in Area 1.

Figure 3. General Location of Sites 8-10 in Area 2.

Figure 4. General Location of Sites 11-13 in Area 3.

3. GEOTECHNICAL

3.1. Geology Overview

The East Anglia coastline is formed by Holocene Alluvium (beach deposits, windblown sand, and peat) overlying a succession of glacial and fluvial derived deposit (tills, glaciofluvial sands, sands and gravels). Beneath these are Crag deposits (gravels, sands, silts and clays) that were deposited in estuarine or shallow marine conditions. In the study areas the top of the Crag deposits is generally at sea level or lower and therefore rarely outcrops in the costal cliffs.

Underlying the Crag deposits, based on borehole information is Chalk, sometimes with London Clay, Woolwich Beds, and Reading Beds logged as being present between the Crag and Chalk. It is unlikely that a HDD would be at sufficient depth to encounter chalk except at the most northerly sites (Sites 1 and 2).

A summary of the general geology for each of the areas is given in Table 3, Table 4, and Table 5 below. Note that Area 1 (Sites 1-7) covers approximately 10km (6 miles) of coastline and there will be some variation in the thickness of units and the elevation of unit boundaries.

GENERAL STRATIGRAPHY OF AREA 1: BACTON TO WINTERTON		
UNIT	**DESCRIPTION**	**THICKNESS**
Holocene Alluvium:	Coastal Barrier Deposits (Sand And Gravel) and/or Blown Sand Deposits (Sand) and/or Marine Beach deposits (Sand And Gravel) and/or Peat (in the southern section; Waxham to Winterton)	0 – 6m
Walcott Till Member	Diamicton. Superficial Deposits formed up to 2 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions.	0 – 5m.
Bacton Green Till Member	Diamicton. Superficial Deposits formed up to 3 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions.	0 - 5m.
Happisburgh Glacigenic Formation	Sand And Gravel in the upper (Corton Sand Member) and mid lower (Happisburgh Sand Member) sections. Diamicton in the mid (Corton Till Member) and basal sections (Ostend Clay Member overlying Happisburgh Till Member). Superficial Deposits formed up to 3 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions	5m - 20m.
Wroxham Crag Formation:	Interbedded gravels, sands, silts and clays. The gravels are dominated by flint (up to c.80%) and by quartz and quartzite (up to c.60%). The deposits are interpreted as estuarine and near-shore marine.	5m –25m
Chalk	Chalk with flints. With discrete marl seams, nodular chalk, sponge-rich and flint seams throughout	>10m

Table 3. General stratigraphy of Sites 1-7.

<table>
<tr><th colspan="3">GENERAL STRATIGRAPHY OF AREA 2: GORLESTON TO CORTON</th></tr>
<tr><th>UNIT</th><th>DESCRIPTION</th><th>THICKNESS</th></tr>
<tr><td>Holocene Alluvium:</td><td>Blown Sand Deposits (Sand) and/or
Marine Beach deposits (Sand And Gravel)</td><td>0 – 5m</td></tr>
<tr><td>Corton Woods Sand And Gravel Member</td><td>Sand And Gravel. Medium gravels and fine- to coarse-grained sands. The gravels comprise mainly flint, with subordinate quartz and quartzite.</td><td>0 – 5m.</td></tr>
<tr><td>Lowestoft Formation</td><td>Diamicton. Chalky till with clay layers (Oulton Clay Member). Superficial Deposits formed up to 2 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions</td><td>5m - 10m.</td></tr>
<tr><td>Happisburgh Glacigenic Formation</td><td>Sands in upper sections (Corton Sand Member), Sand And Gravel in the mid lower section (Leet Hill Sand and Gravel Member) and Diamicton in the lower section (Corton Till Member). Superficial Deposits formed up to 3 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions</td><td>10m - 15m.</td></tr>
<tr><td>Wroxham Crag Formation:</td><td>Interbedded gravels, sands, silts and clays. The gravels are dominated by flint (up to c.80%) and by quartz and quartzite (up to c.60%). The deposits are interpreted as estuarine and near-shore marine.</td><td>>12m</td></tr>
</table>

Table 4. General stratigraphy of Sites 7-10.

<table>
<tr><th colspan="3">GENERAL STRATIGRAPHY OF AREA 3: PAKEFIELD TO KESSINGLAND</th></tr>
<tr><th>UNIT</th><th>DESCRIPTION</th><th>THICKNESS</th></tr>
<tr><td>Holocene Alluvium:</td><td>Blown Sand Deposits (Sand) and/or
Marine Beach deposits (Sand And Gravel)</td><td>0 – 5m</td></tr>
<tr><td>Lowestoft Formation</td><td>Diamicton. Chalky till. Superficial Deposits formed up to 2 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions</td><td>5m - 10m.</td></tr>
<tr><td>Happisburgh Glacigenic Formation</td><td>Sands in upper sections (Corton Sand Member) and Sand And Gravel in the lower section (Leet Hill Sand and Gravel Member). Superficial Deposits formed up to 3 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions</td><td>10m - 15m.</td></tr>
<tr><td>Wroxham Crag Formation:</td><td>Interbedded gravels, sands, silts and clays. The gravels are dominated by flint (up to c.80%) and by quartz and quartzite (up to c.60%). The deposits are interpreted as estuarine and near-shore marine.</td><td>>20m</td></tr>
</table>

Table 5. General stratigraphy of Sites 11-13.

3.2. Borehole Information

The publicly available BGS boreholes contain a range of boreholes drilled over the past 120 years with varying quality of geological logging. Many of the boreholes have been drilled for water bores prior to 1950 and have little or no information.

Boreholes considered to have useful information in reasonable proximity to the sites are given in Table 6 below.

AREA 1		AREA 2	AREA 3
TG33SE1	TG33SE8	TG50SW12	TM58NW2 - 6
TG33SE11	TG33SE9	TG50SW144	TM58NW8 - 11
TG33SE20	TG33SE16	TG50SW180	TM58NW17
TG33SE27 - 28	TG33SE17	TG50SW182	TM58NW152
TG32NE8	TG32NE34	TM59NW12 - 16	
TG42NW5	TG42NW7	TM59NW25	
TG42SE2	TG42SW6	TM59NW112 - 117	
		TM59NW164	

Table 6. Available BGS Boreholes logs reviewed in the study areas.

In some locations there are boreholes for which the BGS only allows restricted access. These are mostly from sea defence investigations; examples are boreholes TG42NW9 to TG42NW11 at Eccles-on-Sea. They might provide useful information for final stages of site selection.

3.3. Suitability of Ground Conditions for HDD

3.3.1 Holocene Alluvium

The sands and sands and gravels of the Holocene Alluvium are generally loose and will require either support from drilling fluid or, if encountered above mean sea level, they will probably require casing or excavation. However the unit is only likely to be encountered at the immediate entry and exit points and can be mitigated if it is encountered.

3.3.2 Till Members

The various till members within the formations in the study areas are expected to form a stable borehole when drilled with HDD. No large boulders or beds of cobbles were seen in any of the tills during the site visit, however locally they might occur. If boulders or cobbles within a till were encountered during a HDD they would cause inconvenience (additional time required to clean the borehole) and a relatively small cost increase for the contractor. They would be unlikely to require re-drilling or re-routing of the HDD.

Figure 5. Happisburgh Till member exposed in cliffs at Happisburgh.

3.3.3 *Happisburgh Glacigenic Formation*

The sand members (Corton Sand Member and Happisburgh Sand Member) within the Happisburgh Formation tend to be fine grained with gravel content varying from none up to 50% in some layers. The members are generally medium dense and stand near vertically in the eroded cliffs. This suggests that they should form a stable borehole when supported by drilling fluid.

Sections of HDD borehole above sea level through the sand and gravel have the potential for localised roof collapse once the HDD exits into the sea. This is because the drilling fluid level in the HDD will equilibrate with sea level and the ground loses the benefit of support by drilling fluid. The options in these zones will be to install temporary casing support or to rely on the reamer preceding the duct to clean the borehole adequately during installation.

The choice of mitigation method for potential roof collapse will be driven by the results of ground investigations and testing, and the client or contractors assessment of the risk. In many cases HDD's encountering roof collapse within the final 20m of installation are successfully pulled as the reamer and drilling fluid liquefies the fallen material.

Figure 6. Cliff exposure at Happisburgh with stratigraphy shown.

3.3.4 *Norwich and Wroxham Crag*

The Crag is comprised of interbedded sands, gravels, silts and clays and is usually dense and well graded (i.e. they contain a range of grain sizes). Figure 7 and Figure 8 illustrate some typical coarser grained layers within the Crag. These characteristics, along with near horizontal stratification indicates they should usually stand up well when drilled with HDD and with the support of drilling fluid they will form a very stable borehole. A proviso to this is the potential existence of running sands within the Crag, mentioned by Ander *et Al* (2006) in their regional analysis of the Crag.

A few of the BGS borehole logs indicate running sand in the considerable thicknesses of Crag drilled for mostly water extraction boreholes. Regionally, the presence of running sands and percentage of gravel appears to steadily increase southward between Sites 1-7. Site 1 has sandy Crag, Site 5 has extensive thicknesses of blowing sand and discrete gravel layers.

Any flint within the Crag will lead to greater than normal wear on downhole equipment and possibly the drilling fluid recycling equipment. It might also require additional time to physically remove from the borehole but both wear and hole cleaning can be factored into schedule (perhaps an additional 1 to 2 days per HDD) and price by the HDD contractor.

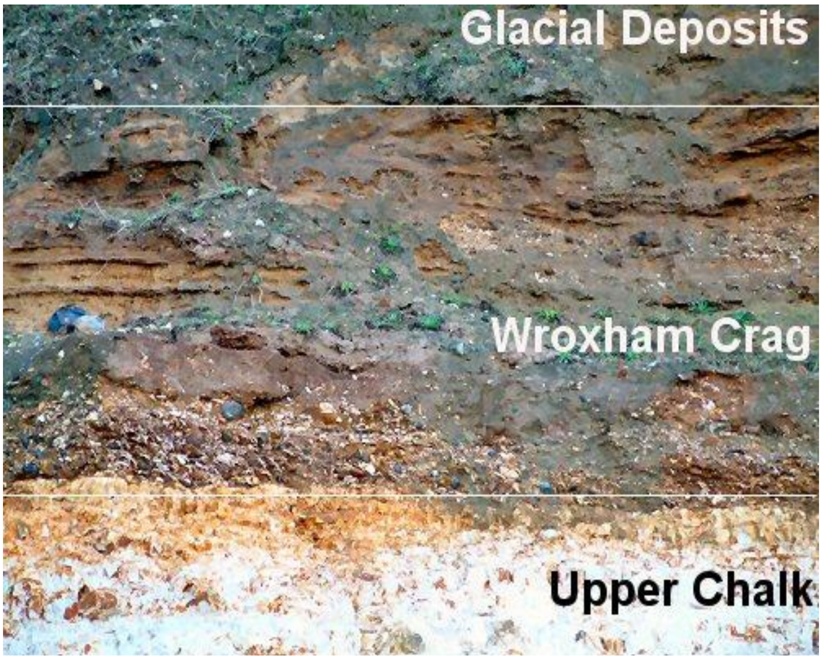


Figure 7. Cliff exposure from Weybourne, Norfolk showing Crag deposits. Photograph from http://www.weybourne.ukfossils.co.uk/Weybourne-Fossils-Geology/geology-guide.htm.

Figure 8. Cliff exposure from Weybourne, Norfolk showing Crag deposit overlying chalk. Note the well graded nature of the crag. Photograph from http://www.weybourne.ukfossils.co.uk/Weybourne-Fossils-Geology/geology-guide.htm.

3.3.5 Upper Chalk

The Upper Chalk has been drilled by HDD on other projects within the UK. It is normally good ground for HDD drilling, although there is the potential for losses of drilling fluid into permeable zones and localised chert beds can increase equipment wear. Rock strength is likely to be in the order of 10-15 MPa requiring tri cone roller bits rather than jetting assemblies to drill. There is the possibility of soft weathered areas (putty chalk) occurring, particularly at the top of the chalk.

The mapping of the Cromer Shoal Chalk Beds Marine Conservation Zone indicates chalk beds outcropping on the seabed in the vicinity of Sites 1 and 2. It is possible that these reefs would be of higher strength chalk in the 15MPa – 20 MPa range.

3.4. Hydrogeology

The Cretaceous Chalk forms the most important aquifer in England, whilst the Crag is a locally important resource over its outcrop area in East Anglia. None of the study areas is within a Groundwater Source Protection Zone according to the Environment Agency interactive mapping. The mapping also shows that none of the sites is within a Drinking Water or Groundwater Safeguard Zone.

The Environment Agency interactive mapping of Water Abstraction Licences indicates the only groundwater abstraction sites within 1.5km of any of the potential HDD’s are:

> **Site 1**: Bore 850m west- southwest, medium size abstraction for irrigation. The BGS borehole log TG33SW39 for the bore indicates water was struck at 4.45m depth. The well was drilled to 46m depth in the chalk, suggesting that the primary aquifer was at depth in the chalk.
>
> **Site 2**: Bore 440m south-southwest, The Chimneys, medium size abstraction for irrigation. The BGS borehole log TG33SE1 for the bore at The Chimneys indicates the well struck water in the chalk at a depth of 33.5m (-18.3m ODN). The landfall HDD design at Site 2 is likely to be above this level.

Given the location of the HDD’s on the low lying coastal margin it is unlikely that groundwater flow at Sites 1 and 2 will be south-westward (inland) leading to contamination of abstraction points by drilling fluid. Additionally, drilling fluid losses into aquifers would only occur in high flow groundwater regimes because the drilling fluid is designed to seal the annulus of the borehole by forming a filter cake around the wall of the bore.

BGS Groundwater Vulnerability Mapping indicates that most of the examined sites are over or adjacent to areas designated a Major Aquifer with High Vulnerability. Therefore, despite the significant distance to abstraction points, any ground investigations and design for a final HDD will need to consider and assess the risk to groundwater from the works.

3.5. Assessment of Geology and Groundwater at Individual Sites

3.5.1 Site 1

From surface to -5m ODN the ground is expected to be dominantly glacial till and sands (Corton Sands). The Crag is expected to be found between -5m ODN and -17m ODN and the majority of the HDD is expected to be within this zone. Below -17m ODN is the Chalk. Ideally the HDD would be at -15m to be above any basal gravel that might be in the Crag but have sufficient depth beneath any sheet piles from the sea defences.

The nearby water bores are all 10m into the Chalk for their water supply. A very old well nearby, BGS log TG33SE35, was 7.6m depth (-2.6m ODN) in the Crag. Water pH was 6.7 and was brackish, 6% sea water.

The geology appears suitable for HDD. The Crag is logged as sandy in boreholes on both sides of the site and there is no mention of gravel. Groundwater is not under artesian pressure and should be sealed by drilling fluid. There is no indication of collapsing ground in the borehole logs.

3.5.2 Site 2

The geology is expected to be brown glacial till (Walcott Till?) overlying sands (Happisburgh Sand?) and grey till (Happisburgh Till?) with the base at approximately -9m ODN. Underlying this is probably 3m of Crag (orange sand) with Chalk bedrock at -12m ODN.

Mapping in the DEFRA (2015) document on the Cromer Shoal Chalk Beds Recommended MCZ shows the near shore area at Site 2 as being sub tidal chalk.

Given that the sea wall at the location is sheet piled the HDD would probably need to be drilled through chalk at some point. It is unlikely that it would reach the depth in the chalk at which most of the water bores in the area draw from, however there is some risk of significant groundwater flows. These might need to be sealed with special additives and the risk to the chalk aquifer needs to be considered.

The elevation (+12m ODN) of the entry site means that after exiting the borehole above sea level will be dry and unsupported by drilling fluid. This might lead to localised roof collapses in the Sands but less likely in the glacial till. The vertical thickness of sand above sea level is probably around three metres so the effects of any collapse would be localised. Mitigation of roof collapse is discussed in Section 3.6.

The geology is generally suitable for HDD but will be slower than other sites because of needing to drill the harder chalk and ground investigations would need to assess any risk from groundwater flows and ground collapse in sediments above sea level.

3.5.3 Sites 3a and 3b

The geology is expected to be Pleistocene glacial till and sand with some gravel down to approximately -2m ODN. Beneath is Crag extending down to the Chalk at approximately -38m ODN.

The Crag will probably form the majority of the ground drilled by a HDD and is mostly silty sand with occasional gravel. Running sand is noted at three points (-3.5m ODN, -10m ODN, -6m ODN) in boreholes TG32NE33 and TG32NE34 near Site 3b and these discreet zones might be initially unstable in a HDD. Borehole TG33SE19 records 2.4m of shingle at -11m ODN, however the bore was extended to -46m for water production suggesting that, being in the Crag, the shingle layer is weakly cemented. These zones might be locally problematic for a HDD, particularly the shingle, and could require additional time and cost to clean and stabilise.

The groundwater level is recorded as -1.0m, the water bores were drilled approximately 10m into the chalk and it appears to be the production aquifer.

The ground is expected to be able to be drilled by HDD but the Crag here is more gravelly and possibly coarser in pockets and could require additional time and cost to stabilise if encountered.

3.5.4 Sites 4a and 4b

These sites suffer from a lack of sufficiently deep boreholes, the nearest being 1.8km southwest. The two available boreholes in the area extend to only -7m ODN, much of which is sand and gravel with some layers of peat and clay. Based on the nearest deep borehole the HDD could be mostly in Crag and it notes blowing sands (another name for running sands) within the Crag, the first at -12m ODN.

These sites will probably be more difficult to drill for a HDD than Sites 1-3 because of the thicknesses of sand and gravel extending to -7m ODN or deeper and the possibility of blowing sands within the Crag. Site 4a will probably be more suitable than 4b because the shorter HDD is more viable. There is no offshore rock defence allowing the option of drilling at a higher elevation and possibly avoiding blowing sands.

Further ground investigations are required before confidence could be gained in the ground conditions being suitable for HDD.

3.5.5 Site 5

Site 5 benefits from borehole TG42NW5 being very close to the site. The geology is suitable for HDD down to elevation -13.2mAOD with mostly glacial till. However below this depth a HDD would be difficult as the borehole records a 23m thickness of blowing sands with a 1.5m gravel layer in the middle.

If there were no other option a HDD could be completed above -13m elevation but there would be a moderately high risk of either breakout of drilling fluid or encountering blowing sands because of changes in the depth of the glacial till. The HDD would probably need to be 500m in length to exit beyond the offshore rock walls, compounding the breakout risk.

3.5.6 Sites 6 and 7

Sites 6 and 7 have no borehole logs of any value nearby. The nearest, TG42SE2 describes the first 8.7m as silty Clay and Peat underlain by sand and gravel to 13m (end of borehole). Sites 6 and 7 could be expected to have a similar geology. The peat layers are problematic for retaining drilling fluids and extended lengths drilled in sand and gravel come with the risk of roof collapse in the borehole.

3.5.7 Sites 8, 9 and 10

The available borehole information near Sites 8, 9 and 10 (the cliffs are inaccessible) shows that above 0m ODN is medium dense, fine to coarse silty Sand (Corton Sand Member). From approximately 0m to -2m is likely to be a gravel or sandy gravel layer often described as pebbly sand; this is the Leet Hill Sand Member of the Happisburgh Formation. Borehole TM59NW25 indicates blowing sand within the Leet Hill Sand Member.

Below -2m ODN is generally brown sand, and occasionally sand with gravel, forming the Crag. The deepest borehole within 500m shows Crag to -14m ODN and boreholes 3km north and 3km to the southwest show Crag to elevation -25m and -70m respectively so it can be expected that the length of HDD below sea level will be drilled within Crag.

The ground below sea level is likely to be good drilling for HDD. Above sea level the Coton Sands and Leet Hill pebbly sand should form a stable borehole when drilled and reamed. However when the borehole exits into the sea the drilling fluid will drain from the borehole creating the risk of localised collapse. The pebbly sand in particular might be prone to collapse and this is potentially compounded by fluid levels in the borehole fluctuating with the tide.

If a HDD is planned for Sites 8, 9 or 10 a number of ground investigation boreholes will be required along the land section of the design to determine the risk of localised collapse of dry borehole. The planning and costing should include provision for pre-grouting of the ground traversed in the initial 50-70m of the HDD until it is below sea level.

3.5.8 Sites 11, 12, 13

The uppermost geology is the Lowestoft Till the base of which appears to be at around 12m ODN near Site 11 and lower (approaching 6m ODN) at the southern sites. Underlying the till is medium dense fine glacial sand (Corton Sand) to approximately 1m ODN. The base of the Corton Sand can vary; along one section of the cliffs it has cut a channel into the Forest Beds at the top of the Crag.

The Crag formation varies in composition with depth. From 1m ODN to -9m ODN it is generally sandy clay or clayey sand with some gravel. Between -9m and -15m it is sand and gravel. Beneath the sand and gravel is fine sand; borehole TM8NW17 recorded live sand (blowing sand and running sand are alternative descriptions) between -12 and -14m ODN. The fine sand extended to the base of borehole TN58NW152 at -32m ODN.

For similar reasons to Sites 8-10 a HDD through this geology would require considerable ground investigation and provision for pre-treatment of ground above sea level. The Coton Sands are ideal for HDD while supported by drilling fluid, but given the likely 660mm borehole diameter there is a risk of roof collapse when the borehole becomes dry after exit. The sites also have the risk of running sands, identified at -12m to -14m ODN near Site 11, when drilling below sea level in the Crag.

The mitigation options are to accept the risk and rely on the reamer fluidising the collapsed sections as the duct is installed or to strengthen the ground prior to drilling. Pre-treatment would be over a length of 40m to 50m, the section of hole in Glacial Till shouldn't need treatment. Ground investigations are essential in evaluating the risks and planning mitigation methods because the available borehole information is scant and of low quality.

3.6. Topography

The topography of the coastline has an impact on the feasibility of a HDD. Ideally the entry elevation should be as close to sea level as possible to minimise the length of HDD borehole unsupported by drilling fluid. A secondary advantage is a reduction in the risk of drilling fluid "breakout" or "frac-out" (loss of drilling fluid to the surface).

During pilot hole drilling the entire borehole should be full of drilling fluid. The drilling fluid serves a number of purposes but two of the most important are removing the drill cuttings from the borehole and supporting the walls and roof of the drilled borehole. Greater detail on drilling fluid can be found in Section 8.4.

When the drill exits on the seabed the drilling fluid will equilibrate to the sea level. If the entry elevation is significantly higher than the sea level the result is a length of borehole at the entry point that is dry and therefore unsupported. As a result there is a significant increase in risk of ground collapse into the borehole, particularly in weak sediments. The risk increases with increasing borehole diameter because arch support in the ground is reduced.

Table 7 below indicates the length of unsupported borehole (after sea exit) for different scenarios.

LENGTH (m) OF HDD BOREHOLE WITHOUT FLUID AFTER EXIT ON SEAFLOOR										
Entry Angle (degrees)		**Entry Elevation in metres above sea level**								
		2	4	6	8	10	12	14	16	18
Upper entry angle for HDD	17	7	14	21	27	34	41	48	55	62
	15	8	15	23	31	39	46	54	62	70
	12	10	19	29	38	48	58	67	77	87
Low Entry angle to reduce cable installation forces	10	12	23	35	46	58	69	81	92	104

Table 7. Effect of elevation and entry angle on length of borehole unsupported by drilling fluid after exit.

It can be seen from the table that an entry level of 18m above sea level results in a minimum 62m length of borehole left unsupported by drilling fluid after the HDD has exited. The chance of collapse of the unsupported borehole will depend on the type of soil, strength of the soil, and diameter of the borehole. Ground investigations and sample testing will allow evaluation of the risk.

Borehole collapse can be mitigated by either casing the borehole for the section at risk of collapse or less commonly by the use of ground improvement. Ground improvement is most likely to take the form of pre-grouting the weak sections of soil along the planned HDD route.

Alternatively, if the scale of the potential collapses and risks to completion of the HDD are assessed as low the contractor might elect to continue without mitigation. They would then rely on the reamer that precedes the duct during the duct installation to fluidise the collapsed ground sufficiently to complete installation. Because of the potential delay and cost implications there should be careful assessment of likelihood and risks prior to, and during, works if no mitigation is proposed for potential zones of collapse.

The assumed duct on this project is 500mm OD SDR11 HDPE. For this duct the minimum HDD borehole size is 24” (610mm = 1.22 x duct OD) and the likely HDD borehole size is 26” (660mm = 1.32 x duct OD). This would require 28” (711mm) to 30” (762mm) steel casing which would normally be in 12m lengths welded together as they are installed. For this diameter of casing 30m to 40m is usually considered the length limit, especially if the casing is to be removed after installation of the duct.

It is therefore preferable that the entry elevation is less than 12m above sea level if ground collapse is considered a risk. If higher elevations are to be considered either the ground must be self supporting in a dry 26” (660mm) borehole or the ground must be improved prior to HDD commencing. A level of 12m above the lowest sea level equates to approximately 10m ODN for the study areas.

Table 8 below summarises the suitability of different entry elevations for the study area.

Entry Elevation m ODN	Recommendation	Mitigation if used
<2	Avoid or mitigate - risk of site flooding on high tides	Working Pad elevated above High Tide level, conductor casing sealed at its toe.
2-4	Ideal	Entry pit of sufficient depth
4-6	Good	Consider casing or excavating loose ground to sea level
6-10	Reasonable	Casing likely to be required
>10	Avoid or mitigate unless in competent ground	Ground improvement - pre-grouting or soil mixing

Table 8. Recommendations for mitigation of risk of dry borehole for differing entry elevations.

3.6.1 Elevation Datum

Water depths on the Admiralty Chart are given in Chart Datum; the depth in metres below the Lowest Astronomical Tide (LAT) in a locality. LAT is approximately the lowest level due to astronomical effects and excluding meteorological effects.

All land elevations on Ordnance Survey mapping are given relative to Ordnance Datum measured at Newlyn (ODN).

The elevation of LAT measured in ODN varies around the coastline. The Admiralty Chart gives the following values:

Gorleston LAT = -1.56m ODN
Great Yarmouth LAT = -1.59m
Winterton LAT = -1.82m ODN
Cromer LAT = -2.75m ODN

For the purpose of this study we will assume that for the stretch of coastline from:

Bacton to Sea Palling (Sites 1-5)	LAT = -2.20mODN
Horsey Gap and Winterton (Sites 6-7)	LAT = -1.82mODN
Gorleston to Corton (Sites 8-10)	LAT = -1.56mODN
Pakefield to Kessingland (Sites 11-13)	LAT = -1.50mODN

For any final HDD designs at a chosen location the prior bathymetric survey should supply data relative to ODN in order to ensure there are no errors in construction. However it should always be remembered that the bathymetry along this section of coast is continually changing.

3.6.2 Tidal Range

The tidal ranges for the study areas are given below, however they indicate astronomical tides and higher values can occur due to meteorological events.

Walcott – maximum tidal range 4.38m
Great Yarmouth – maximum tidal range 3.34m
Lowestoft – maximum tidal range 2.75m

3.6.3 Depth of Cover of HDD

For the assessment of suitable sites the study has assumed that all HDD’s will have a similar vertical profile and similar depth of cover. Depth of cover will impact on thermal conductivity and therefore cable rating. While those HDD’s drilled from higher elevations are likely to have a greater depth of cover as they pass below the cliff line this aspect has been ignored because the higher elevation is already considered as a negative impact for reasons outlined in Section 3.6.

4. ENVIRONMENTAL

The sensitivity of the natural environment will play a part in the acceptability of HDD installation and the routing of any landfall. The main environmental risks affecting the sites are the impact of the HDD on the natural environment (marine, intertidal and terrestrial), the impact of coastal erosion on the cable installation, and the risk of flooding to the HDD works during construction.

There are numerous environmental designation, both land and marine, affecting the sites as outlined in the tables in Section 4.1 and Appendix B.

The environmental designations have been subjectively taken into account in the assessment of site suitability (see Table 11) by reviewing the number of designations, their position (whether they cover entry or exit points), their status (statutory or non-statutory), and the possible impact of HDD on them.

4.1. Designated Areas

A check on the UK government's Magic Map Application revealed the following designations for each of the sites:

SITE	Environmental Designations - Land	Environmental Designations - Marine
1	None	MCZ - Cromer Shoal Chalk Beds
2	None	MCZ - Cromer Shoal Chalk Beds
3a	None	None
3b	CWS adj.	None
4a	CWS	None
4b	CWS	None
5	Norfolk Coast AONB adj	None
6	Norfolk Coast AONB	None
7	Winterton - Horsey Dunes SSSI, SAC Great Yarmouth North Denes SPA Norfolk Coast AONB The Broads NP adj.	None
8		Outer Thames Estuary Inshore SPA
9		Outer Thames Estuary Inshore SPA
10		Outer Thames Estuary Inshore SPA
11		Outer Thames Estuary Inshore SPA
12	Pakefield to Easton Bavents SSSI	Outer Thames Estuary Inshore SPA
13	Pakefield to Easton Bavents SSSI	Outer Thames Estuary Inshore SPA
NOTES	adj. Indicates adjacent to HDD route	

Table 9. Environmental designations covering each site.

Greater details of the designations at each site are given in Appendix B.

Site 7 is unlikely to be considered acceptable by Natural England because it is covered by numerous designations. Site 6 is probably unlikely to be considered acceptable because of its location within an Area of Outstanding Natural Beauty. The stretch of beach is also a breeding site for grey seals during the winter months.

4.1.1 Land Area Designations

County Wildlife Sites: CWS's do not confer statutory protection to a site but identify sites important to wildlife at a county level.

CWS's are located at Sites 4a and 4b and adjacent to Site 3b. The CWS sites have been considered as having low impact in the assessment of site feasibility for HDD. Site 3b is used for cropping and Site 4a was observed to be used for grazing horses on the site visit. Site 4b appears to be used for grazing, and if the conditions of the CWS are problematic at this site the entry point could move 30m south into a cropped field where the impact of the HDD could be argued as being no greater than the agricultural use.

Area of Outstanding Natural Beauty: Sites 6 and 7 are within the Norfolk Coast AONB and Site 5 is adjacent to the AONB. The impact of the AONB on the assessment of the sites for feasibility has been marked as caution for Site 5 and potentially problematic for Site 6. The HDD construction itself would only have a temporary impact on the area, after which it would be returned to its previous state, however it would require considerable time, expense and community consultation to justify the sites for consenting.

Sites of Special Scientific Interest: On other landfalls and HDD projects part of the reason for using the technique is to safely traverse SSSI zones. The Winterton - Horsey Dunes SSSI at Site 7 would not be directly impacted by a HDD because it would pass beneath it. There might be minor impacts in the event of drilling fluid breakout but the risk can be mitigated and the potential impact on the SSSI would be low. Similarly at Sites 12 and 13 the Pakefield to Easton Bavents SSSI is unlikely to be affected.

In the Site Assessment Table (Table 11) the SSSI's have been marked as potentially problematic because they typically require considerable time and expense to pass the consenting process.

Special Areas of Conservation: The Winterton - Horsey Dunes SAC at Site 7 is designated for the protection of the Atlantic decalcified fixed dunes and the Humid dune slacks. Although the HDD would drill from the car parking area behind Horsey dunes there is no certainty that consent would be granted by the authorities and for feasibility assessment the SAC area has been marked as avoid.

Special Protection Areas: The Great Yarmouth North Denes SPA at Site 7 is designated for important numbers of breeding Little Tern *Sterna albifrons* that feed outside the SPA in nearby waters. The population within the SPA of 220 pairs represents at least 9.2% of the breeding population in Great Britain (5 year mean, 1992-1996). Although the HDD would drill from the car parking area behind Horsey dunes there is no certainty that consent would be granted by the authorities and for feasibility assessment the SPA area has been marked as avoid.

National Park: The Broads National Park is adjacent to Site 7. Given the confluence of SSSI, National Park, SAC and SPA at Site 7 it is not recommended as a realistic HDD location.

4.1.2 Marine Designated Areas

Marine Conservation Zone: The Cromer Shoal Chalk Beds MCZ designated in January 2016 will affect either the landfalls or offshore cable routing for Sites 1 and 2. The MCZ begins 200m offshore from OS Mastermap MLW. The exit point of the short landfall options at Sites 1 and 2 would therefore be outside the MCZ while the long option exits would be inside the MCZ boundary. In both cases the offshore cable routing would pass through the MCZ.

The DEFRA consultation document (2015) states that for “Activities that are likely to be affected : Management decisions are taken on a case by case basis by relevant regulators”. It states that Dudgeon and Sheringham Shoal offshore wind farms are “unlikely to be affected”; however Dudgeon is already consented and Sheringham Shoal is operational.

It is therefore difficult to assess the potential view of consenting bodies to the EAN cable route passing through the MCZ. In the Site Assessment Table (Table 11) the item has been marked amber, however this will need to be reviewed by environmental and / or consenting specialists.

Inshore Special Protection Area: Sites 8-13 are affected by the Outer Thames Estuary ISPA. The site qualifies as an SPA because it supports 28% of the Great Britain population of Red-throated diver *Gavia stellata*.

Given the extensive coverage of the SPA (approximately 200km of coastline from Great Yarmouth in the north to Margate in the south) it is reasonable to expect that the 30m width of temporary marine works for a HDD installation would have no significant impact on the species. In the Site Assessment Table (Table 11) the SPA has been marked amber, however this will need to be reviewed by environmental and / or consenting specialists.

4.2. Coastal Erosion

The areas covered by the sites are all subject to coastal erosion. The process has been occurring along East Anglia for centuries and will continue to do so, in part accelerated by sea level rise. The worst affected section of the coast in recent history is at Happisburgh (near Site 3a) where up to 170m has been lost in the past sixty years.

Shoreline Management Plans (SMP’s) have been developed for Kelling to Lowestoft Ness (covering Sites 1-10) and Lowestoft Ness to Benacre Ness (covering Sites 11-13). The SMP’s indicate coastal management policy for the Short (to 2025), Medium (to 2055) and Long (to 2105) term. The proposed strategies (e.g. No Active Intervention, Managed Realignment, or Hold the Line) at each site have been taken into account for their impact on the position of the HDD entry site and length of drill.

The Kelling to Lowestoft Ness SMP gives indications of possible shoreline positions in the medium and long term (2055 and 2105) and these have been used, where available or necessary, in determining the required position of the HDD entry point at each site in Table 17 (Appendix C). The calculations in the table give the entry point such that coastal erosion at the considered time (2055 or 2015) reaches a point where the installed cable is at elevation -3m ODN. For all of the sites this elevation is below Lowest Astronomical Tide (LAT) and the cable should not therefore be exposed at the shoreline.

4.2.1 Coastal Defences

To combat the effects of coastal erosion on property and resources much of the coastline has been protected with coastal defences. Sites 1-10 have all had some form of defence constructed over the preceding 50 years. Over the coming years the defences at Sites 1, 4a, 4b, 5, 6 and 7 are expected to be maintained to hold the current coastline position.

The defences at Sites 2, 3a, 8, 9, and 10 are already falling into disrepair and are unlikely to be refurbished in the coming years. The different styles of defences used can be clearly seen in the photographs from the site visit contained in Appendix G.

The design of defences oriented parallel to the shore will need to be considered for the HDD design profile to ensure that the HDD avoids any piling. It is probable that the maximum piling depth is likely to be 12m below the level of the beach. The 12m pile length is based on typical sheet pile lengths for transport by HGV. Additionally, in a number of Google Earth photographs piles can be seen stockpiled at EA compounds used for coastal defences construction and the measures length of these match the standard 12m length.

The drawing in Figure 9 from Withers (2001) shows the design of the defences at Site 1 but does not contain dimensions. Prior to commitment to a site records and designs should be sought from the Environment Agency to ensure the design has adequate depth below any coastal defence structures.

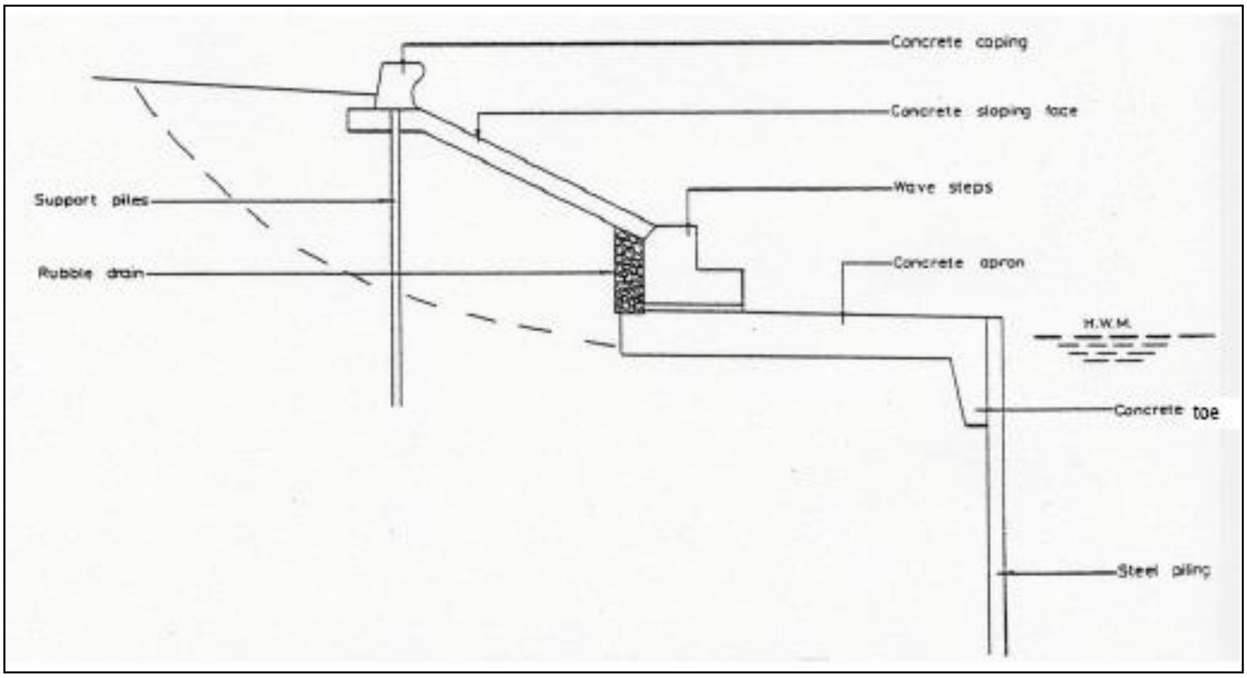


Figure 9. Sloping seawall design, such as that built at Bacton and Walcott around 1954. From Withers (2001).

4.2.2 Length of HDD

The distance of coastal erosion at each site not only has implications for the position of the HDD entry point in relation to the existing coastline, but also on the overall length of the HDD. The overall cost of the HDD is proportionate to the length, but the geotechnical and drilling risks also increase with length. Additionally the length of the HDD can impact on cable rating and cable pulling forces.

Table 17 in Appendix C gives estimates for the minimum HDD length at each site for a short option, exiting at approximately Lowest Astronomical Tide (LAT), and a longer option exiting at 3m below LAT. The short option is to indicate the approximate length for exiting on the beach to eliminate any offshore works for the HDD other than towing the duct to position for installation.

An aspect that has not been evaluated in this report is seabed scouring or accretion at the exit point and the resulting implications for the installed cable. This is beyond the scope and expertise of this report and is usually addressed in the offshore routing studies.

4.2.3 Exit position

For this study it has been assumed that all the HDD’s will exit either close to the LAT, the **Short HDD Option**, or at approximately -3.0m LAT, the **Long HDD Option**. This allows a comparison between sites but is in no way intended to restrict the exit points to these elevations. Evaluation of records from six previous projects exiting below LAT show a range from -1.0m LAT to -20.0m LAT with the median depth being -5m LAT. Commonly the choice of exit depth is driven by the sea bottom profile and the thickness and type of sediment.

For the preferred HDD routes on the EAN project the final choice of exit point will be decided by factors such as the bottom profile, sediment depth, sediment grain size, projections for scouring or accretion on the sea floor and the suitability for cable laying vessels. Assessment of these parameters will require marine surveys; therefore stating a preferred exit depth for the long option is beyond the ability or scope of this study.

An example of the Short HDD Option is the cable landfalls at Easington drilled in 2012 for the Humber Gateway project by Stockton Drilling. The pair of HDD’s exited 60m from the shoreline at approximately -0.75m ODN and 50m apart horizontally. The HDD’s were 320m in length and Figure 10 shows the exit position at low tide in an area of sand, gravel and cobble.

Figure 10. HDD exit on the Humber Gateway project illustrating the short HDD option of exit near MLW.

An example of the Long HDD Option is the cable landfalls for the Western Link project completed in 2015 at Ardneil Bay, Ayrshire. These HDD’s were 600m long, with 10m horizontal separation between the two HDD’s. The exits were at -3m LAT through a considerable thickness (8m vertical thickness) of sand with medium cobble content. The exit position and barge for duct installation is illustrated in Figure 11.

At the same time as the Western Link HDD's another pair of ducts were installed approximately 100m to the north for the Hunterston – Kintyre Undersea Cable, however the chosen exit point was a further 200m offshore at approximately -7m LAT.

Figure 11. Barge in position during installation of ducts for the Western Link HDD Landfalls.

4.3. Flooding

The site visit on 19-20 January 2016 followed 6 weeks of near average winter rainfall for the region. There was no flooding in the region or at any of the potential HDD sites. The lower lying sites (<4m ODN elevation) are mapped as having low flood risk by the Environment Agency Mapping.

The site mapped as having the highest flooding risk is Site 1 at Walcott. This is due to it being exposed to waves overtopping the sea defences during tidal surges as happened in December 2013 (Rush, 2013). Images show debris strewn across the proposed drilling site following the event. It is likely, however, that the flooding event would be limited to the duration of the surge because excess water would quickly drain back to the sea as the sea level dropped.

The 2013 tidal surge was the highest event since the 1953 surge. The borehole log TG32NE34 indicates that the 1953 surge level at Site 3b was at +3.75m elevation.

In the event of a surge similar to the 1953 event there is a risk of the lower lying sites (<4m ODN elevation) being submerged for a considerable time and it is likely that roads to the sites in such an event would be impassable for days to weeks. Sites 8-13 would presumably be less disrupted by road closures due to their close proximity to the A12.

5. ANTHROPOGENIC FACTORS

A number of anthropogenic (mad made) factors have been considered in the Site Assessment Table (Table 11) for ranking the sites. Of the sites the one that is most likely to be adversely affected by archaeological considerations is Site 8 where there is well documented evidence of a Roman field system and possible settlement. Regardless of which site is chosen an archaeological desk study will be required as a minimum.

Consultation with nearby residents will be required regardless of the chosen site and any site beside a holiday camp, caravan or camping site will need to consider off-season construction dates and have a constructive dialogue with the proprietors. Site 13 is probably the least favourable in terms of disturbance to residents but all sites are viable; the more populated sites will require more time and cost to mitigate noise, light, and traffic concerns.

Land ownership of the sites has not been addressed in this report.

The coastline saw extensive defensive installations during World War II and the ports of Lowestoft and Great Yarmouth were heavily bombed. A UXO desk study of the chosen site will be required to determine the risk of unexploded ordnance and determine the level of any detection required during ground investigations and construction. Sites 8-13 are the most likely to require a higher level of study and detection.

5.1. Archaeology

The study area has a long archaeological history. The oldest (800,000 years) human footprints in northern Europe were found at Happisburgh, artefacts and structures from Roman Britain have been found near many of the sites, there is a rich medieval history along the coastline, and it also contains a significant number of military structures from World War II.

An indication of possible archaeological restrictions on the sites was gained by examining the Suffolk Heritage Explorer Mapping and Norfolk Heritage Explorer Mapping websites. The complete results of the searches are given in Appendix D.

Archaeology at the sites is only expected to be of concern at the entry sites and the impact will usually be limited to the entry pit excavation and possibly the excavated anchor block if one is required. The entry pit is typically of dimensions 3m width x 4m length x 2.5m depth. The anchor block is typically 3m W x 2m L x 2m D. This study is not taking into consideration the joint bay for the cable installation because there will be some flexibility in where it is positioned.

Archaeological finds at the exit positions, while possible, are less likely due to the intertidal or marine environment. If finds do exist they are unlikely to survive or be recorded because of their environs. The impact of the exit point is also reduced to the diameter of the borehole, so any archaeology present at exit is not expected to cause risk to the viability of a HDD.

Regardless of which site is chosen an archaeological study will be required to ensure that any finds are known prior to final design.

The pertinent results of the searches that might impact on the feasibility of an individual HDD site are as follows:

Site 3a: Bronze Age barrow cemetery, prehistoric and medieval finds and crop marks of ditches indicate that some form of archaeological investigation will be required. The results might impact on the available position for the HDD rig and require excavation of the entry pit and anchor block prior to construction to avoid delays if there are finds.

The position of the wreck of the Hunter will need to be checked for final design of the HDD exit points.

Site 3b: Cropmarks of a possible Roman field system will need to be investigated. The results might impact on the available position for the HDD rig and require excavation of the entry pit and anchor block prior to construction.

Site 4b: The position of the undated wreck will need to be determined for final design of the HDD exit points.

Site 5: Will require a check on the position of any remaining WWII structures but is unlikely to be problematic.

Site 8: Well documented Cropmarks of a planned field system and possible settlement at the site. Investigation and advice required from specialists on the potential impact on permitting HDD works and cable installation.

Site 9: Field system and trackway will require investigation but the entry point can be positioned to avoid sensitive areas. Check of position and depth of WWII radar station and structures required before final route design.

Site 10: Finds from Neolithic, Roman and Medieval periods indicate a possible area of settlement.

Site 11: Position and depth of WWII structures will need to be surveyed to ensure they are avoided by the final HDD design. They are not expected to render the HDD infeasible.

5.2. Residential Properties

The number and proximity of permanent residences, holiday homes and holiday parks has been subjectively taken into account in the Site Assessment Table (Table 11). The primary concern for nearby residents during HDD work is increased noise levels but traffic disruption, lighting for night working, vibration and dust should also be considered. Night working can be particularly disruptive to residents and should be avoided or mitigated if possible.

5.2.1 Noise

The impact of noise tends to be reduced during works in winter periods because residents spend less time outdoors or with windows open. At 50m distance from an average HDD site the noise level is 70dB(A), equivalent to a vacuum cleaner and at 100m it is typically 60dB(A), within the range of normal conversation. However wind direction can greatly increase noise levels downwind from a site. As a rough rule of thumb residents within 100m are likely to be disrupted by the works if no noise mitigation measures are in place.

For noise mitigation attenuation fencing is commonly used and can be extremely effective when strategically placed. In urban areas with properties within 50m of the equipment sea containers are often used as noise screens. They can be stacked to increase the height but stability in high winds should be assessed.

Many of the sites will already be subjected to elevated noise levels during the holiday season and from agricultural equipment tilling and harvesting the fields. Good community relations are invaluable in managing the impact of noise on the local community; regularly discussing the nature, timing and duration of the works with residents often resolves issues before they materialise.

Of the sites reviewed, Site 13 is the most affected by the works because of the number of residences in close proximity and overlooking the works. Additionally the works are set within a natural bowl so noise will not be dispersed as readily as at other sites. Works here would require careful planning of noise screening and lighting, and night working would not be advisable.

Site 12 would require careful consultation with Pontins Holiday Village which is adjacent to the site. The holiday cabins will be more affected than a normal house because of their light construction and any works during peak holiday times could have a considerable financial impact on the business. Realistically, works would probably need to be undertaken in winter and with noise mitigation measures in place. The site could potentially be moved southwards, although the elevation would then be slightly increased.

Site 9 would have similar issues to Site 12 because of the caravan park on its southern side, although there is scope to move the site northwards away from the caravans.

Adverse noise levels for local residents at all other sites are expected to be easily avoidable with standard noise mitigation methods of arranging the equipment so that noise sources are shielded from residents and acoustic panels are placed on heras fencing where shielding is absent.

5.2.2 Light

Light pollution affects similar receptors to noise pollution and is usually easily combated by careful planning of lighting, with particular attention to the height and orientation of any lighting towers.

5.2.3 Traffic

For Sites 1-7, and to a lesser extent 8-10, traffic congestion is a significant problem over holiday periods. The level of traffic movements generated by the HDD works will not be significant relative to other traffic but there is a risk that they might be perceived as adding to local congestion. From the contractor’s view, work during the summer holiday period is best avoided as any mobilisation, deliveries and crew travel will potentially be disrupted.

5.3. Land Ownership

Negotiation of access to sites is an import logistical consideration that is outside the scope and expertise of this report. Some locations will require access through a number of land parcels, but in any case this will be required for the land cabling route. For this report there has been no attempt to prioritise sites based on the likelihood of obtaining landowner access agreements.

5.4. Unexploded Ordnance

Regional Unexploded Bomb county maps by Zetica indicate that Sites 8-13 are in areas of moderate risk, being either side of Lowestoft which is marked as high risk primarily due to the 528 high explosive bombs that were dropped on the Lowestoft Borough during WWII.

Heritage mapping, Liddiard & Sims (2014) and Albone et al (2007), reveals that there were numerous military installations in the vicinity of Sites 8-13. These include:

- Hopton Radar Station at Site 9
- Bombing decoy site at Site 10
- Military strongpoint with practice trenches and firing range at Site 11
- Pakefield Radar Station (near Site 12)
- Defence batteries with 2 x 6” guns at Kessingland & Pakefield (in vicinity of Site 12 & 13)

A summary of the search results from Heritage Mapping is given in Appendix D.

The Zetica mapping for Norfolk does not give an assessment for Sites 1-7. However interactive mapping from Norfolk Heritage Explorer Mapping shows that military emplacements and training existed along this stretch of coastline. Sites 1, 2, 3a, 3b, 4a, 4b, 5, 6, and 7 had military uses indicated as being within100m or above the potential HDD routes.

Prior to any ground investigations or HDD construction Sites 1-7 will require an initial UXO desk study to assess the risk and inform whether UXO site investigations are required.

It is expected that Sites 8-13 will require a detailed UXO desk study, UXO detection during any ground investigations and possibly UXO detention prior to entry site construction.

6. CONSTRUCTION LOGISTICS

6.1. Easement Widths

The HDD Site Assessment Table (Table 11) summarises the restrictions on working width along the potential HDD routes. The location of the restrictions are indicated by E for entry site, S for restrictions at the shoreline, and O for restrictions offshore.

Narrow widths offshore will be the most limiting factor for the number of HDD's that can be landed at a single site. This study assumes 20m separation between a pair of ducts and 50m spacing between adjacent pairs of ducts. It might be possible to reduce the distance between the exit points, for example the Western Link landfalls used 10m separation at exit in 3m water depth, but the final separation distance will be driven by the offshore installation methods.

At the entry point a minimum horizontal separation of 5m has been assumed. If there are easement restrictions at the shoreline it is assumed that the HDD's will be a minimum of 10m apart. Figure 12 below shows the conceptual arrangement in plan view.

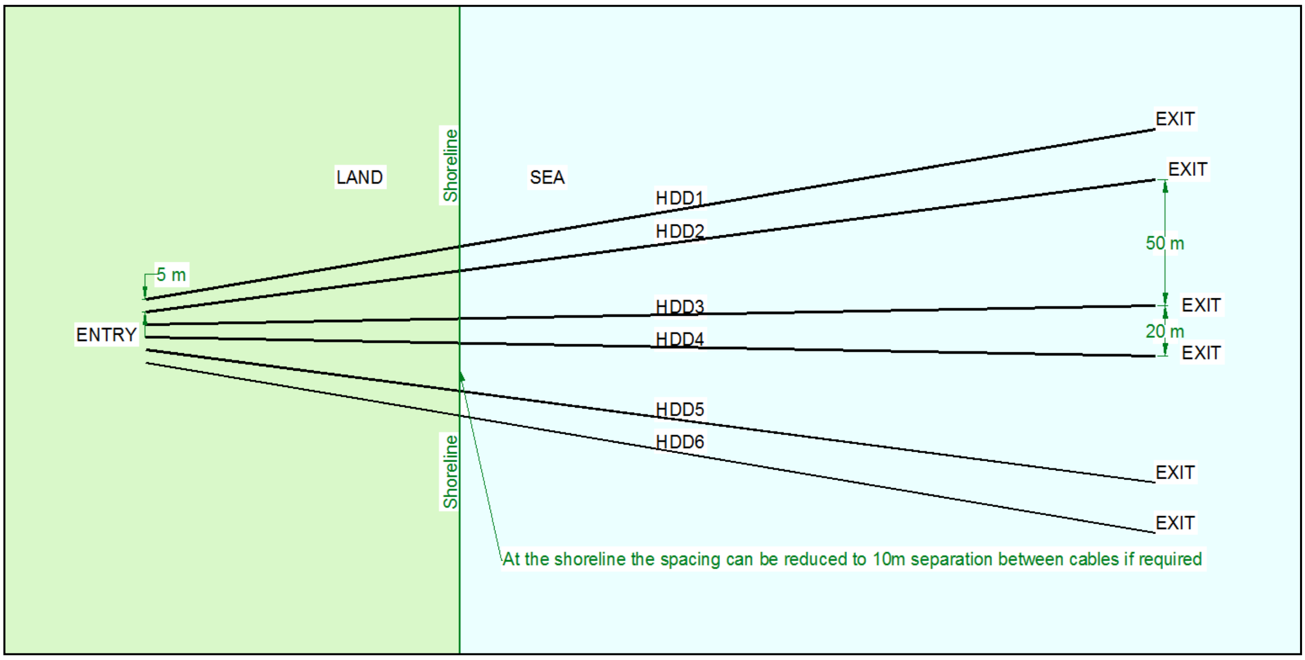


Figure 12. Plan of conceptual fanned arrangement for HDD's with horizontal separation between ducts indicated.

6.2. Access to Entry Site

All of the potential sites have sufficient room for establishing an entry site and suitable access from the nearest main road. Sites 1, 2, and 8-13 benefit from being closest to regular HGV routes but all sites are accessible for the expected size of HDD equipment.

The Site Assessment Table (Table 11) summarises the key aspects of access to individual sites. Sites 4a and 4b have the lowest overall ranking because of considerable lengths of single lane roads leading to the site. These single lane sections will require traffic management during mobilisation and demobilisation of the HDD equipment. They are probably acceptable for HDD equipment weights and widths because they are used by agricultural equipment including combine harvesters. However routes should be checked prior to any firm commitment to using a site.

6.3. Access to the Beach

Access to the beach is an important consideration for the option of a short HDD exiting near the Mean Low Water level (MLW) to enable connection works for duct installation. A tracked excavator is typically used for the work, although in suitable locations tractors and 4WD vehicles can also be brought onto the beach to assist with equipment transport.

At the time of the site visit the beach access conditions were as follows:

Site 1: Ramped access to beach 350m north of the alignment. If works are during an erosive cycle there is a chance of needing temporary ramps made from in situ sediment to negotiate over two wooden groynes.

Site 2: Ramped access to beach 600m north of the alignment. A temporary ramp over wooden ramparts made from in situ sands might be required for the access.

Site 3a: Ramped access at Happisburgh (liable to erosion but anticipated to be maintained). The beach is clear of sea defences. Alternatively there might be direct access over the dunes along the drill alignment.

Site 3b: Cart Gap ramp adjacent to the drill alignment.

Site 4a, 4b: North Gap ramp with clear access along the beach.

Site 5: Sea Palling ramp with clear access along the beach.

Site 6: Existing track over the dunes used for sea defence construction equipment

Site 7: Horsey Gap beach access adjacent to the drill alignment.

Site 8: Ramp at Marine Parade, Gorleston, 800m north of the alignment. There might need to be temporary ramps over a number of wooden groynes if works are during an erosive phase.

Site 9: Difficult unless the Environment Agency allow temporary removal of a section of timber ramparts. A ramp is visible on aerial photographs at Broadland Sands Holiday Park, 150m south of the alignment. To access the low tide area any machinery or equipment would need to traverse the timber rampart currently at mid tide level (see Figure 50 and Figure 51 in Appendix G).

Site 10: Difficult unless the Environment Agency allow temporary removal of a section of timber ramparts. Broadland Sands Holiday Park ramp 700m north. To access low tide area any machinery or equipment would need to traverse the timber rampart currently at mid tide level. (See Figure 54 in Appendix G).

Site 11: Ramp at All Saints Road, Pakefield 1.2km north of HDD alignment. Approximately 50% of the beach distance is accessible at high tide.

Site 12: Ramp at All Saints Road, Pakefield 2.0km north or ramp at Kessingland, 2.7km south of alignment. Sections of the beach are not accessible at high tide.

Site 13: Ramp at Kessingland, 1.2km south of alignment; clear beach between with sands above high tide level.

It can be seen that Sites 9 and 10 are very difficult for beach access. The short option HDD at these location should not be considered unless access has been agreed for the ramp at Broadland Sands Holiday Park and the Environment Agency have agreed to temporary removal of sections of the timber rampart to gain access to the low tide area. An alternative access option would be to use a marine landing craft.

Sites 2, 8, 11, 12, 13 have suitable access but might require temporary works to negotiate sea defences along the beach.

Sites 1 and 3 – 7 all have straightforward beach access for the short HDD option.

6.4. Water Supply

The Site Assessment Table (Table 11) summarises the probable water sources for each site. The greatest rate of water usage on site will be during the forward reaming stages. An approximate figure for water consumption over a 10 hour shift of reaming is 40m^3 (40,000 litres) based on 12m^3 of new hole cut per shift, pumping at 1000 lpm with 2% cuttings carrying capacity and 5% losses.

The required water volume of 40m^3 per shift could easily be supplied from an external source using a tractor towing a medium sized bowser (11,000 litres). Similar projects have used on site water storage in addition to the drilling fluid system; 10 m^3 – 20m^3 storage is typical to ensure drilling progress is not interrupted. All of the sites have access to a hydrant location within 3km of site and water supply is not, therefore, a critical factor in selection of the HDD site.

The impact of any tractor and bowser movements for water supply should be included when considering the impact of traffic movements and in traffic management plans.

6.5. Overhead Lines

A number of sites might need management of crossing points beneath overhead lines (“goal Posts “ etc. The following sites have been identified as requiring consideration of overhead lines but at no site are they considered as being significant to site selection:

- Site 1 – Beside access to Anglian Water pumping station
- Site 3a - Rollesby Way
- Site 3b - Cart Gap Road, and entry site
- Site 4a - Beach Road and Access through field from Beach Road
- Site 4b – Turning into Castle Farm
- Site 5 – Access track turning from Waxham Road
- Site 11 – Track from A12

6.6. Buried Services

No buried services searches have been conducted for the sites. Most of the sites are within agricultural fields and any buried services are likely to be running parallel to the coast and should not impact the suitability of any of the sites.

On the site visit to Site 2 unlabelled markers and air bleed valves for a pipeline were noted, possibly for the farm irrigation system.

Pumping stations, presumably for the sewer, were noted near Sites 1, 4b and 10. The sewer network is expected to run parallel to the coast at Site 1; its location and depth will need to be determined for any final design but is highly unlikely to require any change to the initial HDD design profile.

6.7. Field Conditions, Drains and Gates

The site visit was conducted after a winter period of average rainfall but most of the fields were quite well drained at Sites 1-7 due to the generally sandy soil. Standard construction methods of either bog mats or geotextile covered with stone or suitable fill will probably be suitable for access through fields. For the entry site geotextile covered with stone or suitable fill is preferable as a working area.

The soils at Sites 8-12 are heavier than the northern sites but are still suited to access and HDD sites using the methods for Sites 1-7.

Site 13 would be the most difficult; the ground was very heavy at the time of the site visit with standing water in the ploughed furrows of the clayey soil. However it is within the normal range of ground conditions encountered on a typical pipeline or cabling route.

At a number of the sites there might be a need to upgrade culverts and widen gates for entry to fields from main roads. Sites 8-10 will probably require consultation with the Highways Agency to enable access from the A12.The remaining sites will need to consult with the relevant local councils.

7. RANKING OF SITES

The HDD sites have been compared by compiling all of the sites and their characteristics into a Site Assessment Table, Table 11 on the following page. An initial subjective ranking of sites by the author was then reviewed against a matrix based ranking.

The matrix was constructed from the Site Assessment Table. Each of the cells in the spreadsheet is assigned a value based on their colour. Green = 1, Yellow = 2, Orange = 3, Brown = 3.5, and Red = 4.

A weighting was given to each of the assessment criteria in the Site Assessment Table. The most heavily weighted criteria are Elevation, Geology, and Land Environmental Designations. The matrix with weightings and scores is shown in Appendix E.

The results of the matrix and subjective ranking methods are shown below in Table 10. The results confirm that the top three sites are Sites 1, 3a and 3b. For the remainder of this study Sites 1 and 3a will be examined in more detail. Site 3b can be considered as a composite of Sites 1 and 3a. The geometry in plan view of any HDD design at Site 3b will be similar to that for Site 1; both have a 50m easement near the shoreline. The vertical (sectional) geometry of a design for 3b will be similar to 3a because of similar geology at the sites.

Sites 3a and 3b could easily change position depending on the weighting of criteria. Site 3a will require a longer access track – but this might be required for the onward installation of the cabling anyway. Another disadvantage of 3a is that the short option is complicated by the timber sea defence parallel to the beach near the low tide mark, however these are timber construction and dilapidated. Site 3b potentially has more archaeological problems. Site 3b also has a narrow easement that will limit the number of HDD's relative to Site 3a.

The Tier 2 sites were similar for both ranking methods although Site 2 is ranked three places higher by the matrix and Site 5 is ranked four places lower. The subjective ranking has also removed Site 6 for consideration because of environmental concerns.

MATRIX - ALL CRITERIA WEIGHTED		
RANK	SITE	SCORE
#1	1	31
#2	3a	35
#3	3b	36
#4	4a	40
#5 (=)	2	41
#5 (=)	11	41
#7 (=)	4b	42
#7 (=)	8	42
#9	6	43
#10	10	45
#11 (=)	5	46
#11 (=)	9	46
#13	12	48
#14	7	49
#15	13	54

AUTHOR'S SUBJECTIVE RANKING		
RANK	SITE	TIER
#1	1	Tier 1: Suitable for HDD
#2	3a	
#3	3b	
#4	4a	Tier 2: Suitable for HDD with some mitigation measures.
#5	4b	
#6	11	
#7	5	Tier 3: Potential for Significant Risks to HDD completion. Investigation and mitigation required.
#8	2	
#9	8	
#10	9	
#11	10	
#12	12	
#13	13	
#14	6	Tier 4: Not suitable for HDD
#15	7	

Table 10. Results of matrix and subjective evaluation of suitability of sites for HDD

SITE	DIMENSIONAL CONSIDERATIONS					GEOTECHNICAL		ENVIRONMENTAL						ANTHROPOGENIC					CONSTRUCTION LOGISTICS				
	Elevation at likely Entry point	Available Rig Site Area	Easement Width Restrictn	Calculated HDD LENGTH for shoreline position in 2055		Geology	Groundwater	Environmental Designations - Land	Environmental Designations - Marine	Flood Risk from Rivers and Sea	Coastal Defences	Predicted 50 year shoreline change	Shoreline Management Plan	Offshore or Neashore Obstacles	Archaeology	Residences within 100m of Entry site	Residences possibly visible from Entry	UXO	Access Summary	Roads - Single Lane Length	New Access Track Length	Vehicle access to beach	Water Supply
No.	mODN		m	Short	Long							m	to 2055, 2105							m	m		
1	5		S-50	190	430	sandy Crag	Crag		MCZ	High, FZ3	C (SP) Sea Wal	-60	H, MR			8 P, 5H	31P. 5H		A149-8km	0	70	Ramp x 2	H
2	12		E-200	330	540	Crag & Chalk	Crag & Chalk		MCZ	None	SP Sea Wall	-160	MR, MR	Chalk reefs?		6P	29P		A149-8km	1400	140	Ramp Walco	H
3a	7		E-150, S-10	180	480	Crag w gravel	Crag			Very Low	T 100m offshr	-90	MR/H, MR/(H)	Wreck	B, M, wreck	3P	3P, 10H		A149-10km	800	300	Ramp x 2	H
3b	5		E,S-50	190	490	Crag w gravel	Crag	CWS adj.		Very Low	C Sea Wall	-100	H, (H)		R, field system	4P, 9H	8P, 28H		A149-10km	900	50	Ramp x 2	H
4a	3		E-50	120	410	Sand & Gravel	Crag	CWS		Low, FZ3	T Groynes	-15	H, (H)	Rock reef		4P, 7H	7P,7H		A149-7km	2000	350	Ramp	H
4b	4		O-200	160	410	Sand & Gravel	Crag	CWS		Very Low	R 250m offshr	-15	H, (H)	Reef, wreck	wreck	1P	6P,1H		A149-8km	3000	60	Ramp	E
5	1		O-100	250	500	Blowing Sand	Crag	AONB adj		Low, FZ3	R 280m offshr	-25	H, (H)		WWII	2H	43P, 11H		A149-9km	340	80	Ramp	H/E
6	4		E-150	280	520	Peat, S & G	Peat	AONB		Low, FZ3	R Sea wall	-35	H, (H)			0	1P		A149-13km	280	0	Dune track	E
7	0		E-50	240	630	Peat, S & G	Peat	SSSI, SPA, SAC,	AONB, NP adj.	Low, FZ3	C Sea Wall	0	H, (H)	Ness		0	0		A149-11km	340	30	Dune track	E
8	12		E-80	490	580	Sand, S&G Crag	Crag		ISPA	None	T Sea Wall	-80	NAI, NAI	Wreck?	R crop&settle	3P	7P,7H		A12 direct	0	350-650	Ramp	H/S
9	12		E-200	500	620	Sand, S&G Crag	Crag		ISPA	None	SP,C Sea Wall	-60	MR, MR		W radar stn	1P, 15H	4P, 30H	Radar Stn	A12 - 2km	0	40-300	Difficult	H/E
10	16		E-250	190	280	Sand, S&G Crag	Crag		ISPA	None	SP,C Sea Wall	-90	MR, MR		N,R,M finds	1P, 5H	20P, 42H	Bomb Decoy	A12 - 2.2km	0	130	Difficult	H/E
11	12		E-80	190	370	Sand, S&G Crag	Crag		ISPA	None	None	-65	NAI, NAI	Shoals, cables	W structures	0	40P, 21H	Military Camp	A12 direct	0	200-370	1.2km N	H/E
12	15		E-120	200	410	Sand, S&G Crag	Crag	SSSI	ISPA	None	None	-50	NAI, NAI	Shoals, cables		0	4P, 40+H	Radar Stn	A12 direct	0	450	2.0km N	H/E
13	15		E,S-60	440	1390	Sand, S&G Crag	Crag	SSSI	ISPA	None	None	-25	NAI, NAI	Shoals, cables		16P	46P	nr Battery	A12 direct	0	450-650	2.7km S	H
NOTES			E=Entry S=Shore O=Off-shore	HDD Exiting at LAT	HDD Exiting at -3m rel. LAT	Dominant lith for drill		adj. Indicates adjacent to HDD route		FZ = Flood Zone	C=Concrete SP=Sheet Pile T=Timber R=Rock	Black = SMP pred Green = hypothetical	Bracket indicates provisional		N=Neolithic B=Bronze Age R=Roman M=Medieval W=WWII	P = Permanent H = Holiday Residences	Within 400m range					Highlighted yellow liable to erosion	H = Hydrant S=natural Source E=External
ABBREVIATIONS		AONB	Area of Outsatnding Natural Beauty				LAT	Lowest Astronomical Tide			NR	Nature Reserve			ODN	Ordnance Datum Newlyn			SSSI	Site of Special Scientific Interest			
		CWS	County Wildlife Sites				MCZ	Marine Conservation Zone			NP	National Park			SAC	Special Area of Conservation			SPA	Special Protection Area			
KEY	2-4	Ample	Good	<200	<400	Good	Good	Low risk	Low risk	None	Low risk	>= 0	Low risk	Low risk	Unlikely	Low risk	Low risk	UXO unlikley	Low risk	Low risk	Low cost	Low risk	Low cost
KEY	4-6	Constraint	Acceptabl	200-299	400-599	Fair	Fair	Caution	Caution	Very Low	Caution	0 to -50	Caution	Caution	Minor	Caution	Caution	UXO possible	Caution	Caution	Low-med	Caution	Low-med
KEY	6-8, <2	Difficult	Caution	300-399	600-799	Caution	Caution	Problematic	Problematic	Low	Problematic	-50 to -10	Problematic	Problematic	Possible	Problemati	Problemati	UXO prob rqd	Problemati	Problemati	Med cost	Problemati	Med cost
KEY	>8	Insufficien	Too narro	>400	>800	Difficult	Difficult	Avoid	Avoid	High	Avoid	> -100	Avoid	Avoid	High	Avoid	Avoid	UXO rqd	Avoid	Avoid	High cost	Avoid	High cost

Table 11. Site Assessment Table compiling judgement criteria for all sites.

8. OUTLINE HDD METHODOLOGY

The conceptual HDD designs are relatively straightforward HDD landfalls with the ground expected to be mostly medium dense sand at both Site 1 and Site 3a. The following methodology outlines the most commonly used techniques for this type of HDD however tenderers might suggest variations or alternative methods for some aspects of the HDD.

8.1. Site Setup

Prior to arrival of HDD equipment the vehicle access, drilling pad and working area at the entry site will be prepared. Any uneven ground should be made level and access should be suitable for the haulage equipment. Topsoil should be removed and stockpiled for reinstatement after completion of the works. If necessary, the access track will be upgraded with bog mats or geotextile and hard standing material.

Any drainage work required to make the site safe for working and to prevent environmental damage through contaminated runoff should be complete.

All services, below ground and above, should be located and protected from damage or isolated as needed.

A water supply of suitable quality and flow rate will be used for mixing drilling fluid. This will probably come from the nearest mains water supply hydrant point.

A traffic management plan and haulage route for heavy equipment should be implemented prior to arrival of equipment.

The entry point should be accurately surveyed and clearly marked, as should a number of alignment pegs for positioning of the rig and points for any surface tracking cable, if used.

An anchor block or sheet piling will be required at the front of the rig to ensure stability when drilling and installing the duct. Anchor blocks are typically 4m x 2m x 2m depth poured concrete blocks with steel I beams set in them to allow connection to the front foot plate of the HDD rig. Sheet piles are usually 4m or longer across a 3-4m width with I beams welded or bolted to the top for connection to the HDD rig.

Personnel on the drill site should wear standard PPE including safety boots and hard hats. Personnel working on the rig will need gloves for manual handling and appropriate eye protection when welding, grinding, etc. The mud man on the drilling fluid mixing unit will need to wear appropriate hand and eye protection and dust masks when handling powdered bentonite and additives and complete PPE with coveralls if caustic soda is used to adjust the fluid pH.

Prior to commencement of drilling barrier mesh should be placed around any open excavations and measures taken to prevent public access to the site. High pressure hoses from the mud pumps should have appropriate safety lanyards. Personnel should hold the relevant permits and licences for any plant and equipment they are operating.

An indicative site layout for the HDD works is shown in Drawing No’s. 20151001RA-C/03 and 20151001RA-C/04 (Appendix G).

During the works nearby residences might experience elevated noise levels. Prior to work commencement background noise levels should be monitored and then ongoing monitoring carried out during the works. The HDD contractor's equipment is usually contained within soundproofing containers, however the contractor will need to ensure that noise levels will not cause nuisance, particularly at night if working 24hrs. Strategically placed noise attenuating barriers can be used to mitigate noise levels; in extreme cases these might take the form of stacked shipping containers along a site boundary.

Figure 13. Example HDD rig of similar size to that required for the HDD's.

If there are residences nearby the lighting for any 24hr working should be designed to minimise nuisance. Lighting arrangements might also need to be discussed with relevant marine shipping authorities.

8.2. Casing

If the initial section of ground to be drilled is loose or very soft it might need to be cased. The most cost efficient method is likely to be large diameter steel casing usually supplied in 12m lengths and welded to create lengths up to 30m or 40m. The casing will need to be a larger diameter than the final ream size and in this case might need to be 30" (760mm) diameter. After duct installation the casing can be removed, generally by being pulled out by the drilling rig.

Alternatives to casing are pre-treatment using soil mixing or grout injection to strengthen any weak ground. Pre treatment requires good access above the areas to be treated and usually involves a significant additional cost.

8.3. Pilot Hole

Prior to drilling an entry pit is excavated; generally several metres square and 1.5m to 2.0m in depth. The entry pit has the dual purpose of containing drilling fluid returns and ensuring any buried services are exposed prior to drilling. A pump in the pit transfers fluid to the mud recycling unit.

The HDD drilling contractor is likely to use a jetting assembly and jetting bit for the downhole drilling assembly on this project (Figure 14). If they consider the presence of concretions, cobbles and boulders to be a significant risk based on ground investigations, they might opt for a jetting assembly with a tri-cone bit. A tri-cone drilling bit powered by a downhole motor (DHM) is normally only used for drilling in rock.

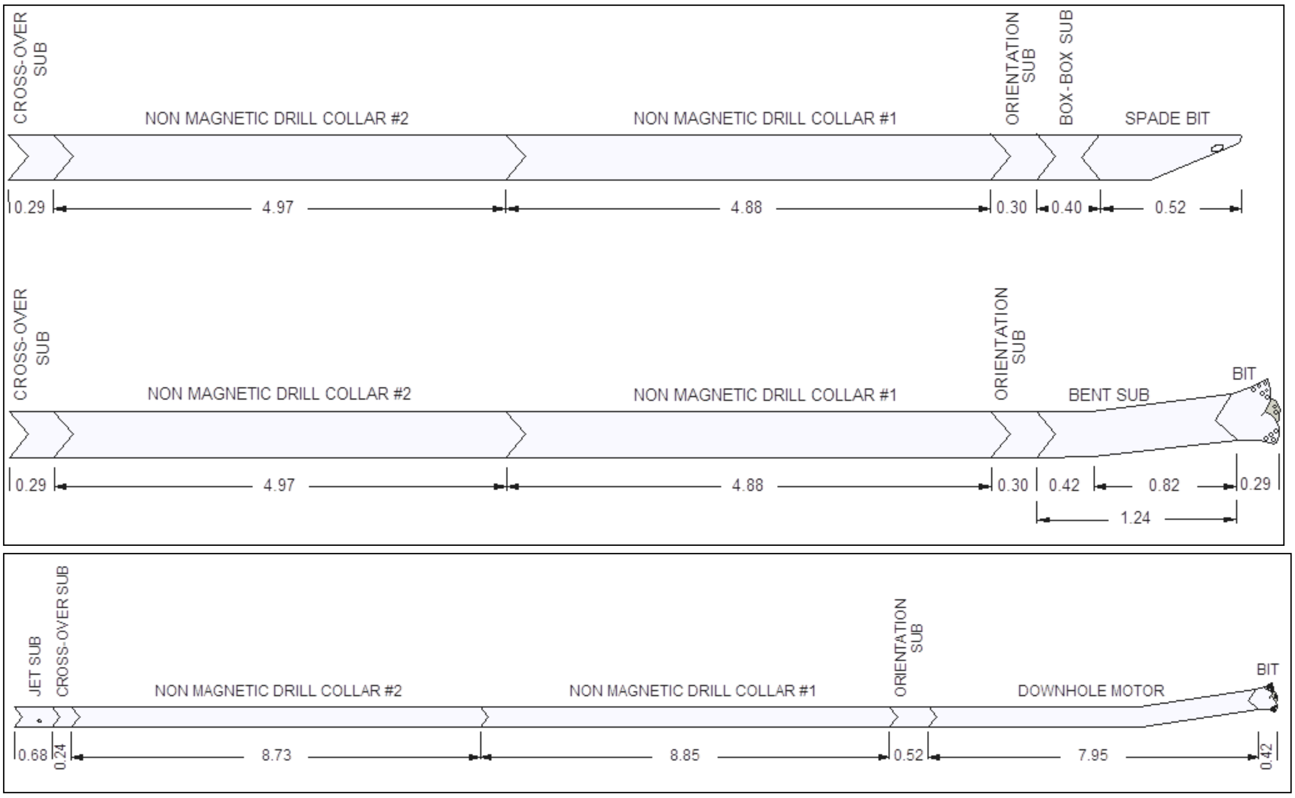


Figure 14. Example drilling assemblies; Jetting assembly with spade bit at top, jetting assembly with tri-cone bit in centre, and downhole motor assembly with tri-cone bit at bottom.

A jetting assembly uses the high pressured jets omitted from the nozzles in the bit to hydraulically excavate the ground ahead. To drill a straight section of hole the entire string of drilling rods is rotated. To drill a curved section of hole the angled shoe of the bit is oriented and then pushed forwards to steer in the required direction. In stiff clays a tri-cone bit might be used to better cut away the ground and the function of the jetted fluid is more to clear away the cuttings.

Behind the jetting assembly or DHM will be the guidance probe followed by the drilling rods. Between the components there may be various connection subs to provide connections between differing types and sizes of threads. All connections are torqued to recommended values as they are added at the drilling rig.

On occasion the drilling assembly may need to be torqued using chain tongues. This operation should only be performed by experienced personnel and all non essential personnel should stand well clear.

Behind the jetting assembly are guidance sensors that allow tracking of the borehole position during the pilot hole drilling. The sensors are connected to processing equipment at the surface by an insulated cable running through the centre of the drill rods. The guidance system will probably either be a Gyro system or a Magnetic Guidance System (MGS) with surface tracking. If an MGS is used tracking cable will be placed at points along the surface alignment of the bore to give an independent position of the HDD. On this project it is likely that the tracking cable would be extended to the low tide level but will not be required all the way to exit.

During drilling operations the drilling rods will be turning at around 60-90 rpm. All personnel should stand clear of the rotating rods. Loose clothing should be avoided for those working around the rig; high visibility vests tend to be a risk in these conditions and should be replaced with high visibility clothing or jackets.

When a drilling rod has been drilled down the rod is disconnected from the drive head. The drive head is pulled back to the top of the mast and a new drill rod is added. A wireline cable inside the drilling rods is extended and connected before the new drilling rod is torque ready for drilling down.

During the procedure of adding and removing drill rods there is potential for accidents involving pinch points and rotating equipment. Only trained and experienced rig hands should be working on the rig at these times.

Downhole positional surveys are taken at the end of each drilled rod. While a new drilling rod is added the guidance engineer plots the position of the HDD and formulates instructions for drilling the next rod so that the bore remains on course. The driller will adapt drilling forces as the rod progresses to effect efficient and stable drilling. The driller keeps a log recording the drilling parameters and any notes on ground conditions for each rod. The pilot drilling process continues until exit is reached.

On long crossings or in hard ground the drilling rig can be exerting 25 tonne or more force on the drill rods. On rare occasions the drill rods can suddenly buckle, potentially deflecting sideways and injuring bystanders. Personnel should stand well to the side of the drill rods during operation.

If the pilot drill deviates too far off course at any point the bit can be pulled back (by removing drilling rods) to a suitable point. A sidetrack off the old borehole can then be cut and the new section of hole steered onto the correct course.

8.4. Drilling Fluids

The drilling fluid serves many purposes. Its primary role is to create a gel thick enough to suspend soil and rock cuttings and carry them out of the hole. In addition the drilling fluid hydraulically excavates soil in soft ground, powers the downhole motor in hard ground, cools the drilling equipment, clears debris from the drilling bit and face, and lubricates the borehole to reduce friction on the drilling equipment.

The drilling fluid predominantly used in HDD is a mix of water and a naturally occurring swelling clay, bentonite. On occasions the chemical properties of the drilled soil or rock reduce the effectiveness of the drilling fluid. As a result additives such as natural xanthum gum and gypsum are sometimes added to improve the properties of the fluid.

Bentonite drilling fluid is non-toxic however if sufficient quantity enters a watercourse it can potentially settle on the bottom, smothering benthic flora and affecting faunal feeding and breeding sites. In saltwater environments the smothering affect is less problematic because seawater degrades the bentonite fluid causing it to flocculate, allowing faster dispersal.

Bentonite is supplied in powdered form in either 25kg bags or bulk bags. The bentonite is fed into a hopper where it is mixed with water circulated through the mixing tank. From the mixing tank the fluid is transferred to the active tank. High pressure pumps then pump the fluid downhole. The operator of the fluid system (the “mud man”) will need to wear appropriate hand and eye protection and dust masks when handling powdered bentonite and additives. If caustic soda is used to adjust the fluid pH complete PPE with coveralls should be worn.

Figure 15. A drilling fluid recycling unit with hydrocyclones and shaker screens on the upper level and active mud tank underneath. The blue bins capture cuttings as they are removed by the shaker screens. On the right is a grey transfer pump for transferring cuttings from the entry pit (foreground) to the hydrocyclones and shaker screens.

The bentonite drilling fluid is circulated down through the drill rods and back up the outside the rods in the annulus of the borehole. Exiting into the entry pit, the fluid is then pumped to the mud recycling unit (Figure 15) where hydro-cyclones and shaker screens remove cuttings. The cuttings accumulate beneath the shakers and are usually disposed of at landfill sites. The cleaned drilling fluid transfers to the active tank ready for circulation through the hole.

The mud man will keep records of drilling fluid parameters at regular intervals and monitor drilling fluid volumes so that any losses to the formation are identified. The driller will monitor and record downhole fluid pressures and returns to the entry pit to also ensure that any losses are recognised quickly.

During pilot hole drilling the use of a Pressure While Drilling (PWD) tool is recommended to reduce the risk of breakout, formation damage, and equipment becoming stuck because of inadequate hole cleaning. A PWD tool is located with the downhole surveying assembly behind the downhole motor and measures the annular pressure in the borehole; the pressure of the drilling fluid flowing between the outside of the drill rods and the borehole wall. It is a standard add-on module for Gyro and MWD guidance systems. It is particularly useful in giving early warning of any swelling clays restricting the annulus of the borehole allowing mitigation measures to be implemented quickly.

8.5. Reaming

Once the pilot hole is completed the bit, jetting sub and steering equipment is removed. For landfall projects the pilot hole is usually stopped short of the exit point, perhaps 30m to 40m short for the long HDD's, so that drilling fluid returns are not lost to the sea. The pilot hole is then enlarged using forward reaming; the reamer / hole opener being advanced from entry towards exit. The drilling fluid is pumped down through the drilling rods onto the cutting face of the reamer and then carries the cuttings back up the hole to the entry pit. From the entry pit the fluid is passed through the recycling unit to remove the cuttings before being pumped downhole again.

The safety precautions for pilot hole drilling apply to reaming operations; keeping personnel clear of the drill rods during operations, and only trained personnel on the rig. If chain tongues are used they should only be operated by experienced personnel and all non essential personnel should stand well clear.

The HDD will require several reaming passes with progressively larger diameter reamers until the final hole size is reached. A final decision on the diameter and number of reaming stages is usually made by the drilling contractor once ground conditions have been evaluated from drilling the pilot hole. A possible configuration for this project would be a 12.25" (311mm) pilot hole with reaming stages of 18" and 26" (457mm, 660mm).

To ensure the forward reaming follows the pilot hole, one or more rods and a rounded "bullnose" is usually placed in front of the reamer or hole opener. For the larger diameter reams a front centraliser is often used to ensure that the reamer cuts evenly, and a rear centraliser is often used to ensure evenly distributed force on the reamer or hole opener.

There are a variety of types of reamers and hole openers designed for different ground conditions. For the clayey conditions a flycutter (Figure 16) is likely to be used. For sandy ground, particularly loose sands, barrel reamers are often used (Figure 17) although for forward reaming a flycutter might be judged more suitable in denser sands.

Figure 16. Typical flycutter hole opener

Figure 17. Typical Barrel Reamer

Once the forward reaming is complete to the end of the pilot hole, the pilot hole is then extended to the exit point. At this stage the hydrostatic head of drilling fluid will be lost into the sea. The remainder of the pilot hole is then opened up to the final diameter using conventional (pull) reaming. The reamer is attached at the exit point and pulled towards the entry point. Drilling fluids are pumped from the HDD rig through the drilling rods to the reamer where they remove the cuttings and flow into the sea.

On some landfall HDD's a proprietary drilling fluid called Purebore is used for the conventional reaming. Purebore is CEFAS registered and biodegradable. In environments with strong water currents and sediment loading the release of bentonite fluid might not be of environmental significance because it is a naturally occurring clay and breaks down (flocculates) in saline water.

Studies for the HDD's in the Solent, Hampshire, indicated that the likely plume from the HDD's was insignificant compared to the natural sediment flows from the nearby Beaulieu River.

8.6. Duct Installation

It is likely that the ducts will be floated into position at the exit point, flooded with water, and then pulled into the reamed borehole for installation (commonly termed "pullback"). The ducting can either be fabricated as a single piece (by Pipelife in Norway) and towed to a mooring position nearby awaiting installation, or it can be fabricated at a nearby convenient location by butt fusion welding 12m or 18m lengths to form the duct. This can then be towed to the exit position as required. A typical setup for butt fusion welding of PE pipe is shown in Figure 18.

Prior to installation a cleaning run is preformed with a reamer of slightly smaller diameter than the final hole size, in the case of a 26" reamed hole a 24" reamer would normally be pulled through.

The duct will be prepared for installation by attaching a pulling head (Figure 19) and the duct is then ballasted by filling the duct with water to reduce its buoyancy.

The pulling assembly will consist of the drill rods connected to a reamer of slightly larger diameter than the pipeline. Connected to the reamer is a swivel of adequate strength for the expected pullback forces. When the pulling assembly is torqued to the drill rods the pulling head of the pipeline is bolted to the swivel and pullback can begin.

Pullback proceeds by pulling back and removing a drilling rod then connecting onto the next drill rod and repeating. A typical installation rate for pullback is 100m per hour. During pullback the driller will monitor pulling forces to ensure the maximum allowable pulling force for the pipeline is not exceeded.

During pullback the ducts will displace bentonite fluid from the borehole. In the case of Site 1 and Site 3a the entry point is approximately 5m - 8m above sea level so most of the displaced fluid will flow out into the sea at the exit point. Detail on the expected volumes of fluid losses are given in Section 12.2.

When the pulling assembly reaches the drilling rig it will be disconnected and removed. If there is significant elevation difference between entry and exit one end of the pipeline might need to be secured to ensure the pipeline does not slip down slope in the hole. The duct is normally secured for 12 hours after installation to keep it in position during recovery of stretch in the HDPE.

Figure 18. Typical setup of PE butt fusion welder

Figure 19. Drilling rod, swivel, pulling head and duct being pulled into the entry pit

8.7. Marine Support Works

If the exit point is located below the low water mark the operations at exit side will entail offshore works. This will affect the conventional reaming of the final section of the HDD and the duct installation operations. The approach taken to the offshore works varies between contractors and their preferred method of working will depend on their previous experiences.

The HDD typically exits within a tolerance of 1-2m laterally and 5m longitudinally of the planned exit point.

On previous landfalls a range of methods have been used from large scale grounded barges to smaller scale legged or jack-up barges that eliminate the need for divers. At the small scale end are workboats with divers used to retrieve and connect equipment. In shallow water (<5m) with fair visibility divers are unlikely to be required. The drilling bit will probably extend close to or above the water as it exits and can be brought onto a barge or workboat with a crane or other lifting equipment to allow disconnection and connection of reamers and pulling heads.

Figure 20. Large barge with four point anchoring and workboat. On the right hand side of the barge the duct can be seen being pulled into the HDD. The water depth is approximately 4m.

9. CONCEPTUAL DESIGN & CALCULATIONS

Two conceptual sectional designs have been drawn for each location, a short HDD exiting above the level of Mean Low Water Spring (MLWS) and a long HDD design exiting at approximately -3.0m LAT (-5.5m ODN). The short option is designed to exit on the beach to eliminate any offshore works for the HDD other than towing the duct to position for installation. The long option is designed to be in sufficient water depth to allow recovery of the drilling equipment at exit from either a barge, shallow draught jack-up vessel, or a workboat with divers.

The conceptual designs are shown on Drawing No.'s 20151001RA-C/01 and 20151001RA-C/02 in Appendix G.

The conceptual designs are based on low accuracy land elevations and seafloor bathymetry. The land elevations are interpolated from 5m contours and nearby spot heights on OS Explorer Mapping. The bathymetry is taken from sonar soundings on Navionics Charts. Further design work will require improved accuracy levels. Lidar data or topographical surveys will be required for the chosen land and beach sites. A bathymetric survey will be required for the near shore / offshore areas.

The final exit points will need to account for a number of factors including consideration of working limits for marine installation techniques, surveyed bathymetry, predicted changes in seafloor bathymetry in the longer term and the existing depth of loose sediment at the exit point.

The depth of sediment at the exit point needs to balance the requirements for marine installation techniques and minimising the risk of increased duct installation forces due to loose sediment being dragged into the borehole during installation. Ideally the vertical thickness of loose sediment at exit should be less than 4m; however previous landfalls have been installed without incident through 8m thickness of loose sand and cobble.

9.1. Conceptual Design for Site 1

The key factors influencing the designs at Site 1 are the 50m easement width at the shoreline (plan view), the depth of the foundations and sheet piling for the sea defences, the site elevation, bathymetry, and the predicted position of the future shoreline.

9.1.1 Short HDD

In plan view 6 No. of short HDD's are possible, fanning out from 5m separation at entry to 10m separation at exit on the beach. The position of the beach exit will need to be adjusted when accurate topographical information becomes available.

The entry position of the short HDD's is set further back than the long HDD to permit a geometry that allows them to pass beneath the sea defences and exit on the beach.

In section view the entry and exit angles are set at 15 degrees. Ideally the exit angle should be lower to reduce cable pull, however the 15 degrees is required to ensure adequate depth beneath sea defences and a short exit above the level of MLWS. When definitive information for the depth of the sea defences and topography becomes available there might be opportunity to reduce the exit angle.

The entry angle could be reduced, however the entry point would need to move further from the shore, increasing the overall length of the HDD. Any final design will need to balance reductions in cable installation stresses against increased HDD length and therefore cost.

The radius of the HDD has been set at 300m which is within the tolerances of the proposed duct and capabilities of the drilling equipment. A lower radius could potentially be used but would need to be assessed against any increase in cable installation stresses.

The design has an indicative clearance of 3.41m below the postulated toe of the sheet pile, there is scope to reduce this distance and optimise the design when more accurate information becomes available.

9.1.2 Long HDD

In plan view 4 No. of long HDD’s are possible at Site 1. The HDD’s fan out from 5m separation at entry to duct pairs separated by 20m between their twin and 50m to the next pair of ducts. Changes to the distances between the ducts will potentially affect the number of HDD’s that could be drilled at the site.

In section view the entry angle is set at 15 degrees and exit angle at 10 degrees to reduce cable pull. If ground conditions are suitable the exit angle might be reduced slightly, but benefits in reduced cable installation stresses will need to be balanced against risk of early bentonite breakout and hole opening methods.

The entry angle could be reduced, however the entry point would need to move further from the shore, increasing the overall length of the HDD. Any final design will need to balance reductions in cable installation stresses against increased HDD length and therefore cost.

The radius of the HDD has been set at 300m which is within the tolerances of the proposed duct and capabilities of the drilling equipment. A greater radius could be used at the exit but it will reduce the depth of cover and the associated risks will need to be assessed against any benefits for cable installation.

The design has a clearance of 3.71m below the postulated toe of the sheet pile, there is scope to reduce this distance and optimise the design when more accurate information becomes available.

The average depth of cover beneath the seafloor is approximately 12.8m. On similar projects hydraulic fracture modelling has shown this to be a safe distance for avoiding breakout of drilling fluid, however this should be reviewed following the results of ground investigations and sample testing.

9.2. Conceptual Design for Site 3a

The key factors influencing the designs at Site 3a are the position of sea defences and the possible depth of their foundations, site elevation, bathymetry, and the predicted position of the future shoreline.

9.2.1 Short HDD

In plan view 6 No. of short HDD’s are possible, fanning out from 5m separation at entry to 10m separation at exit on the beach. Another two to four HDD’s would be possible on the northwest side but they would require an easement beneath the adjacent field.

The position of the beach exit will need to be adjusted when more accurate topographical information becomes available. The abandoned line of sea defences appear to be beyond the level of LAT and will be an obstacle for cable laying for the short HDD option.

In section view the entry and exit angles are set at 10 degrees to minimise cable installation stresses.

The entry position of the short HDD’s is set further back than the long HDD to allow a 10 degree entry angle and also keep the entry position away from what might be bronze age burial mounds or ring ditches (see Section 10.2.7). If the archaeology is not present or not significant the entry position could be moved forward 20 metres and the entry angle increased to 15 degrees to achieve the same exit position.

An alternative alignment would be to position the entry points at the same position as those for the long HDD’s and drill in a northerly direction, exiting on the beach at a more oblique angle in plan view. The advantage in this would be that moving the entry further down the coastline lessens the exposure to coastal erosion for as long as the concrete sea wall is maintained.

The radius of the HDD has been set at 300m which is within the tolerances of the proposed duct and capabilities of the drilling equipment. A lower radius could potentially be used but would need to be assessed against any increase in cable installation stresses.

The design has an indicative clearance of 10.51m depth of cover beneath the estimated base of the coastal cliff. There is scope to reduce this distance and optimise the design when accurate survey information and additional ground investigation results becomes available.

9.2.2 Long HDD

In plan view 6 No. of long HDD’s are shown, however an additional pair of HDD’s on either side of the array could see 10 HDD’s as being possible. The outer HDD’s in the array would be approximately 30m longer than those in the centre of the array.

The HDD’s fan out from 5m separation at entry to duct pairs separated by 20m between their twin and 50m to the next pair of ducts. Changes to the distances between the ducts will potentially affect the number of HDD’s that could be drilled at the site.

In section view the entry angle is set at 15 degrees and exit angle at 10 degrees to reduce cable pull. If ground conditions are suitable this angle might be reduced, but benefits in reduced cable installation stresses will need to be balanced against risk of early bentonite breakout and hole opening methods.

The entry angle could be reduced to 10 degrees by moving the entry position 20m backwards, in line with the short HDD entry points. A reduced entry angle will not give any real added protection against future coastal erosion because at the predicted future MLWS level the two designs are in similar positions.

The radius of the HDD has been set at 300m which is within the tolerances of the proposed duct and capabilities of the drilling equipment. A greater radius could be used at entry in conjunction with a lower entry angle and entry point setback. A greater radius could be used at the exit but it will reduce the depth of cover and the associated risks will need to be assessed against any benefits for cable installation.

The design has a clearance of 4.93m below the postulated toe of the sheet piles for HDD5 and HDD6. There is scope to reduce this distance and optimise the design when more accurate information becomes available.

The average depth of cover beneath the seafloor is approximately 12.8m. On similar projects hydraulic fracture modelling has shown this to be a safe distance for avoiding breakout of drilling fluid, however this should be reviewed following ground investigations and sample testing.

9.3. Conceptual Design for Site 3b

A conceptual design has not been drawn for Site 3b, which ranked marginally lower than Site 3a in the list of feasible sites. However the designs at Site 1 and Site 3a give an indication of how a design for Site 3b would look:

Short HDD: Site 3b has a shorter length of sand exposed at low tide than Site 1. As a result any short HDD attempting to exit above the mean low water level will need to be finely tuned to have just sufficient depth beneath the foundations / sheet piles of the coastal defences to allow a beach exit. A conceptual design would be similar to that for Site 1 but moved inland 20-30m metres, passing beneath the sea defences at a higher elevation and steeper angle to allow an exit on the beach.

Because of the 50m easement width at the shoreline the number of HDD's that could be installed will probably to be limited to 4, possibly 5.

Long HDD: A long HDD at Site 3b would have a design that is a composite of the long designs for Sites 1 and 3a. In sectional view the design would be very similar to the long conceptual design for Site 3a. In plan view the design would be similar to Site 1 due to the 50m easement width and four HDD's is probably the limit of what could be installed within the easement.

9.4. Calculations

9.4.1 Drilling Forces and Rig Size

For a 540m long HDD drilled at Site 3a with 6 5/8" drill pipe the on bottom push is calculated as 19t maximum, the pull as 11.5t maximum. The limiting factor for most drilling equipment is the Torque capability; for the stated HDD the calculated torque for reaming 26" is 10kN.m. It is good practice to double the theoretical value to account for any spikes encountered in rough ground (e.g. gravel or cobbles), making 20kN.m the possible peak torque values.

The smallest HDD rig capable of the required torque would be a 70t (pull capacity) machine with 33-40kN.m torque capability. Most contractors would elect to use a 100t machine which typically has 40 kN.m torque available.

For the short HDD's the HDD rig is likely to have 19kN.m torque and therefore would be a 40t rig or larger.

9.4.2 *Installation Forces*

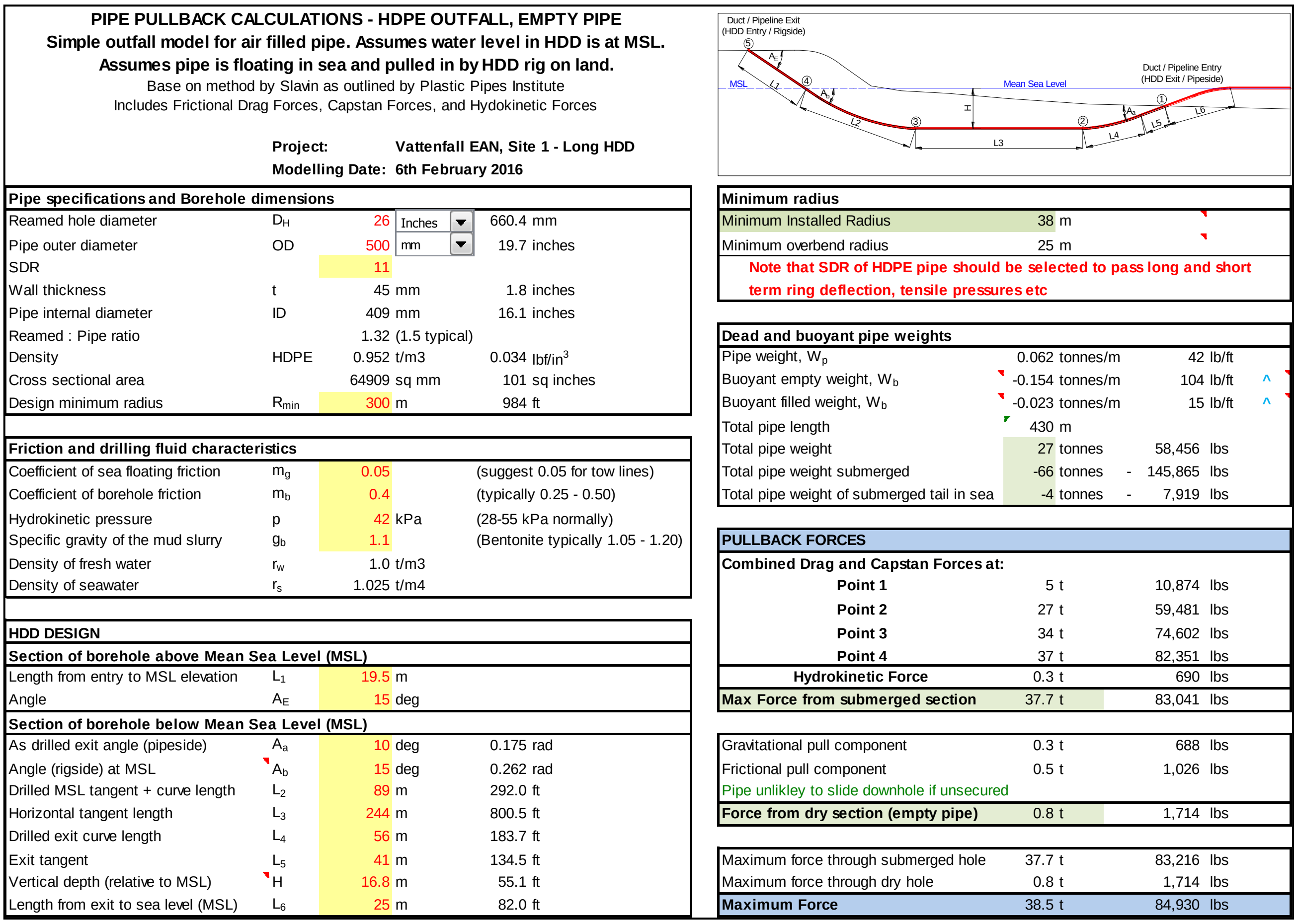
Duct installation forces have been calculated for the long and short options at Sites 1 and 3a. A summary of the results is given in Table 12 below and examples of the calculation sheet are given in Figure 21 and Figure 22.

The calculation show that the ducts should be water filled to minimise installation forces. The recommended maximum pulling force for 500mm SDR11 HDPE is 66.2 tonnes and this is well above the expected pulling force for water filled ducts.

It should be noted that a check of the suitability of the specified duct for operational forces has not been undertaken.

SUMMARY OF PULLBACK CALCULATIONS FOR HDPE 500 mm OD, SDR11, HDPE PIPELINE					
Parameter	**Units**	**Site 1 - Short**	**Site 1 - Long**	**Site 3a - Short**	**Site 3a - Long**
Pipe weight, W_p	tonnes/m	0.06	0.06	0.06	0.06
Water Filled weight, W_{pw}	tonnes/m	0.19	0.19	0.19	0.19
Buoyant air filled weight, W_{ba}	tonnes/m	-0.15	-0.15	-0.15	-0.15
Buoyant water filled weight, W_{bw}	tonnes/m	-0.02	-0.02	-0.02	-0.02
Buoyant seawater filled weight, W_{bs}	tonnes/m	-0.02	-0.02	-0.02	-0.02
Maximum Pullback Force - air filled	tonnes force	9.5	38.5	8.0	44.5
Maximum Pullback Force - water filled	tonnes force	4.1	8.6	6.3	10.9
Maximum Pullback Force - seawater filled	tonnes force	4.2	7.9	7.2	10.2
Maximum Pullback Force - open pipe	tonnes force	3.0	5.3	3.9	6.5

Table 12. Summary of calculated installation forces for long and short HDD options at Site 1 and Site 3a.



PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, EMPTY PIPE
Simple outfall model for air filled pipe. Assumes water level in HDD is at MSL.
Assumes pipe is floating in sea and pulled in by HDD rig on land.
Base on method by Slavin as outlined by Plastic Pipes Institute
Includes Frictional Drag Forces, Capstan Forces, and Hydokinetic Forces

Project: **Vattenfall EAN, Site 1 - Long HDD**
Modelling Date: **6th February 2016**

Pipe specifications and Borehole dimensions				
Reamed hole diameter	D_H	26	Inches	660.4 mm
Pipe outer diameter	OD	500	mm	19.7 inches
SDR		11		
Wall thickness	t	45	mm	1.8 inches
Pipe internal diameter	ID	409	mm	16.1 inches
Reamed : Pipe ratio		1.32	(1.5 typical)	
Density	HDPE	0.952	t/m3	0.034 lbf/in^3
Cross sectional area		64909	sq mm	101 sq inches
Design minimum radius	R_{min}	300	m	984 ft

Friction and drilling fluid characteristics				
Coefficient of sea floating friction	m_g	0.05		(suggest 0.05 for tow lines)
Coefficient of borehole friction	m_b	0.4		(typically 0.25 - 0.50)
Hydrokinetic pressure	p	42	kPa	(28-55 kPa normally)
Specific gravity of the mud slurry	g_b	1.1		(Bentonite typically 1.05 - 1.20)
Density of fresh water	r_w	1.0	t/m3	
Density of seawater	r_s	1.025	t/m4	

HDD DESIGN				
Section of borehole above Mean Sea Level (MSL)				
Length from entry to MSL elevation	L_1	19.5	m	
Angle	A_E	15	deg	
Section of borehole below Mean Sea Level (MSL)				
As drilled exit angle (pipeside)	A_a	10	deg	0.175 rad
Angle (rigside) at MSL	A_b	15	deg	0.262 rad
Drilled MSL tangent + curve length	L_2	89	m	292.0 ft
Horizontal tangent length	L_3	244	m	800.5 ft
Drilled exit curve length	L_4	56	m	183.7 ft
Exit tangent	L_5	41	m	134.5 ft
Vertical depth (relative to MSL)	H	16.8	m	55.1 ft
Length from exit to sea level (MSL)	L_6	25	m	82.0 ft

Minimum radius		
Minimum Installed Radius	38	m
Minimum overbend radius	25	m

Note that SDR of HDPE pipe should be selected to pass long and short term ring deflection, tensile pressures etc

Dead and buoyant pipe weights					
Pipe weight, W_p	0.062	tonnes/m		42	lb/ft
Buoyant empty weight, W_b	-0.154	tonnes/m		104	lb/ft ^
Buoyant filled weight, W_b	-0.023	tonnes/m		15	lb/ft ^
Total pipe length	430	m			
Total pipe weight	27	tonnes		58,456	lbs
Total pipe weight submerged	-66	tonnes	-	145,865	lbs
Total pipe weight of submerged tail in sea	-4	tonnes	-	7,919	lbs

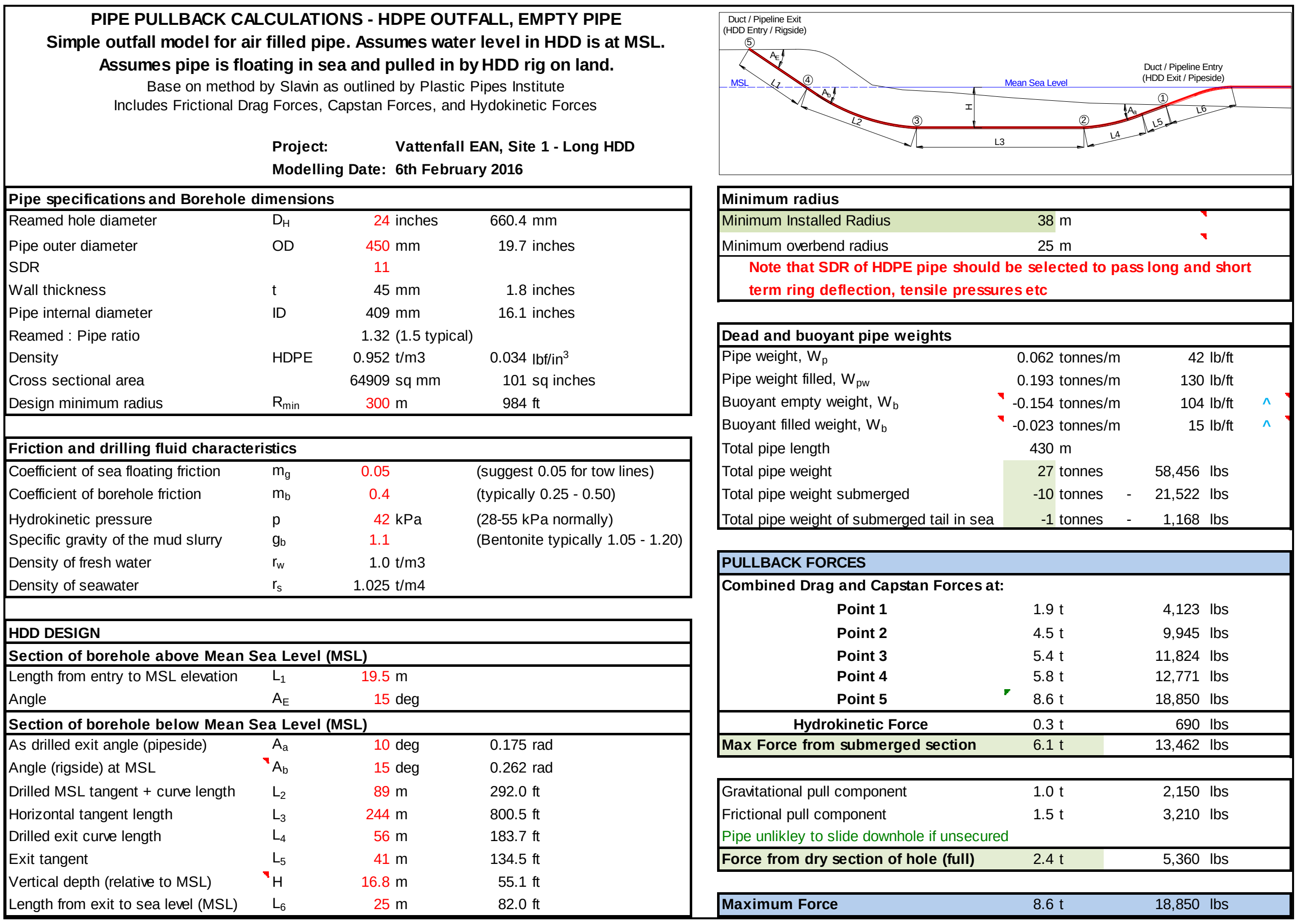
PULLBACK FORCES				
Combined Drag and Capstan Forces at:				
Point 1	5	t	10,874	lbs
Point 2	27	t	59,481	lbs
Point 3	34	t	74,602	lbs
Point 4	37	t	82,351	lbs
Hydrokinetic Force	0.3	t	690	lbs
Max Force from submerged section	37.7	t	83,041	lbs

Gravitational pull component	0.3	t	688	lbs
Frictional pull component	0.5	t	1,026	lbs

Pipe unlikley to slide downhole if unsecured

Force from dry section (empty pipe)	0.8	t	1,714	lbs
Maximum force through submerged hole	37.7	t	83,216	lbs
Maximum force through dry hole	0.8	t	1,714	lbs
Maximum Force	38.5	t	84,930	lbs

Figure 21. Example calculations for air filled duct installed at Site 1 Long HDD.



PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, EMPTY PIPE
Simple outfall model for air filled pipe. Assumes water level in HDD is at MSL.
Assumes pipe is floating in sea and pulled in by HDD rig on land.
Base on method by Slavin as outlined by Plastic Pipes Institute
Includes Frictional Drag Forces, Capstan Forces, and Hydokinetic Forces

Project: **Vattenfall EAN, Site 1 - Long HDD**
Modelling Date: **6th February 2016**

Pipe specifications and Borehole dimensions					
Reamed hole diameter	D_H	24	inches	660.4	mm
Pipe outer diameter	OD	450	mm	19.7	inches
SDR		11			
Wall thickness	t	45	mm	1.8	inches
Pipe internal diameter	ID	409	mm	16.1	inches
Reamed : Pipe ratio		1.32	(1.5 typical)		
Density	HDPE	0.952	t/m3	0.034	lbf/in^3
Cross sectional area		64909	sq mm	101	sq inches
Design minimum radius	R_{min}	300	m	984	ft

Friction and drilling fluid characteristics				
Coefficient of sea floating friction	m_g	0.05		(suggest 0.05 for tow lines)
Coefficient of borehole friction	m_b	0.4		(typically 0.25 - 0.50)
Hydrokinetic pressure	p	42	kPa	(28-55 kPa normally)
Specific gravity of the mud slurry	g_b	1.1		(Bentonite typically 1.05 - 1.20)
Density of fresh water	r_w	1.0	t/m3	
Density of seawater	r_s	1.025	t/m4	

HDD DESIGN					
Section of borehole above Mean Sea Level (MSL)					
Length from entry to MSL elevation	L_1	19.5	m		
Angle	A_E	15	deg		
Section of borehole below Mean Sea Level (MSL)					
As drilled exit angle (pipeside)	A_a	10	deg	0.175	rad
Angle (rigside) at MSL	A_b	15	deg	0.262	rad
Drilled MSL tangent + curve length	L_2	89	m	292.0	ft
Horizontal tangent length	L_3	244	m	800.5	ft
Drilled exit curve length	L_4	56	m	183.7	ft
Exit tangent	L_5	41	m	134.5	ft
Vertical depth (relative to MSL)	H	16.8	m	55.1	ft
Length from exit to sea level (MSL)	L_6	25	m	82.0	ft

Minimum radius		
Minimum Installed Radius	38	m
Minimum overbend radius	25	m

Note that SDR of HDPE pipe should be selected to pass long and short term ring deflection, tensile pressures etc

Dead and buoyant pipe weights						
Pipe weight, W_p	0.062	tonnes/m		42	lb/ft	
Pipe weight filled, W_{pw}	0.193	tonnes/m		130	lb/ft	
Buoyant empty weight, W_b	-0.154	tonnes/m		104	lb/ft	^
Buoyant filled weight, W_b	-0.023	tonnes/m		15	lb/ft	^
Total pipe length	430	m				
Total pipe weight	27	tonnes		58,456	lbs	
Total pipe weight submerged	-10	tonnes	-	21,522	lbs	
Total pipe weight of submerged tail in sea	-1	tonnes	-	1,168	lbs	

PULLBACK FORCES				
Combined Drag and Capstan Forces at:				
Point 1	1.9	t	4,123	lbs
Point 2	4.5	t	9,945	lbs
Point 3	5.4	t	11,824	lbs
Point 4	5.8	t	12,771	lbs
Point 5	8.6	t	18,850	lbs
Hydrokinetic Force	0.3	t	690	lbs
Max Force from submerged section	6.1	t	13,462	lbs

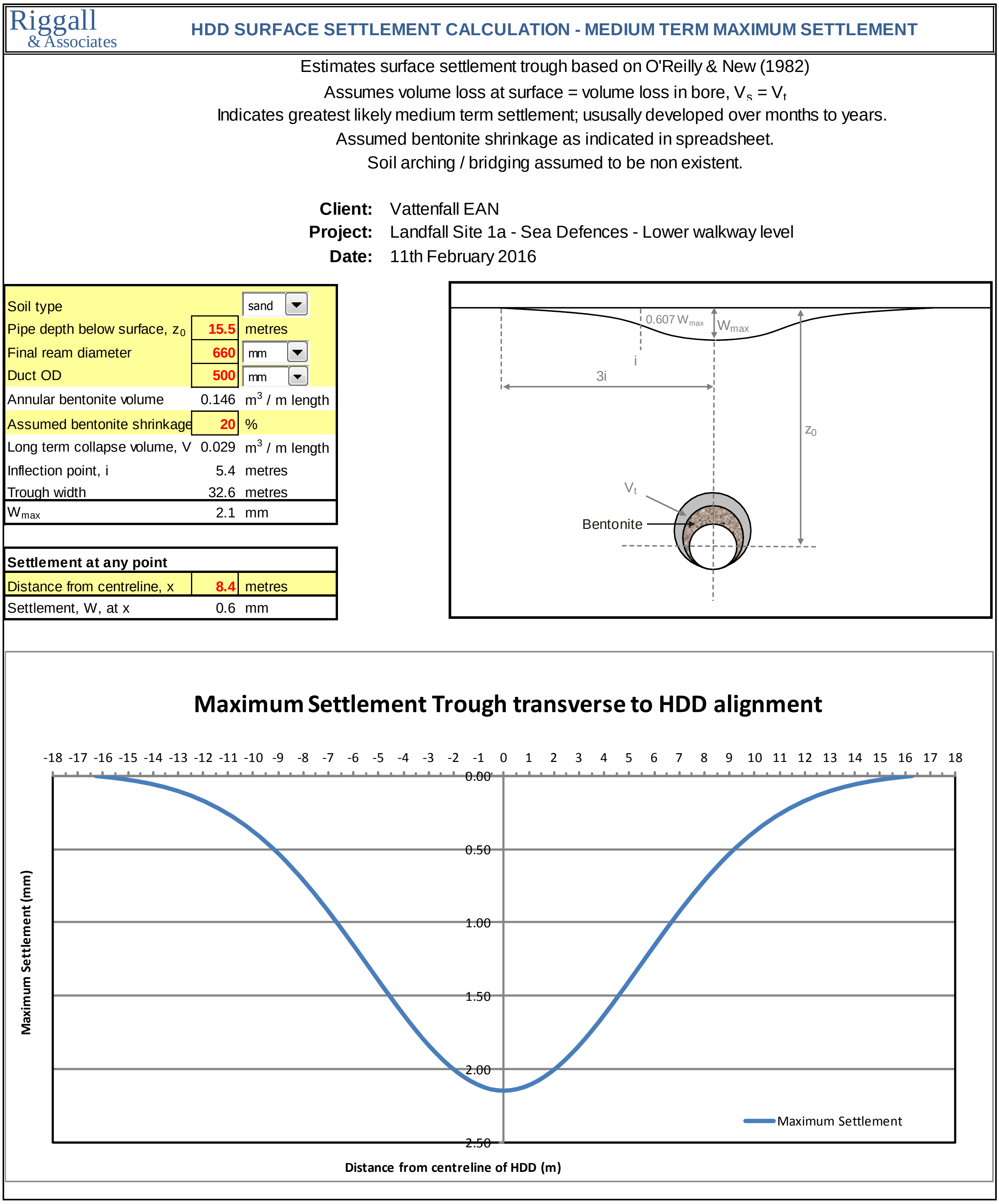
Gravitational pull component	1.0	t	2,150	lbs
Frictional pull component	1.5	t	3,210	lbs
Pipe unlikley to slide downhole if unsecured				
Force from dry section of hole (full)	2.4	t	5,360	lbs
Maximum Force	8.6	t	18,850	lbs

Figure 22. Example calculations for water filled duct installed at Site 1 Long HDD.

9.4.3 Settlement

Settlement modelling was undertaken to gain an understanding of the scale of possible settlement after HDD installation of the ducts. The settlement at the level of the concrete apron (see Figure 9) of the sea defences at Site 1 was modelled. The results are shown in Figure 23 below and indicate a settlement of 2.1mm at the apron level. When the influence of settlement troughs from adjacent parallel HDD's are added the combined settlement above the central HDD's will be 3.3mm. This is not expected to be detrimental to the functioning of the sea defences.

The settlement at the toe of any sheet piles could be of larger magnitude because of their proximity to the HDD, however the function of the piles is to resist bending moments and this function is not expected to be reduced by any HDD induced settlement that might occur.



Riggall
& Associates

HDD SURFACE SETTLEMENT CALCULATION - MEDIUM TERM MAXIMUM SETTLEMENT

Estimates surface settlement trough based on O'Reilly & New (1982)
Assumes volume loss at surface = volume loss in bore, $V_s = V_t$
Indicates greatest likely medium term settlement; ususally developed over months to years.
Assumed bentonite shrinkage as indicated in spreadsheet.
Soil arching / bridging assumed to be non existent.

Client: Vattenfall EAN
Project: Landfall Site 1a - Sea Defences - Lower walkway level
Date: 11th February 2016

Soil type		sand
Pipe depth below surface, z_0	15.5	metres
Final ream diameter	660	mm
Duct OD	500	mm
Annular bentonite volume	0.146	m^3 / m length
Assumed bentonite shrinkage	20	%
Long term collapse volume, V	0.029	m^3 / m length
Inflection point, i	5.4	metres
Trough width	32.6	metres
W_{max}	2.1	mm

Settlement at any point		
Distance from centreline, x	8.4	metres
Settlement, W, at x	0.6	mm

Maximum Settlement Trough transverse to HDD alignment

Figure 23. Settlement calculations for lower walkway level of sea defences at Site 1.

10. HDD SITE REQUIREMENTS - SITES 1 AND 3a

10.1. Site 1

10.1.1 Access

Heavy Goods Vehicles Access for the Bacton Gas Terminal uses the A149 and B1159 (see references: Bacton Development Projects, 2011). This route directly passes Site 1 and this is therefore the most suitable route for a HDD at the site.

Access from the B1159 into the field will probably be from a temporary access created for the works as shown on Drawing No. 2051001RA-C/03 in Appendix F.

The option of using the turning to the Anglian Water pumping station has been examined but is unlikely to be acceptable due to overhead lines with pole mounted transformer immediately west of the entrance. The transformer is probably too low and close for HGV's carrying shipping containers.

Temporary access across the field would require approximately 100m of access track across the field. Geotextile covered with stone or suitable fill would be a suitable construction, although bog mats might also be considered for lengths other than the B1159 entrance area.

Beach access for the short HDD exit point is best obtained via the ramped access to beach 350m north of the alignment. If the beach is experiencing an erosive cycle there is a chance of needing temporary ramps made from in situ sediment to negotiate over two wooden groynes.

10.1.2 Traffic

Because of its coastal location the area is likely to be very congested in holiday seasons (other than Christmas) and the timing of HDD works will need to be cognisant of this. The beachside stretch of road outside the site is often reduced to single lane by cars parked on the southbound side in order to access the beach. For mobilisation and demobilisation of the HDD equipment to site it might be sensible to have stop-go or temporary traffic lights available to manage the process.

Mobilisation typically involves 20 HGV loads delivered over two days with a crane on site (150t to 300t) for one to two days to position equipment.

During the works the additional traffic is not expected to be significant relative to normal traffic levels.

10.1.3 Site Requirements

Drawing No. 2051001RA-C/03 in Appendix G indicates a conceptual site setup for the maximum likely working area. It assumes a maxi (>100t) HDD rig positioned at the short HDD entry point drilling 6 No. HDD's. The dimension of the working site plus parking is 60m x 50m. If 4 No. HDD's are to be drilled the area could be reduced to 55m x 50m and for 2 No. HDD's 50m x 50m.

Including the access track the likely land take would be 3500m^2.

For the short HDD's it might be possible to further reduce the working area by using a smaller HDD rig and equipment more suited to short HDD's. However specifying a smaller working area might limit the number of contractors willing to bid for the work.

The working pad on similar sized HDD projects is most commonly geotextile covered with stone or suitable fill. Topsoil is stripped and stockpiled prior to laying the geotextile and it is often stored in a strategically positioned bund to assist in reducing the impact of noise on nearby neighbours. At Site 1 it could be stored along the eastern boundary of the work area to assist with noise reduction.

Provision should be made on site for settlement ponds to contain site runoff and for silt fencing to clean water to acceptable standards before any discharge to the field drainage.

10.1.4 Buried Services and Overhead Lines

It is expected that there will be a number of buried services either beneath the B1159 or in the adjacent verges. The mains water supply runs beneath the footpath on the southern side of the road and there is a hydrant point 130m east of the HDD alignment. Telecoms are also located beneath the footpath on the southern side of the road.

It is presumed that the Anglian Water pumping station is for the sewage system and that it runs parallel to the road or beneath the road. The sewer system is likely to be the deepest of any buried services and although it is unlikely to change the conceptual design (the sea defences will probably extend to significantly greater depth) it should be accurately identified.

A buried services search should be obtained before any further design work is undertaken.

As noted in Section 10.1.1 there are overhead power lines to the west of the site, terminating at a pole mounted transformer beside the Anglian Water pumping station. The overhead lines are sufficiently distant from the conceptual working area.

10.1.5 Noise & Lighting

The general impact of noise is discussed in Section 5.2.1. For Site 1 the nearest residence is 90m east of the nearest equipment. Stockpiling of topsoil on the eastern site boundary and possibly the use of acoustic panels placed on heras fencing should be sufficient to mitigate noise for daytime working.

If four or more HDD’s are to be drilled in a restricted season (e.g. winter) 24 hour working might be necessary. In this case an improved form of noise mitigation might be required such as a wall constructed of shipping containers.

For pullback (duct installations) 24 hour operations might be provisioned in case of any difficulties in the operation, however they are unlikely to be required as installation should take less than a shift to complete for the long HDD option.

It is recommended that background noise monitoring is undertaken as part of environmental studies to allow planning of noise mitigation.

Lighting is unlikely to cause problems for local residents and can be managed by ensuring any tower lights are positioned so that they can be directed away from residences.

10.1.6 Unexploded Ordnance

Archaeology records on Norfolk Heritage Explorer Mapping indicate the possibility of a World War II military camp within 100m of the site. An initial UXO desk study should be commissioned to assess the risk and inform whether UXO site investigations are required.

10.1.7 Flooding

Site 1 is liable to flooding from overtopping of sea defences by waves during tidal surges, as occurred in 2013 and 1953. The greatest damage is likely to be due to the flow of water and debris across the site during the event (see Rush, 2013).

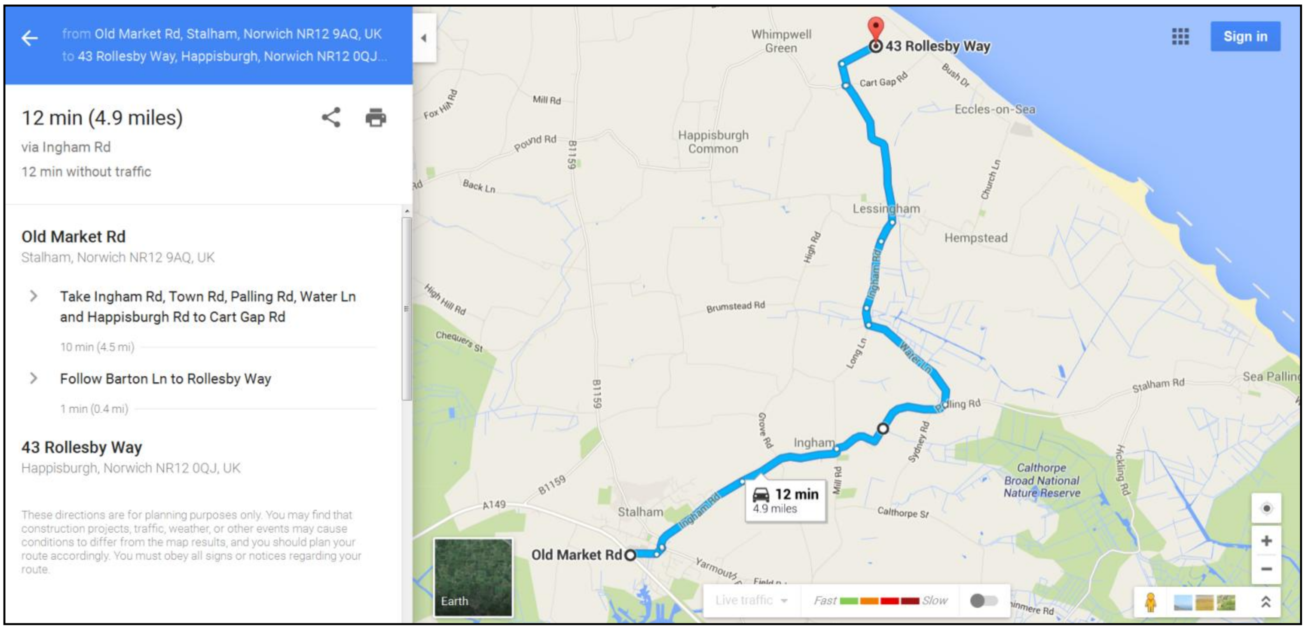
The site is at approximately 5m elevation while the 1953 surge was recorded at elevation 3.75m locally so water would be expected to drain quickly from the site once wave overtopping has ceased. The site setup might consider earth or topsoil bunds along the shore facing side of the site angled to divert any water and debris around the site to the nearest field drains.

10.2.Site 3a

10.2.1 Access

At Site 3a Cart Gap Road is not well suited for access because it is single lane. Doggett's Lane is also single lane and would require work to the unpaved surface. As a result there are two main route options:

Option 1: From the A149 onto Ingham Rd., Town Rd, Palling Rd, Water Ln, Happisburgh Rd and Rollesby Way, Then via a track constructed through the field to site (300m). The route is shown in Figure 24.



from Old Market Rd, Stalham, Norwich NR12 9AQ, UK
to 43 Rollesby Way, Happisburgh, Norwich NR12 0QJ...

12 min (4.9 miles)
via Ingham Rd
12 min without traffic

Old Market Rd
Stalham, Norwich NR12 9AQ, UK

- Take Ingham Rd, Town Rd, Palling Rd, Water Ln and Happisburgh Rd to Cart Gap Rd

  10 min (4.5 mi)
- Follow Barton Ln to Rollesby Way

  1 min (0.4 mi)

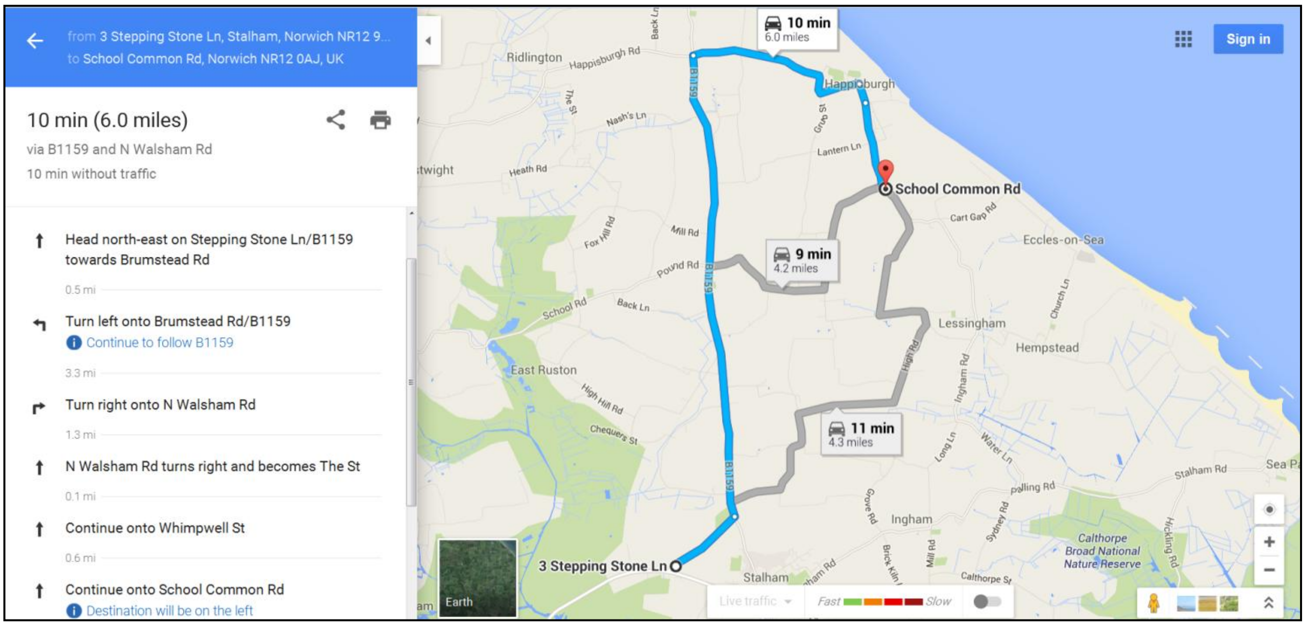
43 Rollesby Way
Happisburgh, Norwich NR12 0QJ, UK

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

Figure 24. Option 1 Access Route to Rollesby Way, Site 3a

Option 2: From the A149 onto the B1159, North Walsham Road, The Street, Whimpwell St., School Common Road. The route is shown in Figure 25.

For Option 2 the turning on to the Street at Happisburgh might necessitate HGV's cutting the corner and require temporary traffic management. From School Common Road there should just be sufficient room to turn into Holly Farm. The farm track could be used until the final 85m but might require upgrading in places. Alternatively a new entrance could be required through the field 170m north of Holly Farm entrance. This would incur an additional 250m of temporary access track construction.



from 3 Stepping Stone Ln, Stalham, Norwich NR12 9...
to School Common Rd, Norwich NR12 0AJ, UK

10 min (6.0 miles)
via B1159 and N Walsham Rd
10 min without traffic

Head north-east on Stepping Stone Ln/B1159 towards Brumstead Rd
0.5 mi

Turn left onto Brumstead Rd/B1159
Continue to follow B1159
3.3 mi

Turn right onto N Walsham Rd
1.3 mi

N Walsham Rd turns right and becomes The St
0.1 mi

Continue onto Whimpwell St
0.6 mi

Continue onto School Common Rd
Destination will be on the left

Figure 25. Option 2 Access Route to Holly Farm at Site 3a.

For beach access there are a number of options. At Happisburgh, 850m to the north, there is a ramped access that is liable to erosion but anticipated to be maintained by cutting back into the cliff as has recently been done. The stretch of beach from the Happisburgh ramp to the short exit point is clear of sea defences.

The second possible access is from the ramp at Cart Gap, 700m to the south of the alignment. At the time of the site visit (January 2016) there was enough sand on the beach to pass over the six wooden groynes between Cart Gap and the short HDD exit. This was helped by the groynes having a section of horizontal boarding removed to make a 3.5m gap at approximately 5m seaward from the concrete sea wall. The gaps appear to be a permanent feature, having been in place since at least 1999.

A third possibility for tracked excavators might be direct access over the dunes close to the drill alignment.

10.2.2 Traffic

Because of its coastal location the area is likely to be very congested in holiday seasons (other than Christmas) and the timing of HDD works will need to be cognisant of this. Both of the route options avoid the use of single lane roads, however during mobilisation and demobilisation there might be temporary disruption at points along the route.

Mobilisation typically involves 20 HGV loads delivered over two days with a crane on site (150t to 300t) for one to two days to position equipment.

Apart from mobilisation and demobilisation, during the works the additional works traffic is not expected to be significant relative to normal traffic levels.

10.2.3 Site Requirements

Drawing No. 2051001RA-C/04 in Appendix G indicates a conceptual site area for the maximum likely working area and the two main options for access tracks. It assumes a maxi (>100t) HDD rig positioned at the short HDD entry point drilling 6 No. HDD's. The dimension of the working site plus parking is 60m x 50m. If 4 No. HDD's are to be drilled the area could be reduced to 55m x 50m and for 2 No. HDD's 50m x 50m.

If the access track to Rollesby Way is used the likely land take would be 4400m^2. If the route through Holly farm is used the land take would be approximately 4000m^2, however this could increase to 5250m^2 if the entrance to Holly Farm is unsuitable and an access through the fields has to be installed. This additional area might be required in any case as part of construction of the land cabling route.

For the short HDD's it might be possible to further reduce the working area by using a smaller HDD rig and equipment more suited to short HDD's. However specifying a smaller working area might limit the number of contractors willing to bid for the work.

The working pad on similar sized HDD projects is most commonly geotextile covered with stone or suitable fill. Topsoil is stripped and stockpiled prior to laying the geotextile and it is often stored in a strategically positioned bund to assist in reducing the impact of noise on nearby neighbours. At Site 3a it could be stored on south western boundary of the work area to assist with noise reduction.

Provision should be made on site for settlement ponds to contain site runoff and for silt fencing to clean water to acceptable standards before any discharge to the field drainage.

10.2.4 Buried Services and Overhead Lines

There are not expected to be any buried services at the site but a search should be obtained before any further design work is undertaken.

There are no overhead lines in the site working area or along the temporary access tracks.

Low Voltage Overhead Lines across School Common Road and at the entrance to Rollesby Way will need to be checked before transport of abnormally high loads.

10.2.5 Noise & Lighting

The nearest residence is located 50m south west of the site perimeter but it is not known if it is a holiday house or permanent residence. If it is a permanent resident noise mitigation for this property will be a priority.

The properties along the coastline to the east and southeast appear to be mostly holiday cottages and are over 100m from site. Consideration of noise levels will be required if they are permanent residences or if works are planned during holiday periods.

If four or more HDD's are to be drilled in a restricted season (e.g. winter) 24 hour working might be necessary. In this case an improved form of noise mitigation might be required such as a wall constructed of shipping containers.

For pullback (duct installations) 24 hour operations might be provisioned in case of any difficulties in the operation, however they are unlikely to be required as installation should take less than a shift to complete for the long HDD option.

10.2.6 Unexploded Ordnance

Archaeology records on Norfolk Heritage Explorer Mapping indicate the possibility of World War II weapons pits above the HDD alignment. An initial UXO desk study should be commissioned to assess the risk and determine whether UXO site investigations are required.

10.2.7 Archaeology

Archaeology records on Norfolk Heritage Explorer Mapping indicate a possible Bronze Age barrow cemetery and ring ditches near the site. Aerial photographs suggest they could be 25m north east of the conceptual Short HDD Option entry points. The mapping also indicates a scatter of prehistoric and medieval finds so an archaeological desk study will be required.

Bathymetric surveys should examine the possible location of the wreck of the Hunter if Short HDD’s are to be considered because it could affect cabling. The cutter was wrecked in 1807 and a sand bar developed around it, however it was blown up in 1903 and the remains might not be significant.

11. HDD RISK ASSESSMENT

A High Level Risk Register has been compiled for the HDD landfalls at Sites 1 and 3a. It intends to address environmental, safety, and project risk.

The risk assessment method outlines the level of risk, prioritised in accordance with their probability and severity and classified into a risk category.

Probability (P)

Probability of Risk	1. Remote	Unlikely but conceivable
	2. Possible	May occur, could well occur
	3. Probable	May occur several times, occurs frequently

Severity (S)

Severity of Risk	1. Minor	*H&S:* Injury with short term effect, not reportable under RIDDOR. Environment: Nuisance to fauna and flora. *Project:* Minor changes required to achieve construction objectives with low cost and/or delivery implications
	2. Severe	*H&S:* Major injury or disability or ill health with long term effect reportable under RIDDOR, single fatality. *Environment:* Potentially fatal to fauna and flora for days / weeks. *Project:* Major changes required to achieve construction objectives with significant cost and/or delivery implications.
	3. Extreme	*H&S:* Multiple fatalities. *Environment:* Detrimental to local ecosystem for months / years *Project:* Catastrophic impact to construction objectives.

Risk Category (R)

PROBABILITY	Minor	Severe	Extreme
Remote	1	2	3
Possible	2	4	6
Probable	3	6	9

1 – 2	Risk is controlled as far as is reasonably practical, no further control measures necessary
3 – 4	Risk is controlled as far as is reasonably practical
6 – 9	Hazard should be avoided

Item	**Risk**	**Risk Classification**			**Mitigation Measures**	**Reduced Risk Classification**		
		P	**S**	**R**		**P**	**S**	**R**
1	Downhole failure of drilling equipment	2	3	6	Check of all drilling equipment before being run into hole	1	2	2
					Trip out to check condition of equipment after set number of hours recommended by manufacturer / supplier	1	2	2
					Monitoring and recording of drilling forces to ensure they are within the tolerances of the equipment	1	2	2
					Ensure sand content of drilling fluid is minimised to reduce abrasive wear	1	2	2
					Fishing for equipment lost in hole	2	2	4
2	Accumulation of cuttings in borehole leading to equipment stuck in hole	2	3	6	Monitoring the volume of cuttings removed from the HDD against volume drilled	1	2	2
					Trained mud engineer in charge of drilling fluids	1	2	2
					Real time downhole Annular Pressure Monitoring to identify restrictions in borehole annulus and trigger remedial action	1	2	2
3	Drill unable to advance because of concretions / boulders / obstructions	1	3	3	Sidetrack around obstacles (laterally or horizontally)	1	3	3
					Additional ground investigations to identify zones	1	3	3
					Drill with downhole motor and rock bit	1	3	3
4	Breakout of drilling fluid to the surface during pilot drilling	2	2	4	HDD Design has sufficient depth below surface for the expected ground conditions	1	2	2
					Monitoring of drilling fluid returns and volumes to warn of inadequate hole cleaning	2	2	4
					Drilling fluid to be of sufficient viscosity and properties for the ground being drilled	2	2	4
					Real time downhole Annular Pressure Monitoring to warn of over-pressuring by drilling fluid	1	2	2
					Have Lost Circulation Materials available on site to seal any breakout	2	2	4
					Grouting if necessary	1	2	2

Item	**Risk**	**Risk Classification**			**Mitigation Measures**	**Reduced Risk Classification**		
5	HDPE duct stuck during pullback	2	3	6	Hole cleaning run(s) performed before pullback	1	3	3
					Installation forces monitored	1	2	2
					Safe pull limit adhered to	1	2	2
6	Release of drilling fluid to sea when drilling out exit	3	2	6	Stopping point of pilot hole considers ground conditions found during pilot drilling	2	2	4
					Drilling fluid pump rate reduced when ground becomes soft	1	2	2
					Evaluate use of alternative drilling fluid or water	1	2	2
7	Breakout of drilling fluid to the sea during forward reaming	2	2	4	Monitoring of drilling fluid returns and volumes to warn of inadequate hole cleaning	2	2	4
					Drilling fluid to be of sufficient viscosity and properties for the ground being drilled	2	2	4
					Pilot hole stopped in competent ground before exit point and only advanced to exit when reaming to that point is completed	1	2	2
					Lost Circulation Materials available on site to seal any breakout	2	2	4
					Grouting if necessary	1	2	2
8	Ground Collapse in borehole due to loose / weak ground or blowing sands	2	3	6	Ensure drilling fluid characteristics are suitable for ground conditions (e.g. viscosity, fluid loss / filter cake)	2	2	4
					Real time downhole Annular Pressure Monitoring to avoid damage to ground by over-pressuring with drilling fluid	1	2	2
					HDD designed to drill in the most suitable ground conditions	1	2	2
					Casing any unstable areas near entry or exit	1	2	2
					Grout any areas of instability downhole	1	2	2
9	Unthreading from downhole equipment during back reaming due to insufficient make-up torque applied to connections on barge / workboat	2	2	4	Competent personnel on barge / workboat making drillpipe / assembly connections	1	2	2
					Drilling technique to maintain consistent torque and avoid over-spinning	2	2	4
					Use of cradles to assist in aligning drill rods	1	2	2
					Hydraulic breakout unit installed on barge / workboat	1	2	2

Item	**Risk**	**Risk Classification**			**Mitigation Measures**	**Reduced Risk Classification**		
10	Forward reaming fails to follow pilot hole	2	2	4	Use of sufficiently long lead rods in front of stabiliser	1	2	2
					Use of a passive tool on lead rods (e.g. bull nose)	1	2	2
					Monitoring of drilling forces during forward reaming and comparison to pilot hole rate of penetration	1	2	2
					Trip out and survey reamed hole if in doubt	1	2	2
11	HDPE duct is damaged during pullback	2	2	4	Design to avoid unsuitable ground conditions if possible	1	2	2
					Cleaning run satisfactorily completed before pullback	1	2	2
					Monitoring of forces during pullback operations	1	2	2
					Duct removed, borehole reconditioned, new or repaired duct installed	1	2	2
12	Swelling clays encountered	2	2	4	Minimise distance drilled in any swelling clays identified in ground investigations	1	2	2
					Trained mud engineer to tailor drilling fluids to conditions	1	2	2
					Shale inhibitor additives in drilling fluid	1	2	2
					Gypsum based drilling fluid	1	2	2
13	HDD collision with sea defence foundations	2	2	4	Accurate survey of known structures and examination of records to identify previous structures that are no longer visible	1	2	2
					Acquire records from relevant authorities on the structures, particularly with regard to foundation and piling depths	1	2	2
					HDD design to allow for accuracy of guidance equipment in design distance from structures	1	2	2
					If encountered, trip pilot drill back and drill a sidetrack around the obstacle	1	2	2
14	Site works or HDD entry encounters Unexploded Ordnance	1	3	6	Commission a UXO specialist to undertake a desk study and any further recommended work	1	2	2
					UXO specialist to advise on precautions and any safe working methods required	1	2	2
					All excavations to be undertaken under a permit to dig system	1	2	2
					Suspected device is to be left in position, and UXO procedures followed.	1	2	2

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
15	Drilling stopped due to nuisance noise / lighting to neighbouring residences	2	2	4	Placement of topsoil stockpiles, office cabins etc as shielding	1	2	2
					Engines etc enclosed in silencing units	1	2	2
					Pre construction baseline noise monitoring & mitigation planning	1	2	2
					Installation of dedicated sound & light barriers	1	2	2
16	Fluid loss into and contamination of chalk aquifer	1	3	3	Ground Investigations to identify position of chalk and design to ensure sufficient elevation above the top of the chalk	1	2	2
					If small voids / losses are encountered attempt to seal with stop loss additives or grout	1	2	2
					If the voids / losses are too large to seal, drill with water rather than drilling fluid	1	3	3
					Abandon pilot hole and drill a new pilot at higher elevation	1	1	1
17	Flooding from tidal surge	2	3	6	Protective ditch and bund on seaward site perimeter to divert wave overwash and debris around site	2	2	4
					Work to cease, equipment and site to be secured and personnel evacuated in advance of any predicted surge.	2	2	4
					Drilling equipment to be removed from borehole and entry to borehole or casing covered and secured if possible	2	2	4
					Prior to the predicted surge, pit pumps, mud pumps, hoses and lines to be prepared for use in dewatering the site following any flooding.	2	2	4
18	Entry point unacceptable due to Archaeological finds.	2	3	6	Early stage archaeology studies at proposed sites to minimise impact on programme and cost	1	3	3
					Identify 10m x 5m area clear of finds as entry point for all HDDs to fan out from and use engineered ground support for equipment to finds protect underlying equipment	1	2	2
					Use of alternative HDD site	1	1	1
					Use suitable location adjacent to site	1	1	1

Item	**Risk**	**Risk Classification**			**Mitigation Measures**	**Reduced Risk Classification**		
19	Collapse of dry borehole above sea level	2	3	6	Selection of entry position with low elevation	2	1	2
					Excavation of areas prone to collapse	1	1	1
					Installation of support casing in affected zones	1	1	1
					Ground improvement (grouting / soil mixing) prior to works commencing	1	1	1
20	Settlement damage to coastal defences or other infrastructure	2	2	4	Design to maximise distance from sensitive structures	1	2	2
					Settlement modelling to quantify settlement risk	2	2	4
					Monitoring programme for sensitive structures covering pre to post construction period	2	2	4
					Post installation grouting of HDD annulus if predicted settlement is unacceptable	1	1	1
21	Drill encounters unexpected ground that is unfavourable to HDD	2	3	6	Thorough Ground Investigations programme including boreholes and geophysical investigations	1	3	3
					Employ mitigation measures for adverse ground (downhole motor drilling, grouting etc.)	1	2	2
					Trip back and sidetrack into favourable ground	1	1	1
					Trip out and re-drill new profile or new location	1	1	1
22	Onward cabling through Marine Conservation Zone (Site 1 only) is not permitted	2	3	6	Early consultation with relevant permitting authorities	1	3	3
					Move HDD's to Site 3a location	1	2	2
23	Permitting authorities do not allow drilling fluid losses to the sea	1	3	3	Early consultation with relevant permitting authorities	1	3	3
					Revert to short option HDD with engineered containment of fluids at exit	1	1	1
24	Rollover / tip over of mobile equipment or heavy haulage	2	3	6	Access roads to be suitable for HGV's and strictly followed by delivery vehicles	1	3	3
					Site area to be stable and level	1	3	3
					Site area ground works designed to accept expected equipment loads	1	3	3
					Drivers to check and secure load prior to moving vehicle	2	2	4
					Banksman to supervise moving plant in site compound	1	3	3
					Only tracked or 4WD vehicles to access beach	1	2	2

Item	Risk	Risk Classification			Mitigation Measures	Reduced Risk Classification		
25	Traffic accidents during movements to / from site	2	3	6	Identification of safest route in Traffic Management Plan	2	3	6
					Access roads to be suitable for HGV's and strictly followed by delivery vehicles	1	3	3
					Site deliveries to be restricted to daylight hours	2	3	6
					Adoption of high standards of driver competency and Drug & Alcohol policy	1	3	3
26	High vehicles coming into contact with overhead lines (OHL's)	2	3	6	Traffic Management Plan to identify route avoiding OHL's	1	3	3
					Any OHL's on access track to be identified by goal posts	1	3	3
					High loads to be met at access points and escorted under OHL's	1	3	3
27	Working at height (HDD rig operatives and mud system operatives)	2	3	6	Safe means of access to the working area to be provided.	1	3	3
					Ensure handrails are in place on equipment where access is required.	1	3	3
					Ensure compliance with the Work at Height. Regulations 2005	1	3	3
28	Failure or tip over of heavy lifting equipment	2	3	6	Mobilisation & demobilisation conducted by contract lift	1	3	3
					HDD contractor to use and follow their safe lift procedures for all lifts during HDD works	1	3	3
					HDD lifting equipment (hiabs, excavators, slings chains etc) to be certified and regularly checked	1	3	3
29	Buried services strike	2	3	6	Buried services search to be undertaken before work commences	1	3	3
					Underground services to be exposed as per HSG47.	1	3	3
					CAT scan to be carried out prior to excavation.	1	3	3
					All excavations to be undertaken under a permit to dig	1	3	3
30	Tool up for drilling Activities – manual handling, slips trips falls	2	3	6	Use mechanical handling were possible	1	3	3
					All electrical equipment to be inspected and tagged prior to use.	1	3	3
					Working area to be kept clean and clear of obstacles	1	3	3
					All spillages to be contained and spill kits to be available at all times.	1	3	3
31	Drilling fluid mixing – manual handling, dust, contact with chemicals	2	2	4	COSHH sheets to issued and the correct PPE to be worn.	1	1	1
					Use mechanical handling where ever possible	1	2	2
					Correct working platforms to be installed at all times.	1	2	2
					Dust masks to be used.	1	1	1

Item	**Risk**	**Risk Classification**			**Mitigation Measures**	**Reduced Risk Classification**		
32	Open excavations	2	3	6	All excavations are to be fenced and signed to prevent unauthorised entry.	1	3	3
					Deep excavations to be suitably battered, stepped or supported with fixed ingress and egress points	1	2	2
					All excavations to be undertaken under a permit to dig system	1	3	3
33	General drilling operations – noise, dust, rotary equipment, moving plant	2	3	6	Signage denoting PPE required and hazard areas	1	3	3
					Site inductions, sign ins, tool box talks, and permit to work systems in place and adhered to	1	3	3
					Only experienced and competent operators to be used (CSCS scheme or equivalent).	1	3	3
					Hearing protection to be issued to all personnel when required and worn in designated areas	1	3	3
					Dust suppression to be employed when required.	1	3	3
					No loose clothing to be worn near rotating equipment. Rig operatives to wear coveralls.	1	3	3
					Emergency stop buttons to be fitted in accessible positions	1	3	3
					All hoses to be secured, gauges to be inspected prior to use.	1	3	3

12. SPECIFIC GEOTECHNICAL AND HDD RISKS

12.1. Ground Collapse

For Sites 1, 3a, and 3b the risk of ground collapse can be separated into three separate scenarios:

- Weak or very loose sediments in a borehole supported by drilling fluid
- Running / Blowing / Live Sands
- Weak or loose sediments in a borehole unsupported by drilling fluid

12.1.1 Weak or Very Loose Sediments in a Fluid Filled Borehole

The first risk is only likely to occur close to the entry point or exit point because the surrounding boreholes indicate that ground strength increases with depth, particularly below 3m from surface. At the entry point any collapse would be mitigated by excavating the fallen material, if necessary. At exit the fallen material will be fluidised and removed by the reamer preceding the duct during installation.

12.1.2 Running / Blowing / Live Sands

The second scenario of running sands describes the situation where, generally fine, sands are transported into the borehole because the fluid in the sand layer is at a higher pressure than the fluid in the borehole. In cable percussion ground investigation drilling this process can be magnified because the plunging effect of the drilling and sampling tool creates a reduced pressure as it is lifted from the hole. In HDD drilling running sands are normally contained in situ by the high viscosity and pressure of the drilling fluid.

The exception where HDD can have difficulty in containing running sands is where running sands are within artesian aquifers. Artesian aquifers are where the groundwater pressure within the strata causes the groundwater to flow to the surface of its own accord. Artesian pressures are not noted in any of the boreholes examined in this study and they are not expected given the design elevations for the HDD’s.

12.1.3 Weak or Loose Sediments in a Dry Borehole

The third scenario is borehole collapse in parts of the HDD above sea level that are unsupported by drilling fluid is discussed in detail in Section 3.6. When the drill exits on the seabed the drilling fluid will equilibrate to the sea level. If the entry elevation is significantly higher than the sea level the result is a length of borehole at the entry point that is dry and therefore unsupported. This causes a significant increase in risk of ground collapse into the borehole, particularly in weak sediments. The risk increases with increasing borehole diameter because arch support in the ground is reduced.

The primary mitigation against borehole collapse in dry hole is by drilling from an elevation close to sea level to minimise the length of dry hole. Engineered mitigated involves either casing the section of borehole at risk of collapse or, less commonly, by use of ground improvement. Ground improvement is most likely to take the form of pre-grouting the weak sections of soil along the planned HDD route.

The choice of mitigation method for potential roof collapse will be driven by the results of ground investigations and testing, and the client or contractors assessment of the risk. In many cases where HDD’s encounter roof collapse within 20m of entry the duct is successfully pulled because the reamer and drilling fluid liquefies the fallen material. Given the low elevation of the entry points at Sites 1 and 3a the effects of third scenario can easily be mitigated by excavating any collapse zone.

12.2. Drilling Fluid Breakout and Losses

There are five distinct scenarios for when drilling fluid might be or will be lost to the surface or the sea for the landfalls.

12.2.1 Loss to Surface

Surface breakout most commonly occurs within the first 30m from entry and a competent contractor will avoid this on 90% of jobs. The HDD contractor will have a person walking the drill alignment checking for breakout. If detected the drilling is stopped immediately and the spill contained and removed.

It is good practice to have a stock of ready filled sandbags on site to contain a breakout if it occurs and a small pump with flexible hose to pump the bentonite back to the exit pit. At Site 1 and 3a, given that the first 30m will be through agricultural fields, mitigation might take the form of digging a sump and bunding around any breakout with the site excavator. Breakouts that do occur are usually constrained to an area 3m x 3m and fluid depth of 0.2m giving a fluid volume of 1.8 m^3.

12.2.2 Loss to Voids

During drilling in ground with high permeability (e.g. peat) or voids (e.g. chalk) drilling fluid can be lost to the ground. The only real possibility of this occurring at Sites 1 or 3a is if the HDD drilled into the underlying chalk and encounters aquifers. Good ground investigations and good design are the main tools in mitigating this risk for the project.

If fluid is lost to the ground the mudman will quickly identify the losses because of the falling fluid levels within their mud tanks. Generally the mudman will identify any losses greater than $2m^3$ in volume. Pumping will then be stopped and action taken to seal the area of loss; usually with stop-loss additives but in extreme cases, such as karst limestone, pumping in cementitious grout might be required. Previous HDD’s on the South Downs that encountered chalk with voids were successfully completed by drilling with water only as the drilling fluid.

12.2.3 Loss on Exit

When the bit enters the sea the length of borehole above sea level will drain into the sea. The greatest losses will be for the Long HDD Option at Site 3a; assuming a 26” (660mm) borehole and 20m length above sea level the volume = 10.3 m^3.

12.2.4 Loss During Final Back Reaming

Normal practice for landfalls is to drill a pilot hole to approximately 30m before the planned exit point. The hole is then forward reamed to the end of the pilot hole and tripped out. The pilot bit is tripped in and drills out the final 30m to exit (Section 12.2.3 above).

The last section of hole then needs to be opened up to final diameter by back reaming from the exit point towards the section of hole that has already been enlarged by forward reaming. The length of back reaming on this project is expected to be 30m with 50m as a worst case. During the back reaming drilling fluid will need to be pumped to remove cuttings from the hole and this will exit into the sea.

For the long HDD's the worst case scenario is that the ground dictates that 3 different sized back reams are necessary. If they progress at 1 minute per metre of drilling advance and the fluid pumping rate is 800 litres/minute then the losses to the sea will be 120m^3.

For the short HDD's there is the possibility of constructing a temporary structure (e.g. a sheet piled coffer dam) around the exit point to prevent the fluid being dispersed as the tide rises above the exit point and transferring the fluid back to the entry pit for recycling.

12.2.5 Loss During Duct Installation

During installation there are two factors contributing to losses; fluid pumped through the reamer in front of the duct to ensure the hole is clean, and fluid displaced by the duct as it is pulled into the hole. For the long HDD's the worst case scenario is an installation rate of 2 metres per minute for the 540m drilled borehole length at Site 3a. At a pumping rate of 500 litres per minute this would result in a pumped volume of 270m^3.

Assuming the initial 20m of borehole at entry is dry, the displacement volume for the 520m of fluid filled borehole by a 500mm duct is 100m^3.

The worst case scenario of total volume lost during installation of the ducts on the long HDD for Site 3a is therefore 370m^3.

For the short HDD's there is the opportunity to capture fluid at the exit point as discussed in Section 12.2.4 above.

12.3. Settlement

Settlement above HDD's can occur if the roof of the HDD collapses, either during drilling, or following installation of the duct. The void created then migrates upwards and outwards towards the surface, resulting in a settlement trough at the surface.

Settlement caused by HDD's is normally only problematic when shallow (less than 5m) and large diameter (greater than 500mm) HDD's are drilled close to sensitive structures (railways, residences etc). An indication of the scale of possible settlement is given in Section 9.4.3. For the concrete apron of the sea defences at Site 1 a combined settlement of 3.3mm was calculated and this is not expected to be of significance for the integrity or function of the structure.

13. INDICATIVE PROGRAMME & COST

An indicative programme of works for HDD landfalls at both Site 1 and Site 3a is shown in Table 13 below. The programmes have been calculated for both long and short options, assuming two HDD's are to be completed.

The programme assumes 12 hour working. For much of the HDD work activities there is the potential to work 24 hours provided there are no restrictions for environmental reasons (in particular the impact on nearby residences). The 24/7 total includes 24hr working for drilling activities and 12 hr working for pullback, site works, mobilisation and demobilisation.

INDICATIVE PROGRAMME FOR HDD WORKS AT SITES 1 AND 3A, LONG AND SHORT OPTIONS

ACTIVITY	**Site 1 - Short HDD's**		**Site 1 - Long HDD's**		**Site 3a - Short HDD's**		**Site 3a - Long HDD's**	
	HDD #1	**HDD#2**	**HDD #1**	**HDD#2**	**HDD #1**	**HDD#2**	**HDD #1**	**HDD#2**
	12hr Shifts	**12hr Shifts**	**12hr Shifts**	**12hr Shifts**	**12hr Shifts**	**12hr Shifts**	**12hr Shifts**	**12hr Shifts**
Site establishment works	7.0	-	7.0	-	7.0	-	7.0	-
Mobilisation & Setup	5.0	2.0	5.0	2.0	5.0	2.0	5.0	2.0
Pilot hole drilling: 0 - 420m	1.8	1.8	4.2	4.2	1.8	1.8	5.0	5.0
Forward ream 16": 0 - 410m	2.1	2.1	5.1	5.1	2.1	2.1	6.1	6.1
Forward ream 22": 0 - 400m	2.0	2.0	5.0	5.0	1.9	1.9	6.0	6.0
Forward ream 26": 0 - 390m	1.9	1.9	4.9	4.9	1.8	1.8	5.9	5.9
Pilot hole drilling: 420 - 450m	0.3	0.3	0.3	0.3	0.3	0.8	0.4	0.4
Offshore works	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Back ream 16": 410 - 450m	0.5	0.5	0.5	0.5	0.5	1.1	0.6	0.6
Back ream 22": 400 - 450m	0.6	0.6	0.6	0.6	0.6	1.2	0.8	0.8
Back ream 26": 390 - 450m	0.8	0.8	0.8	0.8	0.8	1.3	0.9	0.9
Cleaning pass	0.5	0.5	1.2	1.2	0.5	0.5	1.4	1.4
Pullback of pipeline	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Demobilisation	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Site reinstatement works	-	7	-	7	-	7	-	7
Total 12hr Shifts per HDD	26.0	23.0	38.0	35.0	25.8	24.9	42.6	39.6
Total 12hr Shifts for 2 No. HDD's	**49**		**73**		**51**		**82**	
Total weeks, day working, 7 day weeks	**7.0**		**10.4**		**7.2**		**11.7**	
Total weeks, 24/7 working	**5.4**		**7.1**		**5.5**		**7.8**	

Notes: Time for duct preparation and offshore works are not included as they will be concurrent with HDD works.
No allowance for weather delays to offshore works has been made.

Table 13. Indicative programme of works assuming 12 hr shifts. Assumes no weather delay for offshore works.

Cost estimates have been prepared for the case of a single HDD and are shown in Table 14 below. There will be minor savings on multiple HDD's at the one location due to sharing of the site mobilisation and demobilisation cost. Two estimate methods have been used, by HDD length and diameter, and by programme shifts. The two methods broadly agree.

VATTENFALL EAN - INDICATIVE PRICE RANGE FOR A SINGLE HDD LANDFALL

Site	**Long / Short**	**Length**	**Programme Shifts**	**PRICING BY METERAGE AND DIAMETER**			**PRICING BY PROGRAMME**		
				Lower	**Expected**	**Upper**	**Lower**	**Expected**	**Upper**
1	Short	210	25	£ 189,000	£ 252,000	£ 357,000	£ 196,000	£ 294,000	£ 392,000
1	Long	450	37	£ 405,000	£ 540,000	£ 765,000	£ 439,000	£ 585,000	£ 731,000
3a	Short	205	25	£ 184,500	£ 246,000	£ 348,500	£ 203,000	£ 304,000	£ 405,000
3a	Long	540	41	£ 486,000	£ 648,000	£ 918,000	£ 493,000	£ 657,000	£ 821,000

Notes: The costing is only for the HDD works and does not include site groundworks and access, duct purchase or fabrications, or the cost of marine works to facilitate duct installation.
Pricing includes HDD Contractors profit margin but does not include a margin for any Principal Contractor

Table 14. Indicative costs for a single landfall HDD at each location for long and short options

14. SUMMARY AND CONCLUSIONS

14.1. Evaluation and Ranking of Sites

The site visit took in thirteen prospective HDD landfall sites along three separate stretches of Norfolk and Suffolk coastline. From these thirteen initial sites a total of 15 prospective HDD alignments were identified, because sites 3 and 4 each had two possible HDD locations, designated 3a, 3b, 4a and 4b respectively.

Following a desk study a Site Assessment Table was compiled to compare the sites. The criteria used were:

- Dimensional Factors: entry elevation, working area, easement restrictions, and expected lengths for short and long HDD options
- Geotechnical Factors: geology and groundwater
- Environmental Factors: designated areas, flood risk, coastal defences, predicted shoreline changes and present shoreline management plan policy
- Anthropogenic Factors: marine obstacles, archaeology, residential areas, and unexploded ordnance risk
- Construction Factors: site access, access to beach exits, and water supply

The Site Assessment Table is shown in Table 11 and is colour coded to give a simple visual impression of suitability of each criterion at each site. Using the assessment table a subjective ranking was made of the feasibility of the sites and this is reproduced in Table 15 below.

Site 1 was evaluated as the most suitable location for landfall HDD's, followed closely by Sites 3a and 3b, forming the Tier 1 sites.

AUTHOR'S SUBJECTIVE RANKING		
RANK	**SITE**	**TIER**
#1	1	Tier 1: Suitable for HDD
#2	3a	
#3	3b	
#4	4a	Tier 2: Suitable for HDD with some mitigation measures.
#5	4b	
#6	11	
#7	5	Tier 3: Potential for Significant Risks to HDD completion. Investigation and mitigation required.
#8	2	
#9	8	
#10	9	
#11	10	
#12	12	
#13	13	
#14	6	Tier 4: Not suitable for HDD
#15	7	

Table 15. Subjective ranking of site suitability for HDD landfalls based on the Site Assessment Table.

To quantify and check the subjective ranking a matrix was constructed from the Site Assessment Table. A weighting was given to each of the assessment criteria; the most heavily weighted criteria being Elevation, Geology, and Land Environmental Designations. The matrix with weightings and scores is shown in Appendix E.

The matrix results and subjective rankings were identical for the top four ranked sites and broadly similar for the lower tiers. Sites 5 and 6 showed the greatest variance between the ranking systems but neither is within the top six places in either system.

In the second Tier, Sites 4a, 4b and 11 are deemed suitable for HDD but will probably require some mitigation measures. Sites 4a and 4b might be prone to running sands and collapsing ground and this risk needs ground investigations to evaluate and plan mitigation methods. Site 11 is drilled from an entry elevation of 12m and the section of borehole above sea level is liable to collapse when the HDD exits to the sea unless mitigation measures are in place.

Site 2 was ranked as joint position 5 by the matrix system; however the subjective ranking was eighth because the HDD would probably drill through the chalk. Drilling in the chalk is best avoided because of the risk of encountering voids and aquifers that are a local supply for groundwater.

14.2. Sites 1 and 3a Chosen for Detailed Study

It can be seen from Table 15 that Site 1 is the highest ranking site. Sites 3a and 3b were very similar and ranked second and third. All of these sites are viable locations for a HDD landfall based on the available information.

Site 1 will either drill into a Marine Conservation Zone or the offshore cabling will need to pass through it. The chances of obtaining permission to route through this zone are not known (and are outside the scope of this study) and it remains a risk to the use of Site 1. In recognition of this possibility it was decided to examine both Site 1 and Site 3a in detail as insurance.

Site 3b is also examined in detail, albeit indirectly. The geometry of any HDD design at Site 3b will be similar to that for Site 1; both have a 50m easement near the shoreline. And the geology that will be encountered at Site 3b will be very similar to Site 3a because of their close proximity.

A summary of the features of the top 3 ranked sites is as follows:

Ranking #1: Site 1.
Site 1 has the highest ranking because of favourable geology, favourable elevation, sufficient beach for a short HDD, a long term Hold the line policy for sea defences, and excellent site access.

Negatives for the site are that it is prone to wave wash from tidal surges (although any flooding should quickly drain), the depth of sheet piling associated with sea defences is not known, the depth to the chalk is not accurately known, and the possibility of drilling through the Marine Conservation Zone is not known.

Ranking #2: Site 3a.
Site 3a is expected to have generally favourable geology, has a relatively low entry elevation, few permanent residences nearby, is partly protected by a sea wall designated as a Hold The Line area for coastal defences, and has the possibility of multiple HDD’s fanned out in an array.

Negatives for the site are the potential encroachment of beach erosion to the north, less favourable access, and complications to short HDD's by a line of abandoned wooden sea defences.

Ranking #2: Site 3b.
Site 3b is expected to have generally favourable geology, has low entry elevation, relatively few permanent residences nearby, and is protected by a sea wall designated as a hold the line area for coastal defences

Negatives for Site 3b are that a short HDD is more difficult than Sites 1 and 3a because of the short beach and the concrete sea wall, access is less favourable, and the 50m easement width restricts the number of HDD's that could be drilled.

15. RECOMMENDATIONS

15.1. Site Selection

Based on the available information Sites 1, 3a and 3b are suitable for “long” HDD landfalls exiting in the sea at a nominal elevation of -3.0mLAT. Shallower or deeper exit elevations are possible but will have effects on the HDD length, risk, cost and the methods of offshore working.

Short HDD’s are feasible at Site 1 and 3a and probably feasible at Site 3b based on the available information.

The final site selection will need to account for factors outside those examined in this study; the main ones are expected to be:

- Permission to route through the Marine Conservation Zone at Site 1
- Landowner permissions for HDD work sites and access routes
- Consenting authorities’ approval for drilling fluid releases on the long HDD options
- Results of any ground investigations
- Further information on the design and depth of sea defences
- Risk and cost of installing offshore cabling from short HDD’s as opposed to long HDD’s.
- Offshore cable routing considerations to Site 1 as opposed to Site 3a (non MCZ related)
- The number of ducts required

In the event of Sites 1, 3a and 3b being deemed unsuitable for reasons outside the scope of this study, Sites 4a, 4b and 11 are potentially suitable but will require ground investigations and possibly pre-treatment of potential ground collapse zones.

15.2. Further Information

For any future studies and designs for a chosen site (or sites) the following information and data will be required:

- Preferred cable size and likely pulling length limit
- Preference for a short or long exit
- Suitable depths for exit on long HDD’s
- Horizontal separation distance between ducts at exit point
- LIDAR or topographical survey of the chosen site/s
- Bathymetric survey of the sites and confirmation of ODN to chart datum LAT conversions
- Further ground investigations (see Section 15.3)
- Details of design and foundation depths for sea defences, particularly sheet piling. The information should cover both maintained and abandoned sea defences.
- Details of any EA policy regarding drilling beneath sea defences (if one exists)
- Seek expert advice on any impending changes to coastline management policy
- Seek expert opinion on projected erosion profiles. At Site 3a is the southern corner of the eroding beach likely to deepen at the same rate and will it impact on the planned HDD site? Will protection measures placed at the north end of the Site 3a sea wall be maintained?
- Design life of installations to determine position of joint bays beyond coastal erosion
- Accurate site survey to identify position of utilities, roads, sea defences and beach topography at low tide
- Archaeological and environmental investigations to check the suitability of chosen site/s
- Verification that the 50m easement width at Site 1 is accurate. Is the vacant land between the mobile home and Emergency Lifebuoy / Telephone public land? It is unused since 1999

- An unexploded Ordnance Desk study should be commissioned from an UXO specialist to inform any UXO site investigations that might be required
- If information on sea defences are not available or known geophysical methods could be used to determine sheet pile depths. Boreholes drilled adjacent to any sheet piling could use magnetometer surveys to determine the toe position of the piles.

15.3. Ground Investigations

Figure 26 and Figure 27 below indicate the position and depth of suggested ground investigation boreholes and geophysical survey areas for Sites 1 and 3a. If the long HDD option is to be considered with a deeper exit than -3m LAT the geophysical survey should be extended out to the proposed exit. If the extended length is greater than 50m additional marine boreholes should be planned.

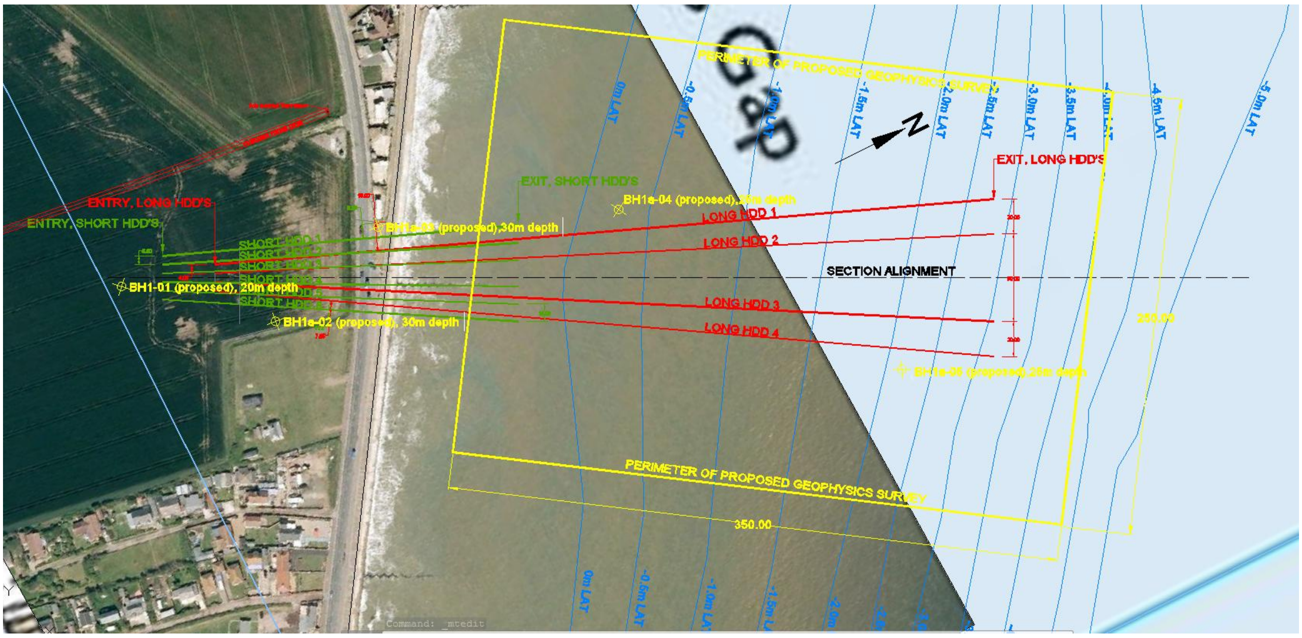


Figure 26. Position of proposed ground investigations at Site 1.

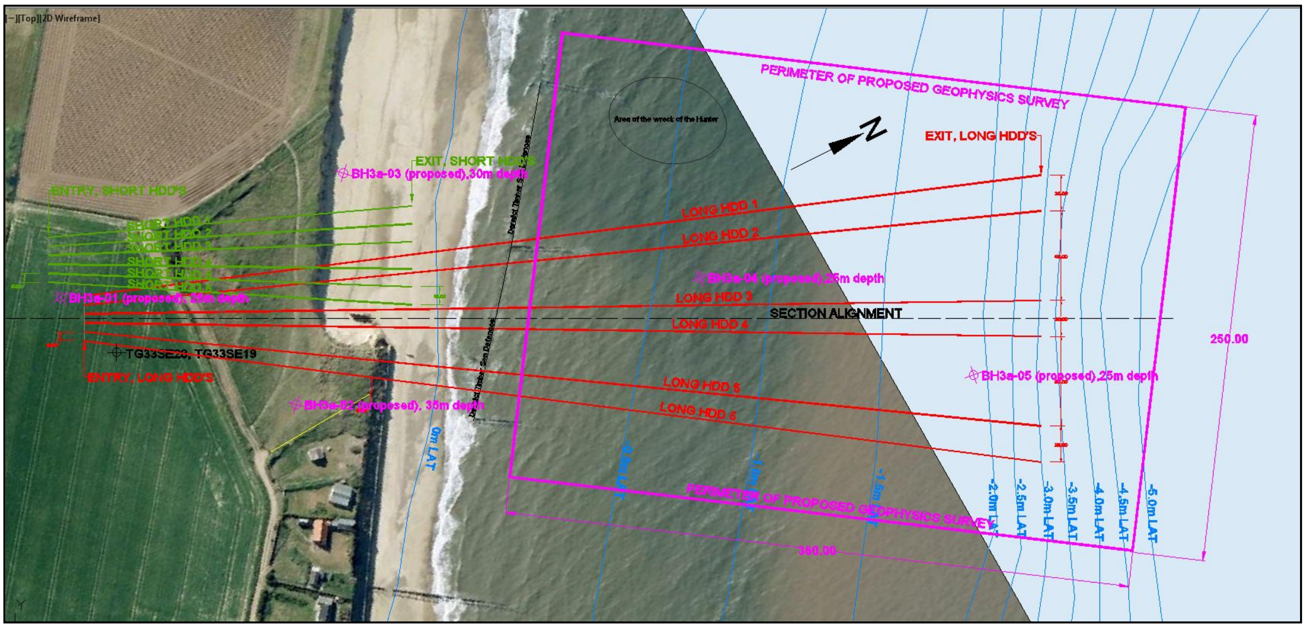


Figure 27. Position of proposed ground investigations at Site 3a.

A phased approach is recommended for the ground investigations to improve the quality of the information. It is suggested that Phase 1 would be land based boreholes, Phase 2 marine boreholes and Phase 3 marine geophysics. If deemed necessary, land based geophysics could be added as Phase 4.

When any of the ground investigation reports is complete it should be reviewed by a HDD specialist to ensure the site is still judged to be suitable for HDD.

The risk of unexploded ordnance should be assessed prior to ground investigations to determine any requirement for UXO searches prior to boring and/or magnetometer readings when boring.

15.3.1 Land Boreholes

The land boreholes are expected to be drilled by cable percussion methods and potentially with rotary coring if the ground proves difficult for cable percussion. All boreholes are to be backfilled with bentonite chippings to ensure they do not provide a route for drilling fluid breakout during HDD drilling.

15.3.2 Marine Boreholes

It is suggested that the Marine boreholes are drilled after the land boreholes have been completed and the geology reviewed. This will allow better targeting and positioning of the marine boreholes.

If the long HDD option is to be considered the marine boreholes are essential in reducing the risk of unplanned breakout to the sea. They are likely to be drilled from a jack up platform and will probably be cable percussion drilled to effectively sample the expected ground conditions.

Vibracore samples near the expected exit points for the long HDD option would be useful in determining the thickness and nature of any loose sediment at the exit point.

15.3.3 In Situ and Laboratory Testing

During cable percussion drilling regular Standard Penetration Tests (SPT's) should be performed and undisturbed samples taken wherever possible (generally in cohesive). Bulk samples are expected to be regularly taken in the granular soil. Any rotary core drilling will supply U100 core, some of which will be sent for laboratory testing.

Apart from SPT's in situ testing is only likely to be falling head permeability tests if significant aquifers are encountered, particularly in chalk.

The following laboratory tests are to be undertaken where the quality of the samples allows.

Cohesive Soils	**Granular Soils**	**Core Samples**
Moisture Content	Particle Size Distribution	Point Load
Atterberg limits	Bulk density	UCS
Density		
Undrained Triaxial testing		

Table 16. Suggested laboratory testing for borehole samples

Thermal conductivity testing is also likely to be required. Cable specialists should advice on the number and location of samples to be tested.

15.3.4 Marine Geophysics

The offshore geophysical survey is likely to be a seismic survey using a towed boomer; however the geophysical survey contractor will advise on the most suitable technique for the expected geology and bottom profile.

At Site 1 the primary aim of the geophysical survey is to identify the depth to the chalk with secondary aims of locating strata within the sediments and Crag overlying the chalk.

At Site 3a the aim of the geophysical survey is to identify boundaries between loose overlying sediments and any strata of differing density within the Crag. The Chalk is at great depth and not expected to be identified.

15.4. Mitigating the Risk of Drilling Fluid Breakout

15.4.1 HDD Design

A suitable HDD design for the ground conditions is the most effective tool to reduce the risk of drilling fluid breakout.

A preliminary HDD design for the chosen site/s should be drafted once the results from ground investigations (onshore and offshore), soil testing results, topographical and bathymetric surveys, and sea defence design information has all been received.

The preliminary design should then be assessed for the risk of breakout using hydrofracture modelling to allow refinement of the design. A review of drilling and installation forces can also be undertaken along with calculation of cable installation forces.

The hydrofracture modelling will also inform the risks associated with different downhole drilling assemblies and pilot hole diameters, allowing selection of suitable drilling techniques and drilling equipment.

15.4.2 Drilling Procedure

A key component of avoiding breakout is effective removal of the cuttings from the borehole. If cuttings are not removed they form cuttings beds on the base of the borehole, decreasing the cross sectional area of the borehole. This causes an increase in annular pressure and therefore increases the risk of breakout. Cuttings in the borehole also lead to increased drilling forces and can eventually cause equipment to be lost or stuck downhole.

A competent HDD contractor will be proactive in ensuring that cuttings are effectively removed and will spend additional time and effort to reduce the risk of both breakout and stuck equipment. An additional tool that is recommended to assist in monitoring the state of the borehole is Downhole Annular Pressure Monitoring. Supplied as a standard add-on to the guidance equipment the tool measures the pressure in the borehole annulus in real-time. The actual value can be compared to limit values calculated from hydrofracture analysis to avoid damaging the ground surrounding the HDD during pilot hole drilling. By avoiding any over-pressuring of the surrounding ground the risk of surface breakout is greatly reduced.

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APPENDIX A

Aerial Photographs Showing Indicative HDD Alignments at all Sites

Indicative HDD Alignments for Site 1(left) and Site 2 (right) in yellow.

Indicative HDD Alignments for Site 3a (left) and Site 3b (right) in yellow.

Indicative HDD Alignments for Site 4a (left) and Site 4b (right) in yellow.

Indicative HDD Alignments for Site 5 (centre) in yellow.

Indicative HDD Alignments near Horsey for Site 6 (left) and Site 7 (right) in yellow.

Indicative HDD Alignment for Site 8 in yellow.

Indicative HDD Alignments for Site 9 (centre) and Site 10 (bottom) in yellow.

Indicative HDD Alignments for Site 11 (top) and Site 12 (bottom) in yellow.

Indicative HDD Alignments for Site 10 (top) and Site 11 (bottom) in yellow.

APPENDIX B

Results from a search of Magic Map Application of Designations, http://www.magic.gov.uk/MagicMap.aspx

Site	On Site	Nearby
1	None	Marine Conservation Zone - Cromer Shoal Chalk Beds – 200m offshore
2	None	Marine Conservation Zone - Cromer Shoal Chalk Beds – 200m offshore
3a	None	None
3b	None	None
4a	None	None
4b	None	None
5	None	Norfolk Coast AONB – 50m south
6	Norfolk Coast AONB	SSSI: Winterton – Horsey Dunes - 1km SE SPA: Winterton – Horsey Dunes - 1km SE SAC: Winterton – Horsey Dunes - 1km SE National Park – The Broads – 700m SW
7	Norfolk Coast AONB SSSI: Winterton – Horsey Dunes SPA: Winterton – Horsey Dunes SAC: Winterton – Horsey Dunes	National Park – The Broads – 300m SW
8	Inshore SPA with Marine Components - Outer Thames Estuary	None
9	Inshore SPA with Marine Components - Outer Thames Estuary	None
10	Inshore SPA with Marine Components - Outer Thames Estuary	None
11	Inshore SPA with Marine Components - Outer Thames Estuary	None
12	Inshore SPA with Marine Components - Outer Thames Estuary SSSI – Pakefield to Easton Bavents	None
13	Inshore SPA with Marine Components - Outer Thames Estuary SSSI – Pakefield to Easton Bavents	None

NOTE: Nitrate Vulnerable Zones, although designated areas and present in some locations, have been excluded from these search results because they are not expected to affect HDD construction and access.

APPENDIX C

CALCULATION OF ENTRY POINT POSITION (FROM EXISTING SHORELINE) AND MINIMUM HDD LENGTH

SITE	BATHYMETRY				ELEVATION & SET BACK			COASTAL ACCRETION / EROSION						SHORT OPTION LENGTH		LONG OPTION LENGTH		NOTES
	Approximate distance (m) from shoreline to indicated water Depth (metres relative to LAT)				Elevation at likely Entry point	Minimum Setback from existing shore for Depth D(m) below ODN	Minimum Setback for logistical reasons	Shoreline Management Plan (SMP) over Medium Term and Long Term		Average Accretion / Erosion over past 20 yrs	Hypothetical Erosion rate accounting for SMP	Accretion / Erosion over N yrs based on SMP Predictions or Hypothetical rate		Calculated minimum HDD Length to 0m LAT for shoreline position at N years		Calculated minimum HDD Length to 3m below LAT for shore position at N years		
No.	0m	-3m	-5m	-10m	mODN	10	m	20-50 years	50-100 years	m/yr	m/yr	50	100	50	100	50	100	
1	110	320	420	920	5	49		H	MR	-0.9	-1.5	-60	-120	200	260	410	470	
2	120	330	410	680	12	72		MR	MR	-0.9	-2	-160	-180	330	350	540	560	
3a	60	360	440	850	7	56		MR/H	MR/(H)	-1.04	-2	-90	-145	180	240	480	540	On SMP Policy Unit boundary
3b	60	360	440	850	5	49		H	(H)	0.3	-2	-100	-200	190	290	490	590	
4a	50	340	470	1000	3	43	50	H	(H)	2.9	-0.3	-15	-30	120	130	410	420	Historical accretion due to offshore rock walls not expected to continue
4b	90	340	470	1000	4	46	50	H	(H)	2.9	-0.3	-15	-30	160	170	410	420	Historical accretion due to offshore rock walls not expected to continue
5	140	390	500	1100	1	36	80	H	(H)	-1.9	-0.5	-25	-50	250	270	500	520	
6	120	360	550	1200	4	46	120	H	(H)	-0.7	-0.7	-35	-70	280	310	520	550	
7	210	600	1300	1700	0	33		H	(H)	3.8	0	0	0	240	240	630	630	Accretion due to northward migration of Ness unlikley to be sustained
8	60	150	320	2000	12	72	350	NAI	NAI	0.5	-1	-80	-150	490	560	580	650	wreck approx 370m offshore?
9	40	160	260	1600	12	72	400	MR	MR	-1.8	-1.5	-60	-130	500	570	620	690	
10	40	125	150	1100	16	85		MR	MR	-0.5	-1	-90	-140	190	240	280	330	
11	80	260	2900	3900	15	82		NAI	NAI	-1.3	-1.3	-65	-130	200	270	380	450	existing cables700m north of site 10, Offshore shoals
12	90	300	2600	3500	15	82		NAI	NAI	-0.3	-1	-50	-100	200	250	410	460	shoals, cables offshore
13	250	1200	2300	3000	15	82	160	NAI	NAI	-0.8	-0.5	-25	-50	440	460	1390	1410	shoals, cables offshore. Northward advance of Ness expected
NOTES						To attain sufficient depth D(m) at existing shoreline	For example availability of accessible land	H = Hold the line (H) = Conditional Hold MR = Managed Realignment		red indicates average of two monitoring positions		Black indicates SMP predictions, green indicates hypothetical		Assumes HDD exits at 0m LAT and is 3m below the future shoreline		Assumes HDD exits at 3m below LAT and is 3m below future shoreline		

Table 17. Entry position and HDD length calculation.

APPENDIX D

Results from a search of Norfolk Heritage explorer, http://www.heritage.norfolk.gov.uk/map

Note: No Scheduled Monuments Indicated at Sites 1-8

Site 1
Within 100m
- 38687 (Monument) Medieval banks
- 38783 (Monument) World War Two pillbox and site of possible military camp
- 13733 (Find Spot) Medieval coin, near Walcott Gap

Above route:
- 38789 (Monument) Site of World War Two coastal defences

Site 2
On site:
- 41019 (Monument) Prehistoric flints, medieval and post medieval artefact scatter

Above route:
- 38787 (Monument) Site of World War Two coastal defences
- 38685 (Maritime) Undated inter-tidal structure or wreck, Ostend Beach

Site 3a
On site
- 5788 (Monument) Bronze Age barrow cemetery
- 41020 (Monument) Prehistoric and post medeival finds scatter
- 38780 (Monument) Cropmarks of undated ditches
- 38779 (Monument) Cropmarks of possible Bronze Age ring ditch

Above route
- 38781 (Monument) Site of World War Two barbed wire obstructions and possible weapons pits
- 41593 (Find Spot) Prehistoric flint artefacts
- 18662 (Maritime) Site of the Hunter, a post medieval wreck

Site 3b
Covering entry site:
- 38585 (Monument) Cropmarks of possible Roman field system and post medieval field boundaries

Above route:
- 38747 (Monument) World War Two coastal defences

Site 4a
Within 100m
- 25959 (Monument) World War Two pillbox
- 27356 (Monument) Site of World War Two military structures -
- 8347 (Monument) Eccles Deserted Village
- 8346 (Monument) Ruins of St Mary's Church, Eccles-next-the-Sea, Lessingham

21649 (Find Spot) Neolithic stone find

Site 4b

Above route

21649 (Monument) World War Two training site on Sea Palling beach
25961 (Maritime) Undated wreck

Site 5

Above route

27298 (Monument) World War Two pillboxes and defensive structures

Within 100m

30625 (Monument) Undated enclosure
27300 (Monument) World War Two gun emplacement
17013 (Find Spot) Palaeolithic flint handaxe

Site 6

Within 150m:

27244 (Monument) Post medieval ditch earthworks
19687 (Monument) Remains of post medieval building
27252 (Monument) Site of World War Two pillbox

Site 7

In general area

42183 (Monument) World War Two military defences and installations on Winterton beach and dunes

42360 (Monument) Possible medieval or post medieval drains and possible pond or broad

29752 (Monument) Winterton Ness World War Two Naval bombing decoy

Site 8

On site:

43494 (Monument) The cropmarks of an extensive late prehistoric to Early Roman settlement, field system and trackways, Hopton-on-Sea

43495 (Monument) The cropmarks of a planned Roman field system and possible settlement, Hopton-on-Sea

45203 (Monument) Multi-period and undated cropmarks

43517 (Monument) The cropmarks of field boundaries of unknown date

Above route:

42262 (Monument) World War Two coastal and invasion defences

42485 (Monument) World War Two coastal and invasion defences, Gorleston Golf Links

32664 (Monument) World War Two coastal defensive structures

Results from a search of Suffolk Heritage explorer

https://heritage.suffolk.gov.uk/map

Note: No Scheduled Monuments Indicated at Sites 9-13

Site 9

On site

COR 017 (Monument) Field system and trackway of unknown date.

Above route:

COR 043 (Monument) World War II and Cold War radar station with various components

COR 053 (Monument) Machine gun emplacement, Corton

Site 10

On site:

COR 004 (Monument) Findspot of a broken Neolithic chipped flint axe. (Neo)

COR 004 (Monument) Findspot of a sherd of Roman C1 pottery. (Rom)

COR 023 (Monument) Roman artefact satter of 5 coins. (Rom)

COR 023 (Monument) Medieval artefact scatter, including a seal, buckle and coin weight. (Med)

COR 010 (Monument) Medieval artefact scatter of pottery, brick and tile from the Medieval village of Corton. (Med)

Above route

COR 040 (Monument) World War II bombing decoy site surrounded by barbed wire obstruction.

COR 010 (Monument) Medieval artefact scatter of pottery, brick and tile from the Medieval village of Corton. (Med)

COR 055 (Monument) Corton historic settlement core

Site 11

On site:

GSE 044 (Monument) World War II practice trenches and barbed wire obstruction.

GSE 027 (Monument) Irregular oval enclosure of unknown date, visible as a cropmark.

LWT 136 (Monument) World War II military strongpoint with various components. (Rifle Range on 1956 OS map)

Site 12

On site

GSE 045 (Monument) A length of World War II tank trap.

Above route:

GSE 061 (Monument) Pakefield Cliffs; Corton Sea Wall

Site 13

Above route:

KSS 024 (Monument) Medieval artefact scatter of pottery, including bowl rims and a cooking pot rim.

KSS 056 (Monument) Wolrd War II gun emplacement.

APPENDIX E

HDD FEASIBILITY ASSESSMENT MATRIX

	Weighting	4	0	1	2	2	4	1	4	0	1	1	1	0	1	1	2	1	1	1	0	0	1	0
Weighted Score using all Criteria	**SITE**	**DIMENSIONAL CONSIDERATIONS**					**GEOTECHNICAL**		**ENVIRONMENTAL**						**ANTHROPOGENIC**					**CONSTRUCTION LOGISTICS**				
		Elevation at likely Entry point	**Available Rig Site Area**	**Easement Width Restrictn**	**Calculated HDD LENGTH for shoreline position in 2055**		**Geology**	**Groundwater**	**Environmental Designations - Land**	**Environmental Designations - Marine**	**Flood Risk from Rivers and Sea**	**Coastal Defences**	**Predicted 50 year shoreline change**	**Shoreline Management Plan**	**Offshore or Neashore Obstacles**	**Archaeology**	**Residences within 100m of Entry site**	**Residences possibly visible from Entry**	**UXO**	**Access Summary**	**Roads - Single Lane Length**	**New Access Track Length**	**Vehicle access to beach**	**Water Supply**
	No.	**mODN**		**m**	**Short**	**Long**							**m**	**to 2055, 2105**							**m**	**m**		
31	1	2	1	3	2	2	1	2	1	2	4	2	3	2	1	1	2	2	2	1	1	1	1	1
41	2	4	1	1	3	2	3	3	1	2	1	2	4	4	2	1	2	2	2	2	2	1	2	1
35	3a	3	1	1	1	2	2	2	1	1	2	3	3	3	2	3	1	1	2	2	2	2	1	1
36	3b	2	1	3	1	2	2	2	1	1	2	2	3	2	1	3	2	2	2	2	2	1	1	1
40	4a	1	1	2	1	2	3	2	2	1	3	1	2	2	2	1	1	1	2	3	3	3	1	1
42	4b	1	1	2	1	2	3	2	2	1	2	3	2	2	2	2	1	1	2	3	3	1	1	2
46	5	3	1	3	2	2	3.5	3	2	1	3	3	2	2	1	2	2	2	2	1	1	1	1	2
43	6	1	1	1	2	2	3.5	3	3	1	3	1	2	2	1	1	1	1	1	1	1	1	1	2
49	7	3	1	2	2	3	3.5	3	4	1	3	2	1	1	2	1	1	1	2	1	1	1	1	2
42	8	4	1	1	4	2	3.5	2	1	2	1	2	3	3	2	4	1	1	3	2	1	3	2	1
46	9	4	1	1	4	3	3.5	2	1	2	1	3	3	3	1	2	2	3	4	1	1	1	4	2
45	10	4	1	1	1	1	3.5	2	1	2	1	3	3	3	1	2	2	2	3	2	1	1	4	2
41	11	4	1	1	2	1	3.5	2	1	2	1	1	3	3	2	2	1	2	4	2	1	3	2	2
54	12	4	1	1	2	2	3.5	2	3	2	1	1	3	3	2	1	3	4	4	2	1	3	2	2
54	13	4	1	2	4	3	3.5	2	3	2	1	1	2	2	2	1	4	4	3	2	1	3	2	1
	KEY	2-4	Ample	Good	<200	<400	Good	Good	Low risk	Low risk	None	Low risk	>= 0	Low risk	Low risk	Unlikely	Low risk	Low risk	UXO unlikley	Low risk	Low risk	Low cost	Low risk	Low cost
	KEY	4-6	Constraint	Acceptable	200-299	400-599	Fair	Fair	Caution	Caution	Very Low	Caution	0 to -50	Caution	Caution	Minor	Caution	Caution	UXO possible	Caution	Caution	Low-med	Caution	Low-med
	KEY	6-8, <2	Difficult	Caution	300-399	600-799	Caution	Caution	Problematic	Problematic	Low	Problematic	-50 to -10	Problematic	Problematic	Possible	Problematic	Problematic	UXO prob rqd	Problematic	Problematic	Med cost	Problematic	Med cost
	KEY	>8	Insufficien	Too narrow	>400	>800	Difficult	Difficult	Avoid	Avoid	High	Avoid	> -100	Avoid	Avoid	High	Avoid	Avoid	UXO rqd	Avoid	Avoid	High cost	Avoid	High cost

APPENDIX F

Site Visit Photographs

Figure 28. Site 1. View of field from B1159 southward with likely entry point mid photograph.

Figure 29. Site 1. View to Southeast from above the potential HDD alignment showing coastal defences and B1159.

Figure 30. Site 2. View from likely entry point (right of picture) southwards to Happisburgh.

Figure 31. Site 2. View Northward towards Ostend. HDD route is through mid distance with likely entry point to left of photograph, exit point on right between the groins but beyond their seaward end. Note cliff height and coastal erosion.

Figure 32. Site 3a. View to southwest from beach access. Beach access will periodically require reinstatement as coastal erosion advances. Site 3a entry point is in far distance before the small headland.

Figure 33. Site 3a. Cliffs at base of access ramp. Cliffs at the site of 3a are half the height (approximately 6m) and consists of the clayey fine sand seen in the upper half of the cliff here. The lower half of this photograph shows glacial till that will form the ground at sea level at Site 3a.

Figure 34. Site 3a. View of field containing entry site. Site is approximately 100m from the viewpoint.

Figure 35. Site 3b. Beach access ramp at Cart Gap, adjacent to Site 3b.

Figure 36. Site 3b. View south from beach access ramp. HDD alignment will be between the ramp and the wooden groyne in mid distance.

Figure 37. Site 3b. Google street view looking east from Cart Cap Road showing field for entry point.

Figure 38. Site 4a. Beach access at North Gap. HDD alignment is 70m to the right of the photograph.

Figure 39. Site 4a. Looking southeast from beach access at North Gap. HDD alignment 4a is 70m along the beach in the mid distance. The alignment for 4b passes between the first and second rock walls in the far distance.

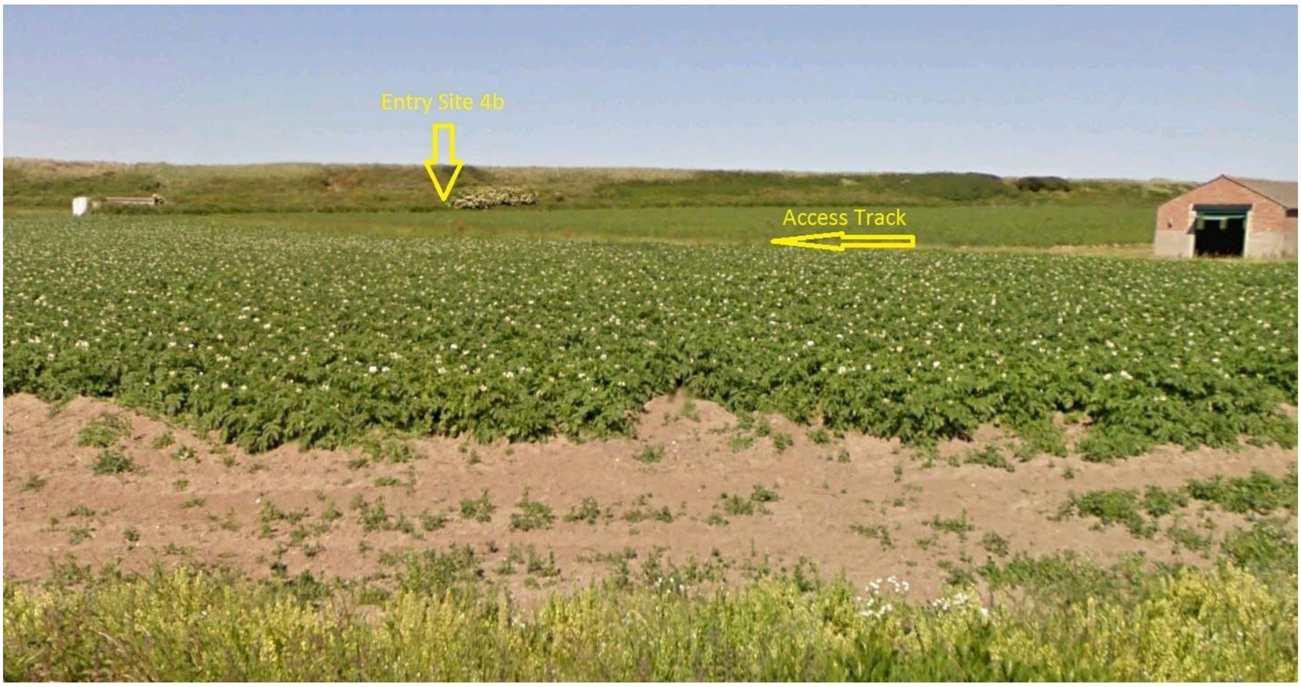


Figure 40. Site 4b. Google Street View from lane looking northeast. Potential HDD entry point is in centre of photograph at far edge where the fields meets the dunes.

Figure 41. Site 5. Beach defences looking south east from Sea Palling beach access. Offshore rock walls are 250m from the shore. The concrete shoreline defences continue beyond the HDD alignment, 300m from the viewpoint. Alignment 5 passes to the left of the offshore rock wall on the left of the photograph.

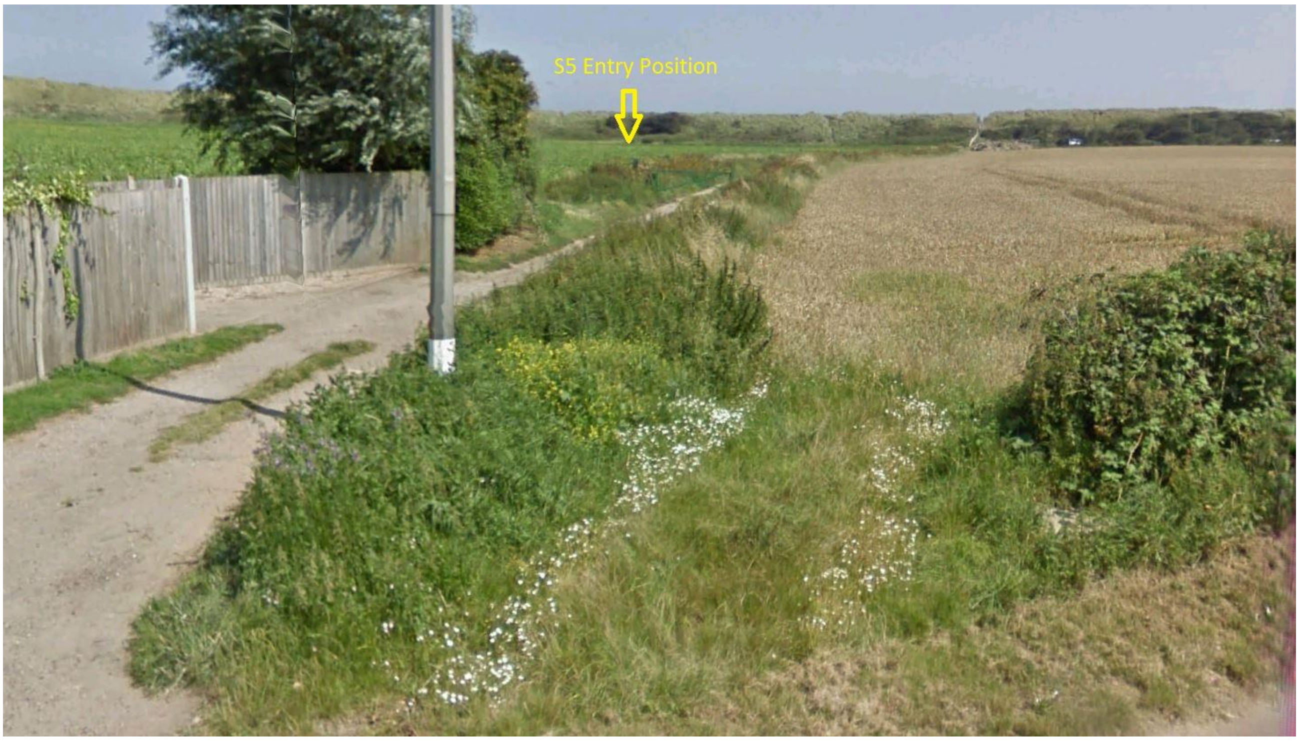


Figure 42. Site 5. Google Street View from Waxham Road looking north-northeast. Potential HDD entry point at end of the field before the dunes. Access track in foreground and junction with Waxham Road might require upgrading for HDD equipment.

Figure 43. Site 6. View from Church Road Waxham to location of Site 6 in centre far distance showing fields leading behind the coastal dunes.

Figure 44. Site 7. Sea defences at Site 7 looking to the northwest.

Figure 45. Site 7. Beach access looking back to potential HDD entry site.

Figure 46. Site 8. Google Street View Photograph of potential access point from the A12. HDD entry point is beyond the line of the trees in the distance.

Figure 47. Site 8. Coastal defences and dune / cliffs near Site 8.

Figure 48. Site 8. Cliff near Site 8 showing eroding sand with some gravel and clay layers.

Figure 49. Site 8. View southwards towards Site 8 from Marine parade Gorleston. Site 8 HDD alignment is located at the 5th Groyne along.

Figure 50. Site 9. Google Earth Panoramio photograph showing damaged sea wall near Site 9. There is now no pedestrian access either along the cliff top or down on the beach except at very low tides with difficulty.

Figure 51. Site 9. Google Earth Panoramio photograph viewed southwards towards Broadlands Sands Holiday Park. Site 9 HDD route crosses the cliffs 50m beyond the people in mid distance. Erosion has since reached the boundary fence, taking the coastal footpath and preventing access. Vehicle access to a short HDD exit position would be very difficult due to sea defences.

Figure 52. Site 9. Google Street View from Coast Road looking eastward towards the coastal cliffs. Approximate line of HDD is indicated in yellow. Building in far distance, centre is a WWII defensive post at the cliff edge.

Figure 53. Site 10. View southwards towards the route of Site 10 HDD, approximately in the middle of the field. Coastel defence structures can be glimpsed on the left of shot.

Figure 54. Site 10. View northwards from Site 10 illustrating the coastal topography and sea defence structures.

Figure 55. Site 11. Coastal cliffs at Site 11 showing erosion of fine sands.

Figure 56. Site 11. Former Artillery Range and Military structures 80m south of Site 11 HDD alignment .

Figure 57. Site 11. View to field that is the potential entry site for Site 11. Phtoograph is taken from clifftop towards the west.

Figure 58. Site 11. View from clifftop near Site 11.

Figure 59. Site 12. Footpath to Pakefield Coastwatch Tower showing eroding cliffs of fine sand.

Figure 60. Site 12. View south from below Pakefield Coastwatch Tower. The HDD for Site 12 would pass approximately beneath the closest pedestrians.

Figure 61. Site 13. Potential HDD entry point in field 30m from viewpoint. Residential properties overlooking the field in the distance.

Figure 62. Site 13. View south from Cliff Farm Lane footpath, 600m north of Site 13. Approximate HDD route indicated in yellow across the Ness. The photograph gives an indication of cliff heights and the width of the Ness.

Figure 63. Site 12-13. Heavy haulage transported by prime movers at front and rear on the A12.

APPENDIX G

Drawings

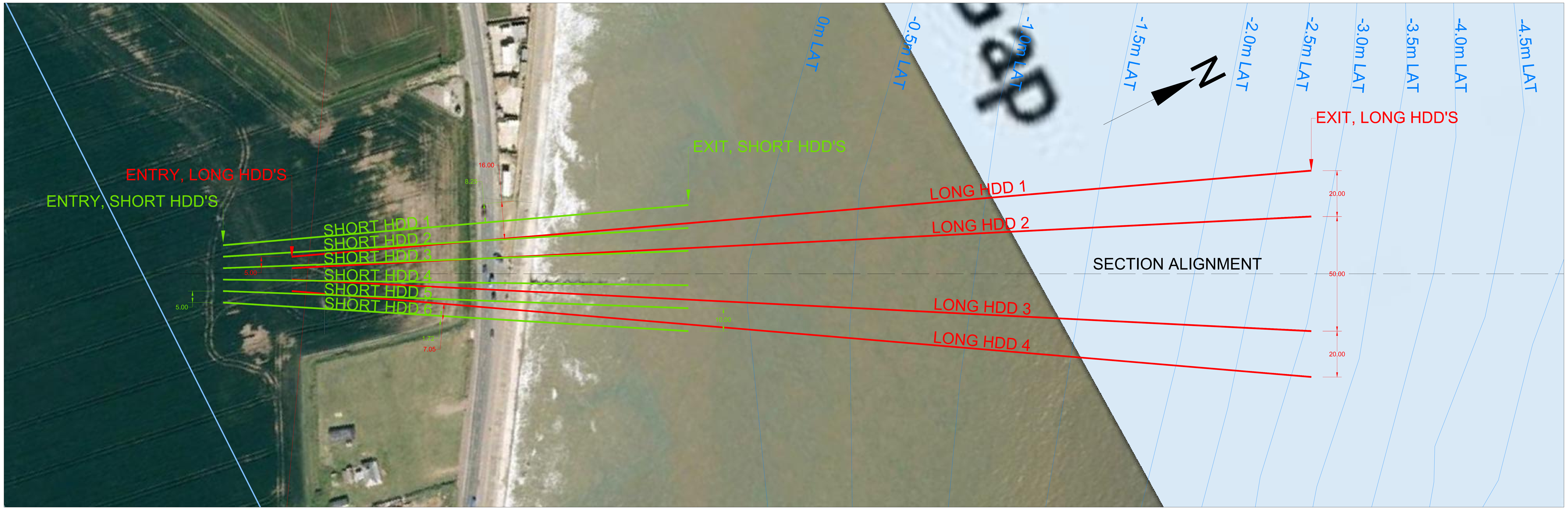
Drawing No's:

20151001RA-C/01 – Conceptual HDD Designs Site 1

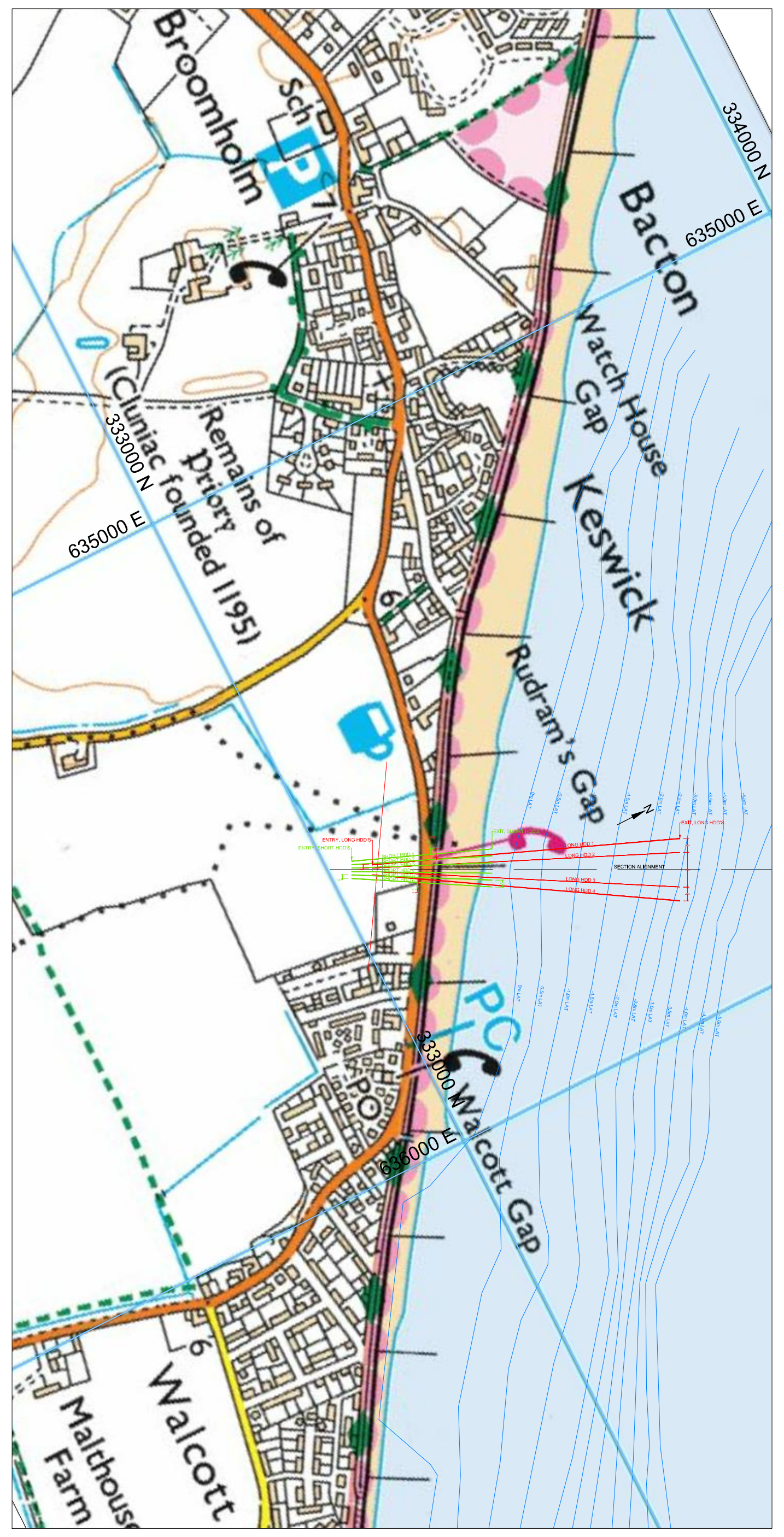
20151001RA-C/02 – Conceptual HDD Designs Site 3a

20151001RA-C/03 – Conceptual HDD Site Layout Site 1

20151001RA-C/04 – Conceptual HDD Site Layout Site 3a

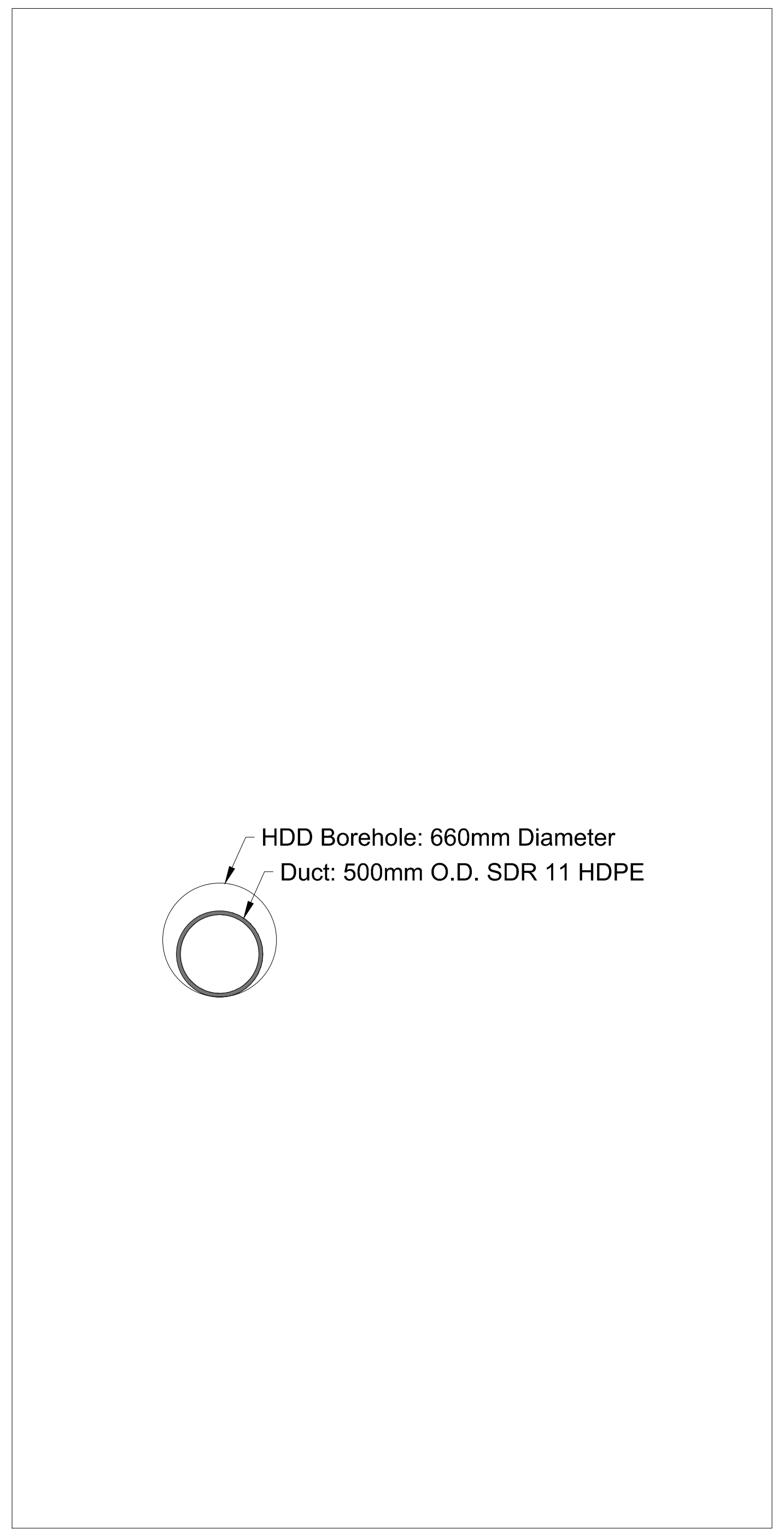


PLAN VIEW - SITE 1



GENERAL LOCATION

SECTION VIEW - SITE 1



DUCT DETAIL

NOTES

1. ALL DIMENSIONS, LEVELS AND CHAINAGES ARE IN METRES UNLESS OTHERWISE STATED. PROPOSED BOREHOLES ARE INDICATED BY YELLOW MARKERS.
2. LAND ELEVATIONS ESTIMATED FROM OS MASTERMAP1:25,000 MAPPING
3. LAT ESTIMATED AT -2.20 ODN FROM INTERPOLATION OF VALUES AT CROMER AND WINTERTON.
4. OS MAPPING AND AERIAL PHOTOGRAPHY CONFLICT ON POSITION OF TIMBER GROYNE. POSITION TO BE SURVEYED FOR ANY FURTHER DESIGNS.
5. GEOLOGY IS BASED ON INTERPRETATION OF AVAILABLE BGS BOREHOLE LOGS AND MAPPING THAT MAY BE SOME DIATANCE AWAY. FURTHER GROUND INVESTIGATIONS WILL BE REQUIRED TO BETTER DETERMINE CONDITIONS AT SITE.

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A	08/02/2016	Draft for discussion	TR

Client
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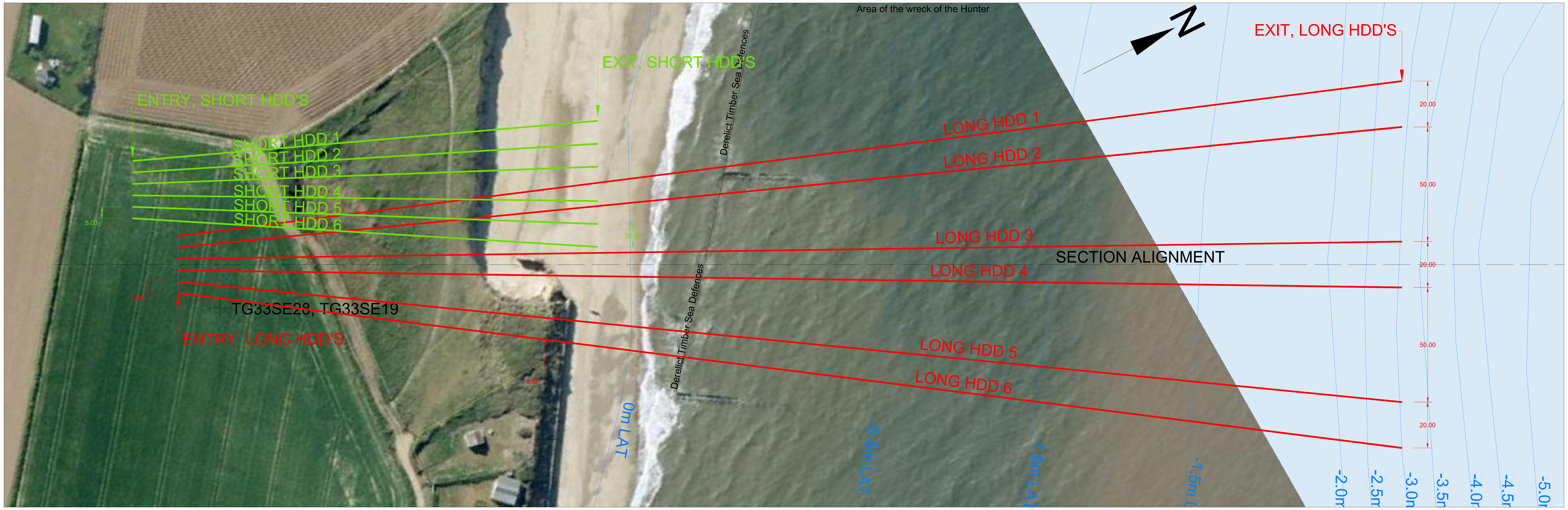
Drawing Number
20151001RA-C/01

Issue
A

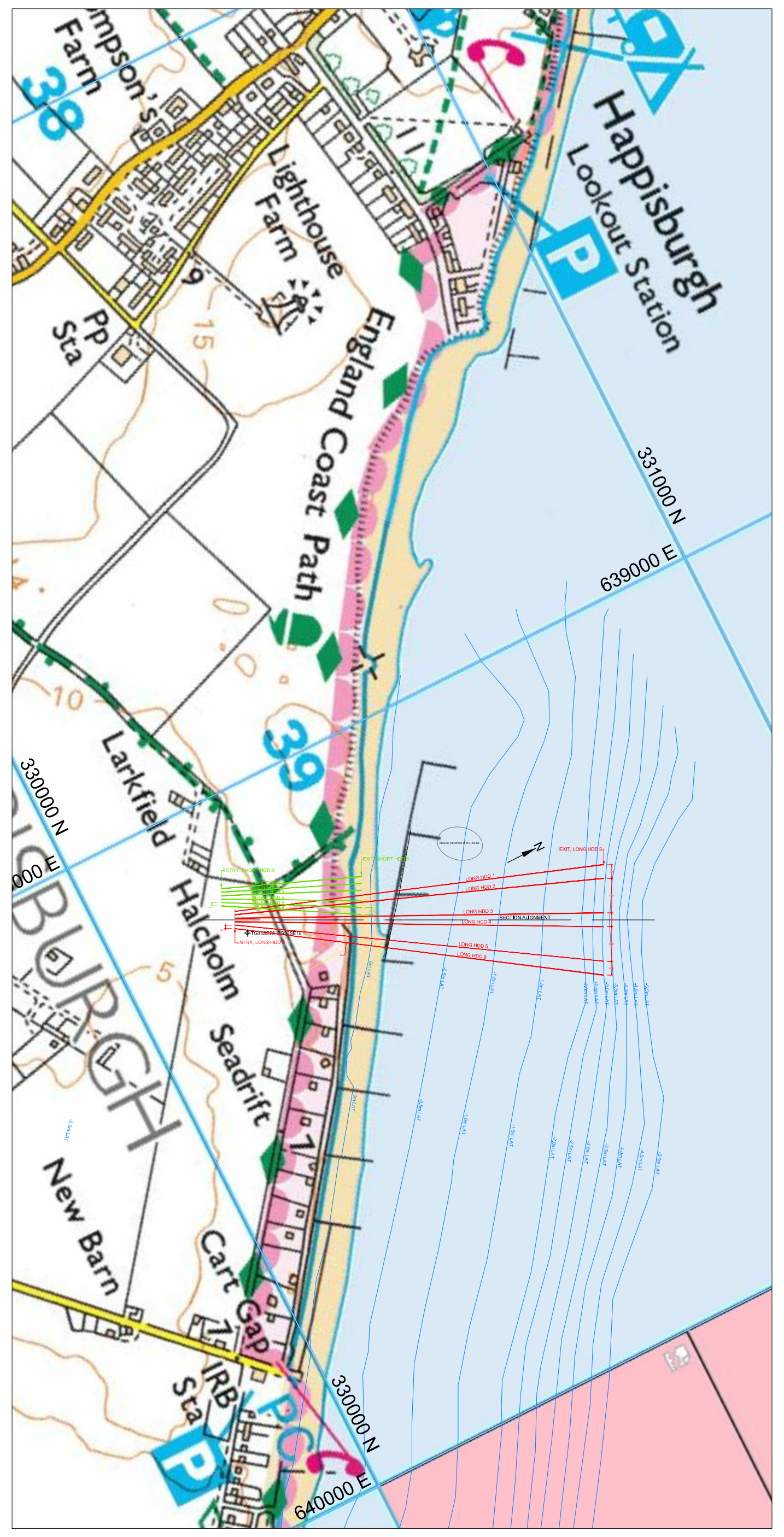
Project Title
EAST ANGLIA NORTH TRANCHE 1 (EAN)
HDD FEASIBILITY STUDY

Drawing Title
CONCEPTUAL HDD DESIGNS
SITE 1

Riggall
& Associates
7 Fairview Close
Watledge
Nailsworth
GL6 0AX
U.K.
Telephone: +44 (0)1453 833913
Email: admin@riggallandassociates.co.uk

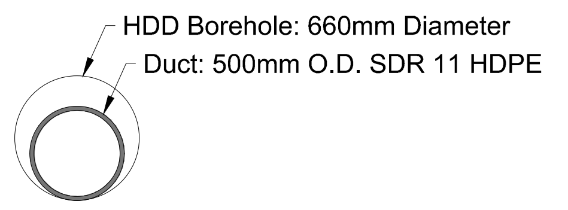


PLAN VIEW - SITE 3a



GENERAL LOCATION

SECTION VIEW - SITE 3a



DUCT DETAIL

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2. LAND ELEVATIONS ESTIMATED FROM OS MASTERMAP1:25,000 MAPPING
3. LAT ESTIMATED AT -2.20 ODN FROM INTERPOLATION OF VALUES AT CROMER AND WINTERTON.
4. POSITION OF SEA DEFENCES TO BE ACCURATELY SURVEYED FOR ANY FURTHER DESIGNS.
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Client
VATTENFALL WIND POWER LTD

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TR			

Drawing Number
20151001RA-C/02

Issue
A

Project Title
EAST ANGLIA NORTH TRANCHE 1 (EAN)
HDD FEASIBILITY STUDY

Drawing Title
CONCEPTUAL HDD DESIGNS
SITE 3a

Riggall
& Associates
7 Fairview Close
Watledge
Nailsworth
GL6 0AX
U.K.
Telephone: +44 (0)1453 833913
Email: admin@riggallandassociates.co.uk

PLAN VIEW - SITE 1

NOTES

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2. LAND ELEVATIONS ESTIMATED FROM OS MASTERMAP1:25,000 MAPPING
3. LAT ESTIMATED AT -2.20 ODN FROM INTERPOLATION OF VALUES AT CROMER AND WINTERTON.
4. POSITION OF SEA DEFENCES TO BE ACCURATELY SURVEYED FOR ANY FURTHER DESIGNS.
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Rev	Date	Description	By

Client
VATTENFALL WIND POWER LTD

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TR			

Drawing Number
20151001RA-C/03

Issue
A

Project Title
EAST ANGLIA NORTH TRANCHE 1 (EAN)
HDD FEASIBILITY STUDY

Drawing Title
CONCEPTUAL HDD SITE LAYOUT
SITE 1

Riggall
& Associates
7 Fairview Close
Watledge
Nailsworth
GL6 0AX
U.K.
Telephone: +44 (0)1453 833913
Email: admin@riggallandassociates.co.uk

PLAN VIEW - SITE 3a

NOTES

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3. LAT ESTIMATED AT -2.20 ODN FROM INTERPOLATION OF VALUES AT CROMER AND WINTERTON.
4. POSITION OF SEA DEFENCES TO BE ACCURATELY SURVEYED FOR ANY FURTHER DESIGNS.
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Client
VATTENFALL WIND POWER LTD

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Designed by	**Checked by**	**Approved by**	**Date approved**
TR			

Drawing Number
20151001RA-C/04

Issue
A

Project Title
EAST ANGLIA NORTH TRANCHE 1 (EAN)
HDD FEASIBILITY STUDY

Drawing Title
CONCEPTUAL HDD SITE LAYOUT
SITE 3a

Riggall
& Associates
7 Fairview Close
Watledge
Nailsworth
GL6 0AX
U.K.
Telephone: +44 (0)1453 833913
Email: admin@riggallandassociates.co.uk