Norfolk Vanguard Offshore Wind Farm

Appendix 4.5

HDD Feasibility Report for EAN Bacton Green Site

Environmental Statement

Volume 3 - Appendices

Applicant: Norfolk Vanguard Limited Document Reference: 6.2.4.5
RHDHV Document Reference: PB4476-005-0045
Pursuant to APFP Regulation: 5(2)(a)

Date: June 2018
Revision: Version 1
Author: Riggall and Associates Ltd

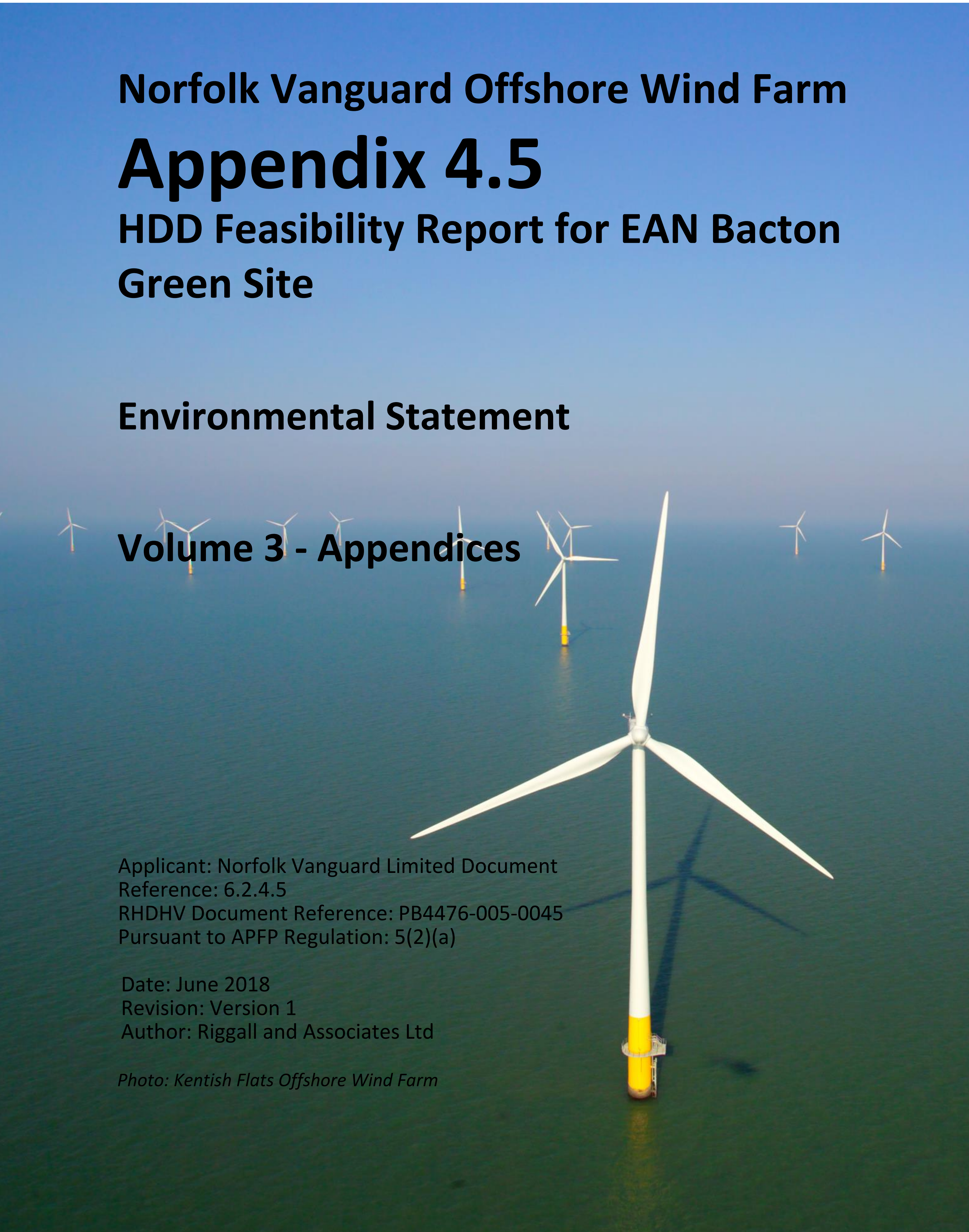

Photo: Kentish Flats Offshore Wind Farm

Environmental Impact Assessment
Environmental Statement

Document Reference: PB4476-005-0045

June 2018

For and on behalf of Norfolk Vanguard Limited

Approved by: Ruari Lean, Rebecca Sherwood

Signed: [redacted]

Date: 8th June 2018

Riggall & Associates Ltd.

HDD FEASIBILITY REPORT

Potential Cable Landfall site at Bacton Green for East Anglia North Tranche 1 (EAN) U.K.

Client: Vattenfall Wind Power Ltd

Date of Issue: 10th October 2016

Report Reference No.: 20160901RA-FR01

Report Issue: Rev 00

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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). Riggall & Associates have previously produced a HDD Feasibility Report (Report Ref. No. 20151001RA-FR01) evaluating 13 potential landfall sites along 47km of coastline to the south of Bacton Green. Following evaluation by Vattenfall, Sites 1, 2 and 3 from the report have been selected for further consideration.

Following completion of the original feasibility report Vattenfall have also identified a location at Bacton Green at the northernmost end of the original search area. The site was not evaluated in the original report but merits further investigation. This report assesses the Bacton green site as a potential HDD landfall location 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 the feasibility of the potential HDD's at Bacon Green. Additionally the feasibility of the Bacton Green site will be compared to Sites 1, 2, and 3 identified in the previous HDD Feasibility Report.

1.3. Reference Documents

The following documents and information sources have been reviewed for this report:

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 27/9/2016	Ordnance Survey
Google Aerial Mapping	Aerial mapping	Accessed 27/9/2016	Google
BGS Geology of Britain Viewer	http://mapapps.bgs.ac.uk/geologyofbritain/home.html 1:50 000 mapping of superficial and bedrock	Accessed 27/9/2016	British Geological Survey
BGS Borehole Logs: TG33SW1 TG33SW3 TG33SW23 TG33SW29 TG33SW65 TG33SW66	Publically available borehole logs.	Accessed 27/9/2016	British Geological Survey
Shoreline_management_plan Kelling-Lowestoft.pdf	Kelling to Lowestoft Ness Shoreline Management Plan	Final Report 3/1//2010 Adopted August 2012	AECOM Limited

Filename / Source	**Title / Description**	**Doc No. and Issue**	**Author**
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
20151001RA-FR01 HDD Feasibility Report for EAN - Rev01.docx	HDD Feasibility Report - Cable Landfalls for East Anglia North Tranche 1 (EAN), U.K.	20151001RA-FR01 26th February 2016	Riggall & Associates Ltd

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. The nearest geotechnical borehole log is located 500m north in the Bacton Gas Plant. The log details SPT values but does not give results of geotechnical testing on samples. 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 SITE

The Bacton Green site is located 14km east-south-east of Cromer on the Norfolk Coast. The general location of the site is shown in Figure 1, along with the location of Sites 1, 2, and 3 from the previous HDD Feasibility Study for comparison. Indicative HDD alignments for the site are shown in Appendix D. The Ordnance Survey grid reference for the site is TG 33879 34256.

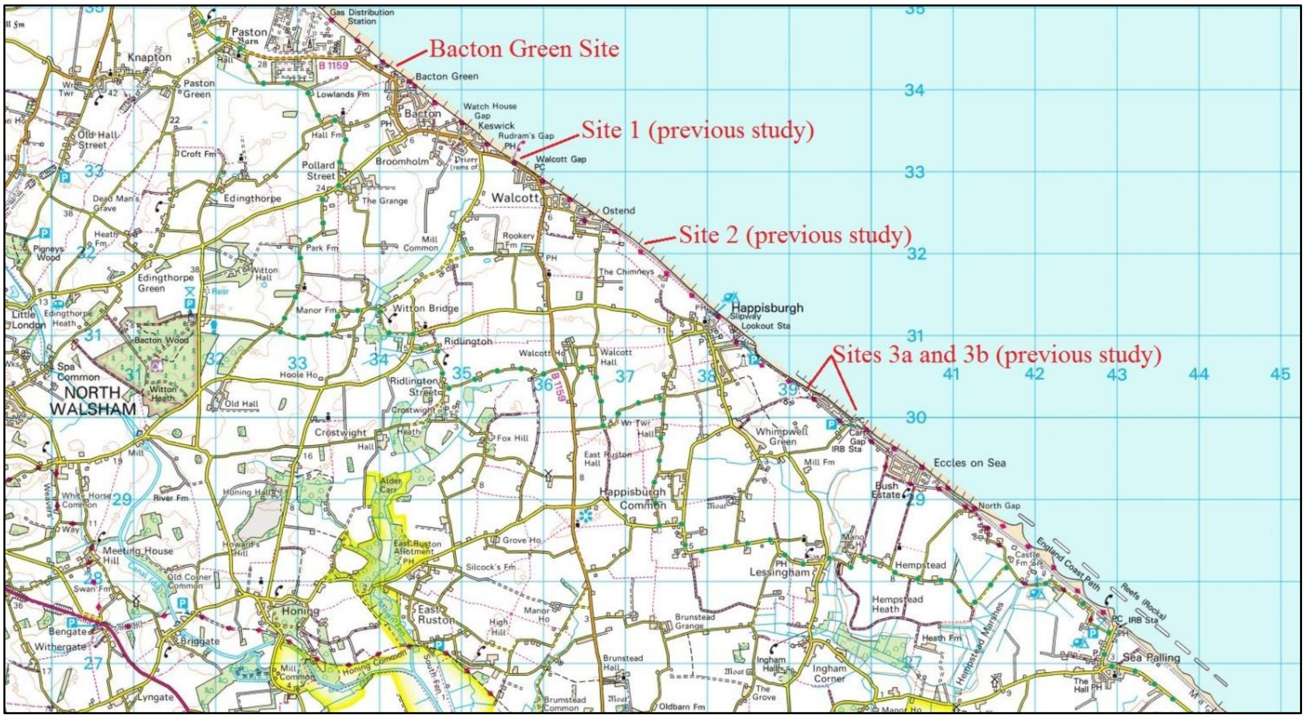

Figure 1. General Location Bacton Green site and sites 1, 2 and 3 from the previous HDD Feasibility Report.

Two possible HDD drilling alignments have been identified at the Bacton Green site. The first alignment, Design 1, is perpendicular to the coastline (bearing 035°). The second alignment, Design 2, is at an angle to the coastline (bearing 060°) in order to avoid indicated existing offshore pipelines and cables. The designs are shown in Drawing No. 20160901RA-C/02 in Appendix D.

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.

At Bacton Green the Holocene Alluvium is only present in any thickness as beach deposits on the beach. The geology exposed in the coastal cliffs are fluvial and glacial deposits shown on BGS mapping as the Head deposits overlying the Happisburgh Glacigenic Formation, although Lee (2008) identifies them as belonging to the Sheringham Cliffs Formation. The Head deposits are remobilised sediments derived from the underlying Happisburgh / Sheringham Formation and similar in composition. The outcrops in the cliffs at the north end of the site are predominantly silty gravelly fine SAND with occasional cobbles. The composition of the gravel and cobble includes chalk and flint. In the lower parts of the cliffs near beach level the outcrops tend towards clayey SAND with gravel.

Based on information from surrounding BGS boreholes the Crag deposits are below sea level with the uppermost level of the Crag probably being the blue clay of the Cromer Forest Beds at approximately -3m ODN elevation. The base of the Forest Beds is at approximately -9m ODN and they are underlain by grey to black sharp sands belonging to the Crag Formation. Underlying the Crag is Chalk with the upper surface being at approximately-15m ODN.

A summary of the general geology at Bacton Green is given in Table 2 below.

GENERAL STRATIGRAPHY AT THE BACTON GREEN SITE		
UNIT	**DESCRIPTION**	**THICKNESS**
Holocene Alluvium:	Marine Beach deposits (Sand And Gravel, significant thicknesses only on the beach)	0 – 3m estimated
Happisburgh Glacigenic Formation	Medium dense to very dense silty Sand And Gravel in the upper sections, clayey Sand and Gravel in the lower sections. Superficial Deposits formed up to 3 million years ago in the Quaternary Period. Local environment previously dominated by ice age conditions	Up to 12m.
Wroxham Crag Formation:	Blue Clay of the Cromer Forest Beds in the upper sections. Predominantly grey to black sharp sands and silts in the lower sections. The deposits are interpreted as estuarine and near-shore marine.	12m
Chalk	Chalk with flints. With discrete marl seams, nodular chalk, sponge-rich and flint seams throughout	>10m

Table 2. General stratigraphy of the Bacton Green Site.

3.2. Suitability of Ground Conditions for HDD

3.2.1 Holocene Alluvium

The sands and sands and gravels of the Holocene Alluvium are only expected to be encountered at Bacton Green at the exit of the HDD, particularly if the exit is close to the shore. Provided they are not of significant depth (>4m) they are not expected to be problematic. Greater thicknesses might require excavation from the exit point in order to mitigate the risk of gravels being dragged into the HDD during duct installation.

3.2.2 Glacigenic Formation

The silty gravelly SAND exposed in the low coastal cliffs tend to be fine grained with gravel content varying from none up to 25% in some layers. They 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. However the sections of the HDD's above sea level will be unsupported by drilling fluid once the HDD exits on the seabed and susceptible to collapse.

The beds seen in the cliffs are stratified with some layers containing higher clay compositions. This is likely to assist in supporting the borehole, and any collapses are expected to be localised. Provided the standard procedure is followed of pulling a reamer in front of the duct during installation there is a low risk of any collapses being problematic.

BGS Borehole TG33SW66 (450m northwest of the site) noted "blowing" sands at 10.5m depth in what is likely to be glacigenic sands and there is a chance that similar conditions exist in pockets below the site. Ground investigations will assess this risk, however it is not expected to be problematic for the HDD as drilling fluid pressure typically counters any groundwater pressures that might be causing blowing sands.

Figure 2. Glacigenic deposits exposed in the cliffs just north of the potential drilling alignment. These figures are also provided at larger scale in Appendix C.

3.2.3 Wroxham Crag

The Wroxham Crag is typically 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 3 illustrates some typical coarser grained layers within the Crag from another Norfolk location. The BGS boreholes around the site describe the Crag as sand or sharp sand and in this area the gravel content could therefore be low.

Based on the surrounding BGS borehole logs the Crag should be a stable formation in which to drill a HDD. Drilling equipment will probably need to be designed to cope with the presence of flint gravel within the very stiff sand matrix, and in places there might be ironstone layers. Another potential risk is the possibility of running sands within the Crag, mentioned by Ander *et Al* (2006) in their regional analysis of the Crag. None of the surrounding BGS borehole logs indicate running sand in the Crag however and the desk study for the areas to the south (report 20151001RA-FR01) suggested that the occurrence of running sands was unlikely in the northern sites, and by extrapolation at Bacton Green.

Ground Investigations boreholes will allow an evaluation of any flint content in the Crag. Flint 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 and price by the HDD contractor.

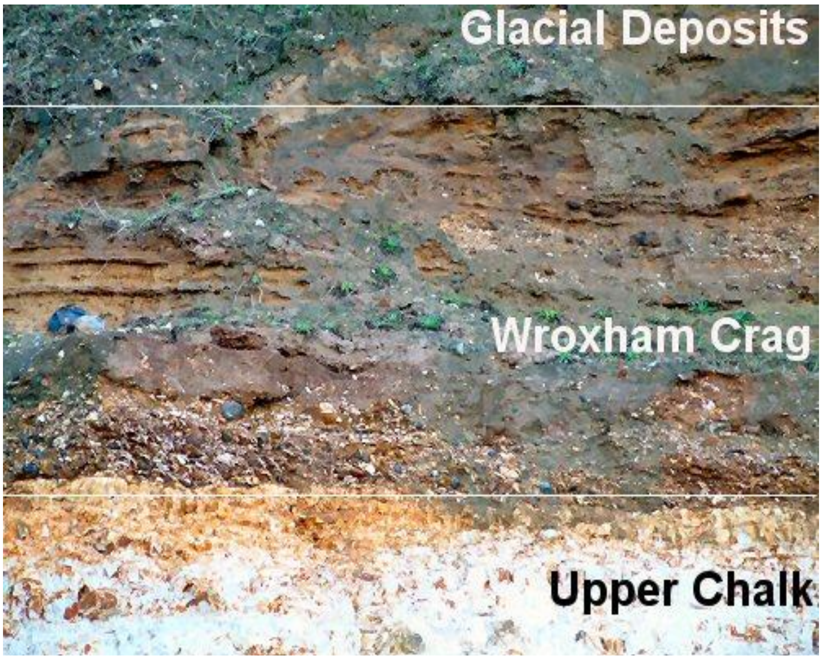

Figure 3. Cliff exposure from Weybourne, Norfolk showing Crag deposits. Photograph from http://www.weybourne.ukfossils.co.uk/Weybourne-Fossils-Geology/geology-guide.htm.

3.2.4 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 nearby BGS borehole TG33SW23 identified the upper 7.5m of the chalk being soft 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, however for the Bacton Green site they are shown as being 2km or more offshore of the potential HDD exit points.

3.3. 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. The study area is not 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 2.0km of the site are:

Bore 1.3km west- northwest at Bacton Gas Plant, medium size abstraction for industrial use.

Bore 1.1km west at Bacton Gas Plant, small size abstraction for industrial use.

Bore 1.7km south-south-east, medium size abstraction for agricultural use.

Given the location of the HDD's on the low lying coastal margin it is unlikely that groundwater flow 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 the site is over 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.

The nearby water bores encountered water at 12m depth (the base of the silty gravelly SAND) and 25m depth (the top of the chalk.

Groundwater is not under artesian pressure and should be sealed by drilling fluid. There is no indication of collapsing ground in the borehole logs.

3.4. 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.

When the drill exits on the seabed the drilling fluid will equilibrate to the sea level. The elevation at the Bacton Green entry site is likely to be 9m ODN. Using Table 3 below the length of unsupported borehole (after sea exit) for is likely to be in the order of 30-35m and can potentially be mitigated by installation of temporary steel casing. However given the density of the glacigenic sands that will form the dry section of hole casing is probably not required.

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

3.4.1 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. For the purpose of this study we will assume that at Bacton Green LAT = -2.20mODN

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.

3.4.2 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.

Bacton Green – maximum tidal range 4.38m

3.4.3 Depth of Cover of HDD

For the assessment of suitable sites the previous HDD Feasibility Study assumed that all HDD's will have a similar vertical profile and similar depth of cover. This assumption is also applied in the assessment of Bacton Green for consistency. The depth of cover will impact on thermal conductivity and therefore cable rating. While 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 3.4.

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.

The environmental designations from Bacton Green and the previous study sites have been subjectively taken into account in the assessment of site suitability (see Table 6). This was done 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 the Bacton Green site.

4.1.1 Land Area Designations

There are no land based designations in the vicinity of the site.

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 the site. The MCZ begins 200m offshore from OS Mastermap MLW. The exit point of the short landfall options 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 6) the item has been marked amber, however this will need to be reviewed by environmental and / or consenting specialists.

Proposed Special Area of Conservation (inshore and offshore):
The site is covered by the proposed Southern North Sea SAC. The designation is to protect the harbour porpoise, *Phocoena phocoena*. The SAC is 500km in length with the coastline affected from Mundesley (4km northwest of site) down to Thorpness, 75km south in Suffolk. This proposed SAC also covers Sites 1, 2, 3a and 3b from the previous study but was not noted in the previous HDD Feasibility Report; the draft proposal was published in January 2016. Because the pSAC covers all of the areas it is not a considered as a factor in ranking the feasibility of the sites.

4.2. Coastal Erosion

The section of Norfolk coastline containing the Bacton Green site is 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.

A Shoreline Management Plans (SMP) has been developed for Kelling to Lowestoft Ness that covers the Bacton Green site. The SMP indicates coastal management policy for the Short (to 2025), Medium (to 2055) and Long term (to 2105). The proposed strategies (e.g. No Active Intervention, Managed Realignment, or Hold the Line) at the site have been taken into account for their impact on the position of the HDD entry site and length of drill. The policies given in the report are as follows.

Policy Unit	Short Term (to 2025)	Medium Term (to 2055)	Long Term (to 20105)
6.10 – Bacton Gas Terminal	Hold	Hold	Hold
6.11 – Bacton, Walcott and Ostend	Hold	Managed Realignment	Managed Realignment

The policy boundary between Unit 6.10 and 6.11 is 380m northwest of the site and is visible in Figure 4 as the most northerly point of the yellow shaded medium term erosion.

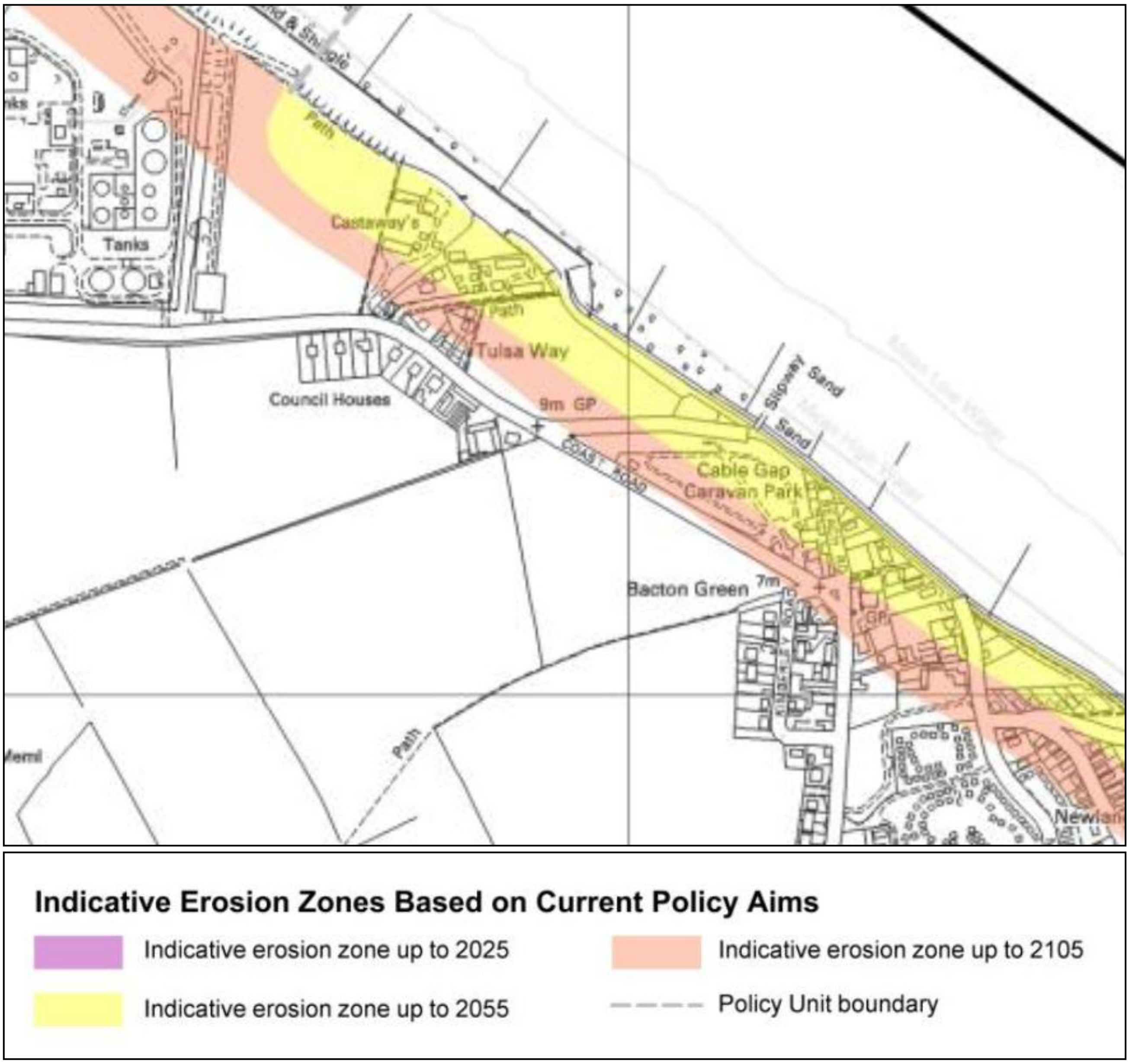

Figure 4. Extract from the Kelling to Lowestoft Ness SMP showing indicative erosion at Bacton Green site.

The Kelling to Lowestoft Ness SMP gives indications of possible shoreline positions in the medium and long term (2055 and 2105) as shown above in Figure 4. This has been taken into account in determining and the required position of the HDD entry point, although the geometry required to pass beneath the sea defences is also critical at this site and the entry point has been placed as close to The B1159 Coast Road as possible.

4.2.1 Coastal Defences

To combat the effects of coastal erosion on property and resources much of the Norfolk coastline has been protected with coastal defences. The Bacton Green site is protected by a number of different styles of defence. In front of the site is a concrete seawall as well as projecting timber groynes. To the north of the site there is a sloping timber revetment that is now detached from the eroded land behind it that have used rock groynes for protection. The different styles of defences used can be clearly seen in Figure 15 to Figure 18 (Appendix C) taken on the site visit.

The toe of the concrete seawall is secured by steel sheet piling and the depth of the piles will need to be determined for any final HDD design. 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 along the Norfolk coast that are used for coastal defences construction and the measures length of these match the standard 12m length.

The drawing in Figure 5 from Withers (2001) indicates the likely design of the sea wall defences at Bacton green 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.

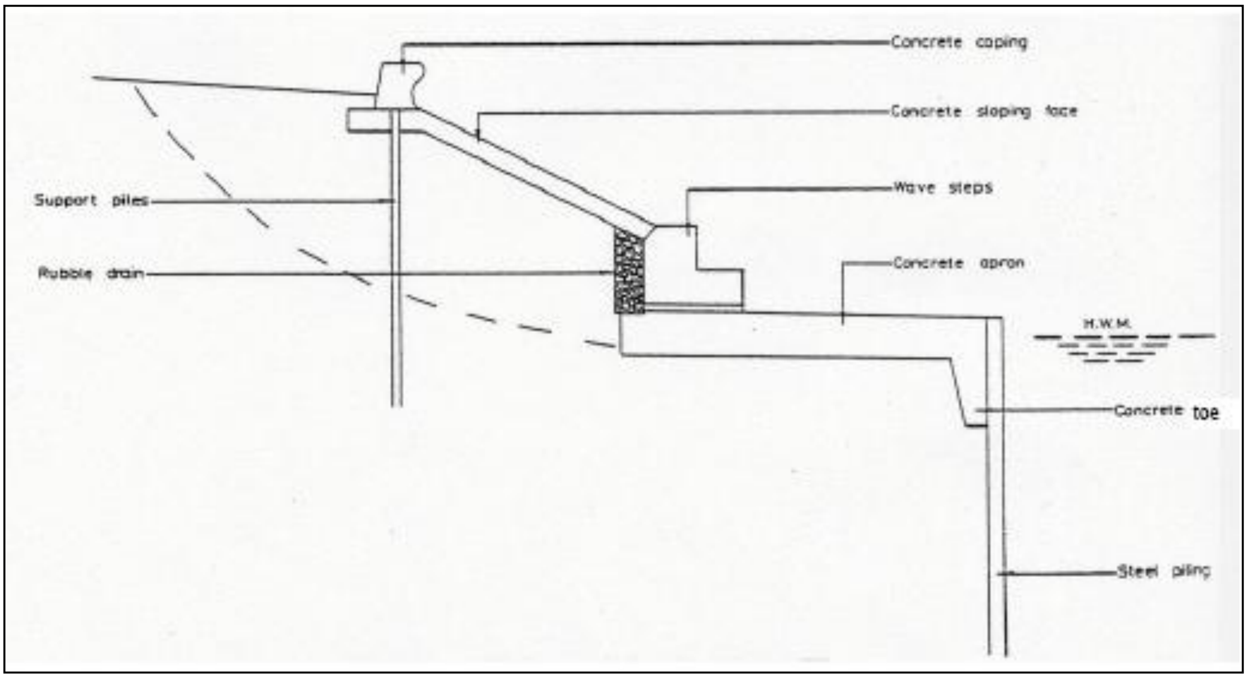

Figure 5. Sloping seawall design, such as that built at Bacton and Walcott around 1954. From Withers (2001).

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 12 in Appendix A 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 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 from the previous study 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.

4.3. Flooding

The Bacton Green site is highly unlikely to be subjected to flooding. The elevation of the site is 8m to 10m ODN. There are no rivers adjacent to the site and there is no significant catchment area that would lead to surface runoff flooding the site. Tidal surge events within the last 100 years have been at lower elevations; the 1953 tidal surge affected land below +3.75m ODN and the 2013 event was at a lower elevation than the 1953 surge.

5. ANTHROPOGENIC FACTORS

A number of anthropogenic (mad made) factors have been considered in the Site Assessment Table (Table 6) for ranking the sites. Assessment of archaeological potential at the sites is primarily based on Norfolk Heritage Explorer (NHE) Mapping.

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. 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. 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.

5.1. Archaeology

The Norfolk coastline has a long archaeological history and this is outlined in the previous Feasibility Report. Archaeology at the site is only expected to have potential to affect the entry pit excavation and possibly the excavated anchor block if one is required. This study is not taking into consideration the joint bay for the cable installation or onward trenched cable installation.

Archaeological finds at the exit positions are unlikely because of the erosive environment and the area affected being restricted to the diameter of the HDD borehole. When a HDD site is chosen an archaeological study will be required to assess any potential prior to final design.

The only archaeological records found for the site are as follows:

- NHE Mapping shows the beach and cliff area contained invasion defences during WW2 (NHER Number: 38791. The defences included anti tank ditches, anti tank blocks, mined areas and pillboxes at Bacton Gap). According to Albone et al (2007) none of the anti-invasion defences in the area survives.

- NHE Mapping shows World War Two barbed wire and weapons pits and spigot mortar base 60m to the west of the site in the field on the western side of Coastal Road (NHER Number: 38985). The mapping includes the general site area within the area.

- NHE Mapping shows the only recorded find near the site was located 200m offshore from Bacton Gap (NHER Number 11192). The find was a Late Roman coin found inside a three and a half pound cod caught off Bacton in 1971; its provenance is probably elsewhere.

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 6). 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 general impact of HDD construction noise is addressed in more detail in the previous Feasibility Report. At Bacton Green the residences directly opposite site on the western side of the B1159 Coast Road will be 25m from the site boundary (Figure 9to Figure 12 in Appendix C). An estimated 7 permanent residences are located within 50m of the site and 17 residences with 100m. There are also 15 mobile homes (assumed seasonal occupation) within 100m at Cable Gap Holiday Park to the south of the site.

Noise attenuation fencing along the roadside site boundary will be required and possibly more substantial measures such as stacked sea containers. Working hours will probably need to be restricted to day and possible evening shifts with 24 hour working only reserved for pipeline installation.

There are some mitigating factors with the nearby residences; most residences have a limited number of windows overlooking the site and the B1159 Coast Road is heavily trafficked so ambient noise levels will be high during the day. Noise studies prior to construction will allow determination of background levels and mitigation requirements for construction.

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.

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 this area of the coast 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. The Bacton Green site appears to be on a single land parcels with direct access from the B1159 Coast Road. The ranking of sites in the Site Assessment Table (Table 6) does not take into account land ownership.

5.4. Unexploded Ordnance

Regional Unexploded Bomb county maps by Zetica were consulted but there is no designation for the area. Heritage mapping and Albone et al (2007), reveals that there were World War 2 coastal defences in the area including mined areas on the beach, pill boxes, a weapons pit and spigot mortar as discussed in Section 5.1.

While the risk to HDD construction is likely to be low, prior to any ground investigations or HDD construction the site will require an initial UXO desk study to assess the risk and inform further requirements.

6. CONSTRUCTION LOGISTICS

6.1. Easement Widths

The HDD Site Assessment Table (Table 6) summarises the restrictions on working width for Bacton Green and the other potential HDD sites. The Bacton Green site has sufficient room for six separate HDD's on the landward area. Offshore there are geometric restrictions placed by the presence of existing landfall cables and a gas pipeline to Bacton Gas Facility.

At the entry point a minimum horizontal separation of 5m has been assumed. 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 but the final separation distance will be driven by the offshore installation methods.

The Bacton Gas pipeline potentially impacts on vessel operation and offshore cabling route for the long HDD options drilled perpendicular to the coast (Design 1 – Long HDD in Drawing No. 20160901RA-C/01). For this design, consent might also be required to drill beneath the telecoms cables marked as unused. For the Design 1 – Short HDD's the "unused" telecoms cables would affect vessels and onward cabling routes. For HDD offshore works floating barges held with anchors might not have sufficient room for anchor positions to the north; jack-up barges might need to be used instead.

The alternative angled alignment shown in Design 2 (Drawing No. 20160901RA-C/02) has sufficient stand-off distance from the "unused" telecoms cables and is well away from the gas pipeline for both the long and short HDD options. There is room to rotate the alignments further if greater distance from the telecoms cable is required. Design 2 therefore eliminates potential problems with existing offshore infrastructure for a relatively small increase in drilled HDD length.

6.2. Access to Entry Site

Access to the Bacton Green site is directly off the B1159 Coast Road. This is on the identified HGV route for Bacton Gas Plant and the route will be suitable for the HDD equipment. The turning to Bacton Gap would probably be used for the site; it is a wide entrance with good visibility in both directions and therefore is very suitable.

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.

The beach access at Bacton Green is better than access for the other considered sites with the possible exception of site 3b. In addition to the timber ramp used by fisherman (Figure 17, Appendix C) there is a low angle ramp behind the sea wall that reaches the beach at the north-western end of the site (Figure 16, Appendix C). A further 400m to the northwest is a larger ramped access to the beach, although it is marked as a private road and access might need to be negotiated.

6.4. Water Supply

The closest hydrant point is directly opposite the site on the western side of the B1159 Coast Road (visible as a yellow mark on footpath in Figure 10, Appendix C). However the hydrant is in an inconvenient position unless a temporary line is installed beneath the road.

There is a hydrant point outside the entrance to Red House Chalets. A temporary PE pipeline would require a 175m length crossing 4 driveways (temporary ramps over) along the B1159 Coast Road. Alternatively a 200m line along the southern boundary of the Red House Chalet land to the field could be possible.

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). This volume 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.

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

There are no overhead lines affecting the site.

6.6. Buried Services

A buried services search has not been conducted for the site. The site itself is an agricultural field, however manhole covers are present on the western edge of the field and they appear to be access covers for a sewer. The approximate position is indicated on Drawing No’s 20160901RA-C/01 and 20160901RA-C/02. The location and depth of the sewer should be confirmed before any construction – it might require surface protection if plant and equipment are to be placed above it.

There are numerous services beneath and in the verges of the B1159 bordering the site. On the site visit water and telecoms were noted.

Directly opposite the site is a transformer serving underground cables (Figure 13, Appendix C). The nature and location of the cables it serves are not known and should be investigated before committing to the site if it is chosen.

6.7. Field Conditions, Drains and Gates

The site visit was conducted after a relatively dry summer. The field appears well drained due to the sandy soil and gentle slope. Standard construction methods of geotextile covered with stone or suitable fill is likely to be used for the working area and very short section of access road.

The existing gate to the site (Figure 14, Appendix C) is suitable and the turning at the lane to Bacton Gap is suitable for all HDD equipment. There is the potential to create a direct access from the B1159 if necessary, but it is unlikely to be needed.

7. RANKING OF SITES

The HDD sites from Bacton Green and the previous HDD Feasibility Study have been compared by compiling all of the sites and their characteristics into a Site Assessment Table, Table 6 on the following page. Note that only Sites 1, 2, 3a and 3b are shown in Table 6. This is because sites 4-13 from the previous study have since been discounted from further evaluation. 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 B.

The results of the matrix and subjective ranking methods are shown below in Table 4. The results including all sites (Sites 1-13) from the previous study are also given in Table 6 in order to give comparative values for the Bacton Green options. The results place Bacton Green Design 2 (BG-D2) in the top Tier sites for both methods of ranking. The Bacton Green Design 1 ranking however varies by method. The subjective method places it much lower primarily because of the offshore complications with the existing telecoms and gas pipeline.

Site 2 still maintains the lowest ranking due to its high entry elevation increasing borehole collapse risks and the probability of drilling through the chalk introducing groundwater and offshore cable burial risks.

MATRIX - ALL CRITERIA WEIGHTED		
RANK	SITE	SCORE
#1 (=)	1	31
#1 (=)	BG-D2	31
#3	BG-D1	33
#4	3a	35
#5	3b	36
#6	2	41

AUTHOR'S SUBJECTIVE RANKING		
RANK	SITE	TIER
#1	1	Tier 1: Suitable for HDD
#2	3a	
#3	BG-D2	
#4	3b	
#5	BG-D1	Tier 2: Suitable for HDD with some mitigation measures.
#6	2	Tier 3: Potential for Significant Risks to HDD completion.

Table 4. Results of matrix and subjective evaluation of suitability of all sites for HDD

MATRIX - ALL CRITERIA WEIGHTED		
RANK	SITE	SCORE
#1 (=)	1	31
#1 (=)	BG-D2	31
#3	BG-D1	33
#4	3a	35
#5	3b	36
#6	4a	40
#7 (=)	2	41
#7 (=)	11	41
#9 (=)	4b	42
#9 (=)	8	42
#11	6	43
#12	10	45
#13 (=)	5	46
#13 (=)	9	46
#15	12	48
#16	7	49
#17	13	54

AUTHOR'S SUBJECTIVE RANKING		
RANK	SITE	TIER
#1	1	Tier 1: Suitable for HDD
#2	3a	
#3	BG-D2	
#4	3b	
#5	4a	Tier 2: Suitable for HDD with some mitigation measures.
#6	BG-D1	
#7	4b	
#8	11	
#9	5	Tier 3: Potential for Significant Risks to HDD completion. Investigation and mitigation required.
#10	2	
#11	8	
#12	9	
#13	10	
#14	12	
#15	13	
#16	6	Tier 4: Not suitable for HDD
#17	7	

Table 5. Results of matrix and subjective evaluation of suitability of all sites for HDD

	DIMENSIONAL CONSIDERATIONS					GEOTECHNICAL		ENVIRONMENTAL						ANTHROPOGENIC					CONSTRUCTION LOGISTICS				
SITE	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		
BG - D2	9		O-200	220	640	S, Crag, (Chlk)	Crag & Chalk		MCZ	None	C (SP) Sea Wall	-50	MR, MR	Gas & cable		17P,15H	21P, 18H		A149-8km	0	0	Ramp x 2	H
BG - D2	9		O-200	220	640	S, Crag, (Chlk)	Crag & Chalk		MCZ	None	C (SP) Sea Wall	-50	MR, MR	ab. telecoms		17P,15H	21P, 18H		A149-8km	0	0	Ramp x 2	H
1	12		S-50	330	540	sandy Crag	Crag		MCZ	High, FZ3	C (SP) Sea Wall	-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 Walcc	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
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 -100	Problematic	Problematic	Possible	Problemati	Problemati	UXO prob rqd	Problemati	Problemati	Med cost	Problemati	Med cost
KEY	>8	Insufficier	Too narrov	>400	>800	Difficult	Difficult	Avoid	Avoid	High	Avoid	> -100	Avoid	Avoid	High	Avoid	Avoid	UXO rqd	Avoid	Avoid	High cost	Avoid	High cost

Table 6. Site Assessment Table compiling judgement criteria for all sites.

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8. OUTLINE HDD METHODOLOGY

The HDD methodology for Bacton Green will be equivalent to those for Sites 1, 2, and 3 from the previous Feasibility Report (Report Reference No.: 20151001RA-FR01) and that report should be examined for information on HDD methodology.

9. CONCEPTUAL DESIGN & CALCULATIONS

Two possible drilling alignments have been identified at Bacton Green. The first alignment, Design 1 is perpendicular to the coastline (bearing 035°). The second alignment, Design 2, is at an angle to the coastline (bearing 060°) in order to avoid indicated existing offshore pipelines and cables.

The conceptual designs are shown on Drawing No.'s 20160901RA-C/01 and 20160901RA-C/02 in Appendix D.

Two conceptual sectional designs have been drawn for the Bacton Green Design 1 Alignment; a short HDD exiting above the level of Mean Low Water Spring (MLWS) and a long HDD design exiting at approximately -3.0m LAT (-5.2m 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.

Conceptual designs have not been drawn for the Design 2 alignment because the designs will be essentially the same as for Design 1. The difference will be an additional 20m of drilled length for the short option and an average additional 50m length for the long option.

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 Bacton Green Design 1

The key factors influencing the designs are the placement of the entry point as close to the B1159 Coast Road as possible, the depth of the foundations and sheet piling for the sea defences, the site elevation, and bathymetry.

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 and will need to consider the unused telecoms cable. Given the short drilling length the Design 2 exit points are likely to be much more favourable than Design 1.

The entry position of the short HDD's is set as far back as possible to allow for future coastal erosion. The distance from the entry point to the coastal defences requires a steep entry angle of 17 degrees but this has potential to be reduced if the sheet piles at the toe of the sea defences are found to be less than 12m in length. A lower entry angle will reduce cable installation forces; it has little effect on the duct installation forces.

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 2.71m 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.

9.1.2 Long HDD

In plan view 6 No. of long HDD's are possible at Bacton Green, however this is subject to the allowable working distances from the offshore gas pipeline and telecom cable. 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 17 degrees for the same reasons as the short HDD design and the comments on the entry angle in Section 9.1.1 are equally applicable to the long design. The exit angle is set at 10 degrees but if ground conditions are suitable the exit angle might be reduced slightly; however benefits in reduced cable installation stresses will need to be balanced against risk of early bentonite breakout and hole opening methods.

The radius of the HDD has been set at 300m for the same reasons as the short HDD design.

The design has a clearance of 3.87m 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 13m. 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. Calculations

9.2.1 Drilling Forces and Rig Size

For a 660m long HDD drilled at Bacton Green Design 2 – Long HDD with 6 5/8" drill pipe the on bottom push is calculated as 23t maximum, the pull as 18t maximum. The limiting factor for most drilling equipment is the Torque capability; for the stated HDD the calculated torque for reaming 26" is 16kN.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 32kN.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 as a minimum 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.

9.2.2 Installation Forces

Duct installation forces have been calculated for the long and short options of Design 2 at Bacton Green. A summary of the results is given in Table 7 below and examples of the calculation sheet are given in Figure 6 and Figure 7.

The calculation show that the ducts should be water filled to minimise installation forces and this is particularly important for the long design. The recommended maximum pulling force for 500mm SDR11 PE100 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.

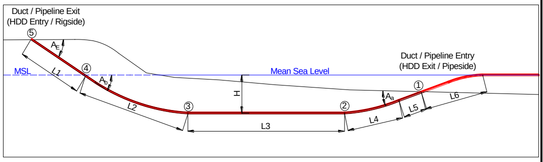
SUMMARY OF PULLBACK CALCULATIONS FOR HDPE 500 mm OD PIPELINE		
Vattenfall EAN, BG-D2 - Short HDD	**7th October 2016**	
Parameter	**500 mm, SDR11**	**Units**
Pipe weight, W_p	0.062	tonnes/m
Water Filled weight, W_{pw}	0.193	tonnes/m
Buoyant air filled weight, W_{ba}	-0.154	tonnes/m
Buoyant water filled weight, W_{bw}	-0.023	tonnes/m
Buoyant seawater filled weight, W_{bs}	-0.019	tonnes/m
Maximum Pullback Force - air filled	13.8	tonnes force
Maximum Pullback Force - water filled	6.3	tonnes force
Maximum Pullback Force - seawater filled	6.1	tonnes force
Maximum Pullback Force - open pipe	3.6	tonnes force

SUMMARY OF PULLBACK CALCULATIONS FOR HDPE 500 mm OD PIPELINE		
Vattenfall EAN, BG-D2 - Long HDD	**7th October 2016**	
Parameter	**500 mm, SDR11**	**Units**
Pipe weight, W_p	0.062	tonnes/m
Water Filled weight, W_{pw}	0.193	tonnes/m
Buoyant air filled weight, W_{ba}	-0.154	tonnes/m
Buoyant water filled weight, W_{bw}	-0.023	tonnes/m
Buoyant seawater filled weight, W_{bs}	-0.019	tonnes/m
Maximum Pullback Force - air filled	59.4	tonnes force
Maximum Pullback Force - water filled	13.0	tonnes force
Maximum Pullback Force - seawater filled	11.9	tonnes force
Maximum Pullback Force - open pipe	7.5	tonnes force

Table 7. Summary of calculated installation forces for long and short HDD options at Bacton Green Design 2.

PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, EMPTY DUCT
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, BG-D2 - Long HDD
Modelling Date: 7th October 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	30 m	
Angle	A_E	17 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	17 deg	0.297 rad
Drilled MSL tangent + curve length	L_2	89 m	292.0 ft
Horizontal tangent length	L_3	443 m	1453.4 ft
Drilled exit curve length	L_4	55 m	180.4 ft
Exit tangent	L_5	43 m	141.1 ft
Vertical depth (relative to MSL)	H	16 m	52.5 ft
Length from exit to sea level (MSL)	L_6	35 m	114.8 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

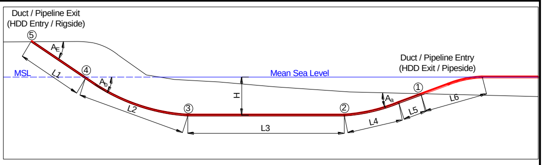
Dead and buoyant pipe weights				
Pipe weight, W_p	0.062 tonnes/m		42 lb/ft	
Buoyant empty weight, W_b	-0.154 tonnes/m		104 lb/ft	^
Buoyant filled weight, W_b	-0.023 tonnes/m		15 lb/ft	^
Total pipe length	630 m			
Total pipe weight	39 tonnes		85,646 lbs	
Total pipe weight submerged	-97 tonnes	-	213,709 lbs	
Total pipe weight of submerged tail in sea	-5 tonnes	-	11,086 lbs	

PULLBACK FORCES		
Combined Drag and Capstan Forces at:		
Point 1	7 t	15,415 lbs
Point 2	43 t	94,776 lbs
Point 3	51 t	112,936 lbs
Point 4	58 t	127,270 lbs
Hydrokinetic Force	0.3 t	690 lbs
Max Force from submerged section	58.2 t	127,960 lbs
Gravitational pull component	0.5 t	1,195 lbs
Frictional pull component	0.7 t	1,563 lbs
Pipe unlikley to slide downhole if unsecured		
Force from dry section (empty pipe)	1.3 t	2,758 lbs
Maximum force through submerged hole	58.2 t	128,229 lbs
Maximum force through dry hole	1.3 t	2,758 lbs
Maximum Force	59.4 t	130,987 lbs

Figure 6. Example calculations for air filled duct installed at Bacton Green – Design 2 Long HDD.

PIPE PULLBACK CALCULATIONS - HDPE OUTFALL, WATER FILLED DUCT
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, BG-D2 - Long HDD
Modelling Date: 7th October 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	30 m	
Angle	A_E	17 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	17 deg	0.297 rad
Drilled MSL tangent + curve length	L_2	89 m	292.0 ft
Horizontal tangent length	L_3	443 m	1453.4 ft
Drilled exit curve length	L_4	55 m	180.4 ft
Exit tangent	L_5	43 m	141.1 ft
Vertical depth (relative to MSL)	H	16 m	52.5 ft
Length from exit to sea level (MSL)	L_6	35 m	114.8 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	630 m			
Total pipe weight	39 tonnes		85,646 lbs	
Total pipe weight submerged	-14 tonnes	-	31,532 lbs	
Total pipe weight of submerged tail in sea	-1 tonnes	-	1,636 lbs	

PULLBACK FORCES		
Combined Drag and Capstan Forces at:		
Point 1	2.7 t	5,965 lbs
Point 2	6.9 t	15,159 lbs
Point 3	8.0 t	17,493 lbs
Point 4	8.8 t	19,408 lbs
Point 5	13.0 t	28,765 lbs
Hydrokinetic Force	0.3 t	690 lbs
Max Force from submerged section	9.1 t	20,098 lbs
Gravitational pull component	1.7 t	3,737 lbs
Frictional pull component	2.2 t	4,889 lbs
Pipe unlikley to slide downhole if unsecured		
Force from dry section of hole (full)	3.9 t	8,625 lbs
Maximum Force	13.0 t	28,765 lbs

Figure 7. Example calculations for water filled duct installed at Bacton Green – Design 2 Long HDD.

9.2.3 Settlement

Settlement modelling was undertaken in the previous study to gain an understanding of the scale of possible settlement after HDD installation of the ducts. Because the depth of the Bacton Green designs is very similar to Site 1 the scale and shape of any settlement trough at Bacton Green will be very similar to Site 1.

The settlement at the level of the concrete apron (see Figure 5) of the sea defences at Site 1 was modelled. The results are shown in Figure 8 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.

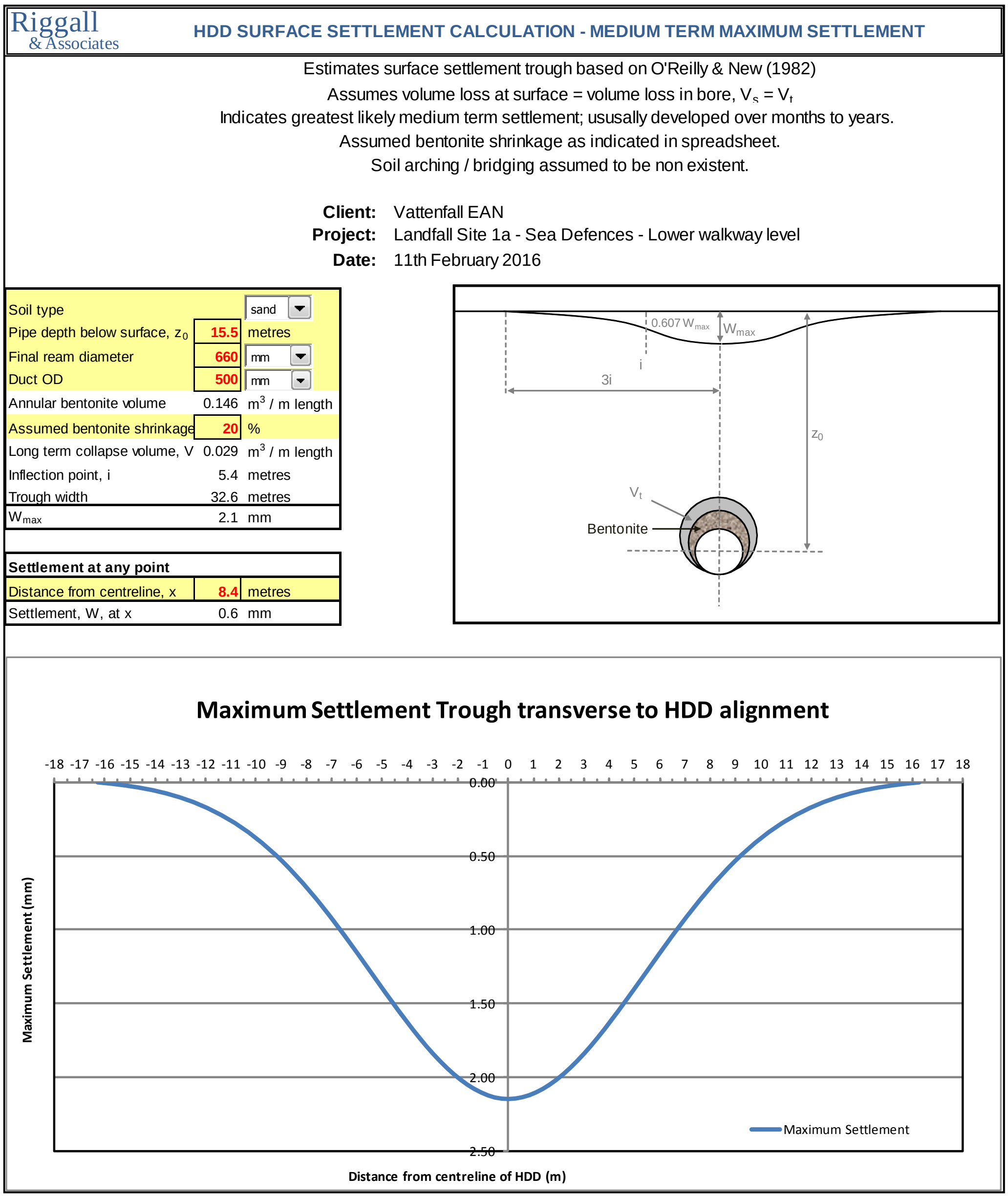


Figure 8. Settlement calculations for lower walkway level of sea defences at Site 1.

10. HDD SITE REQUIREMENTS

10.1. Bacton Green

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 the site and is therefore the most suitable route for HDD equipment and supplies travelling to site.

Access from the B1159 into the field will probably use the existing gates in the south of the field adjacent accessed from the Bacton Gap lane turning. The gates would directly access the site working area. Car parking could be located on the southeast end of the site or at the existing paying car parking area closer to the beach.

Beach access for the short HDD exit point is best obtained via the low angle ramped access that reaches the beach at the northwest end of the beach.

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. 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. 20160901RA-C/03 in Appendix D indicates a conceptual site setup for the maximum likely working area. It assumes a maxi (>100t) HDD rig drilling 6 No. HDD's. The dimension of the working site plus parking is approximately 65m x 45m. If 4 No. HDD's are to be drilled the area could be reduced to 55m x 45m and for 2 No. HDD's 50m x 45m. The likely land take would be 3615m^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 Bacton Green it might be stored on the north-western side of the site; there is probably insufficient room to store it along the B1159 Coast Road boundary.

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.

10.1.4 Buried Services and Overhead Lines

It is expected that there will be a number of buried services either beneath the B1159 Coast Road or in the adjacent verges. The mains water supply runs beneath the footpath on the western side of the road as do telecom cables.

Manhole covers are present on the western edge of the site beside the B1159 that appear to be access covers for a sewer. The approximate position is indicated on Drawing No's 20160901RA-C/01 and 20160901RA-C/02. The location and depth of the sewer should be confirmed before any construction – it might require surface protection if plant and equipment are to be placed above it.

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

No overhead power lines are present on the site. However there is a double pole mounted transformer on the opposite site of the B1159 Coast Road from site (Figure 13, Appendix C). The location of the underground cables feeding it should be investigated before committing to the site.

10.1.5 Noise & Lighting

The impact of noise is discussed in Section 5.2.1. The nearest residences are 25m from site on the opposite of the B1159 Coast Road; as a minimum acoustic panels placed on heras fencing will be required to mitigate noise for daytime working.

If four or more HDD's are to be drilled in a restricted season (e.g. winter) day and evening working might be necessary. In this case an improved form of noise mitigation might be required such as a wall constructed of shipping containers. If continual 24 hour working is required to complete the HDD's within a tight program complete enclosure of equipment in a temporary structure might be the only method to mitigate the noise, however there is still a risk of ground vibration disturbing residents during the night.

For pullback (duct installations) 24 hour operations should 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 prior background noise monitoring is undertaken as part of environmental studies to allow planning of noise mitigation.

The effect of lighting on local residents can be mitigated by strategic positioning of lighting and installation of boarding to shield residents from direct light.

10.1.6 Unexploded Ordnance

Archaeology records on Norfolk Heritage Explorer Mapping indicate the some small scale military facilities within the vicinity 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

The site is unlikely to be liable to flooding from storm surges. The site is at approximately 9m elevation while the 1953 surge was recorded at elevation 3.75m.

11. HDD RISK ASSESSMENT

A High Level Risk Register has been compiled for the HDD landfall at Bacton Green. 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	3	2	6	Placement of topsoil stockpiles, office cabins etc as shielding	2	2	4
					Engines etc enclosed in silencing units	2	2	4
					Pre construction baseline noise monitoring & mitigation planning	2	2	4
					Installation of dedicated engineered 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	1	3	3	HDD site at a sufficient elevation above sea level	1	3	3
					Protective ditch and bund on seaward site perimeter to divert wave overwash and debris around site	1	3	3
					Work to cease, equipment and site to be secured and personnel evacuated in advance of any predicted surge.	1	3	3
					Drilling equipment to be removed from borehole and entry to borehole or casing covered and secured if possible	1	3	3
18	Entry point unacceptable due to Archaeological finds.	1	3	3	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 is not permitted	2	3	6	Early consultation with relevant permitting authorities	1	3	3
					Move HDD's to Site 3 locations	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	1	3	3	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	1	2	2
					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
34	Damage to existing offshore cables or pipelines during HDD operations	2	3	6	Identify position and depth of pipelines and cables	1	3	3
					Ensure suitable separation between HDD's and existing infrastructure	1	3	3
					Ensure sufficient stand-off between offshore vessels, including anchor points, and existing infrastructure	1	3	3
					Use of suitable HDD guidance system with accuracy to avoid any risk of misalignment.	1	3	3

12. SPECIFIC GEOTECHNICAL AND HDD RISKS

12.1. Ground Collapse

For the Bacton Green site 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 2m 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 3.4. 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. 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.

At Bacton Green the risk is in the initial 38m of borehole in the silty gravelly sand. Engineered mitigated is likely to use the installation of steel casing over this length. A less likely method is ground improvement in the form of pre-grouting the weak sections of soil along the planned HDD route.

Ground investigations might indicate that the silty gravelly sand is of sufficient strength to justify drilling without any mitigation methods and make provision to mitigate if ground collapse proves to be a problem. 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.

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 Bacton Green 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 Bacton Green 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.

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 losses for all options at Bacton Green will be approximately 20 m^3 assuming a 26” (660mm) borehole and 38m length above sea level.

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.

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 Design 2 long HDD's the worst case scenario is an installation rate of 2 metres per minute for the 660m drilled borehole length. At a pumping rate of 500 litres per minute this would result in a pumped volume of $330m^3$.

Assuming the initial 38m of borehole at entry is dry, the displacement volume for the 520m of fluid filled borehole by a 500mm duct is $125m^3$.

The worst case scenario of total volume lost during installation of the ducts on the long HDD for Site 3a is therefore $455m^3$.

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 9.2.3. For the concrete apron of the sea defences at Site 1 a combined settlement of 3.3mm was calculated and this scale of settlement at Bacton green is not expected to be of significance for the integrity or function of the structure.

12.4. Location to Existing Offshore Infrastructure

The indicated position of the Balgzand Bacton Line (BBL) interconnector gas pipeline and the telecoms cable marked as "disused" are in close proximity to Design 1. Any consideration of Design 1 as an option will need to evaluate the stand-off distances from this infrastructure. In particular there is likely to be restrictions on anchoring which would impact the use of anchor stayed barges for the HDD offshore works on Design 1.

13. INDICATIVE PROGRAMME & COST

An indicative programme of works for HDD landfalls at both Site 1 and Site 3a is shown in Table 8 below. The programmes have been calculated for both long and short options, assuming six HDD's are to be completed.

The programme assumes 12 hour working. For the Bacton Green site 24 hour working could be difficult to guarantee due to the impact on nearby residents. The 24/7 total shown 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	Bacton Green - Design 2 - Short HDD's						Bacton Green - Design 2 - Long HDD's					
	HDD #1	HDD#2	HDD#3	HDD#4	HDD#5	HDD#6	HDD #1	HDD#2	HDD#3	HDD#4	HDD#5	HDD#6
	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts	12hr Shifts
Site establishment works	7.0	-	-	-	-	-	7.0	-	-	-	-	-
Mobilisation & Setup	5.0	2.0	2.0	2.0	2.0	2.0	5.0	2.0	2.0	2.0	2.0	2.0
Pilot hole drilling: 0 - 420m	1.9	1.9	1.9	1.9	1.9	1.9	6.1	6.1	6.1	6.1	6.1	6.1
Forward ream 16": 0 - 410m	2.3	2.3	2.3	2.3	2.3	2.3	7.4	7.4	7.4	7.4	7.4	7.4
Forward ream 22": 0 - 400m	2.1	2.1	2.1	2.1	2.1	2.1	7.3	7.3	7.3	7.3	7.3	7.3
Forward ream 26": 0 - 390m	2.0	2.0	2.0	2.0	2.0	2.0	7.2	7.2	7.2	7.2	7.2	7.2
Pilot hole drilling: 420 - 450m	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Offshore works	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Back ream 22": 400 - 450m	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Back ream 26": 390 - 450m	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Cleaning pass	0.6	0.6	0.6	0.6	0.6	0.6	1.7	1.7	1.7	1.7	1.7	1.7
Pullback of pipeline	1.0	1.0	1.0	1.0	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	2.0	2.0	2.0	2.0
Site reinstatement works	-	-	-	-	-	7	-	-	-	-	-	7
Total 12hr Shifts per HDD	26.5	16.5	16.5	16.5	16.5	23.5	47.3	37.3	37.3	37.3	37.3	44.3
Total 12hr Shifts for 6 No. HDD's	**116**						**241**					
Total weeks, day working, 7 day weeks	**16.6**						**34.4**					
Total weeks, 24/7 working	**11.7**						**20.6**					

Notes: Time for duct preparation and offshore works are not included as they will be concurrent with HDD works.
Approx lengths of HDD's: Design 2 short = 220m , Design 2 long = 635m
No allowance for weather delays to offshore works has been made.

Table 8. 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 9 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	Duct O.D. (inch)	Programme No. 12 hr Shifts	PRICING BY METERAGE AND DIAMETER			PRICING BY PROGRAMME		
					Lower	Expected	Upper	Lower	Expected	Upper
BG-D2	Short	220	20	27	£ 198,000	£ 264,000	£ 374,000	£ 212,183	£ 318,275	£ 424,367
BG-D2	Long	635	20	47	£ 571,500	£ 762,000	£ 1,079,500	£ 567,794	£ 757,058	£ 946,323
1	Short	210	20	26	£ 189,000	£ 252,000	£ 357,000	£ 208,175	£ 312,263	£ 416,350
1	Long	450	20	38	£ 405,000	£ 540,000	£ 765,000	£ 456,563	£ 608,750	£ 760,938
3a	Short	205	20	26	£ 184,500	£ 246,000	£ 348,500	£ 206,171	£ 309,256	£ 412,342
3a	Long	540	20	43	£ 486,000	£ 648,000	£ 918,000	£ 510,675	£ 680,900	£ 851,125

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 9. 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

Two possible HDD drilling alignments were identified at the Bacton Green site. The first alignment, Design 1, is perpendicular to the coastline (bearing 035°). The second alignment, Design 2, is at an angle to the coastline (bearing 060°) in order to avoid indicated existing offshore pipelines and cables.

The results from the Bacton Green site visit and desk study were compiled in a Site Assessment Table to compare the Bacton Green to the sites evaluated in the previous HDD Feasibility Report (Report Ref. No. 20151001RA-FR01). 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 6 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 10 below.

Site 1 from the previous study was evaluated as the most suitable location for landfall HDD's, followed closely by Site 3a, Bacton Green Design 2 (BG-D2) and Site 3b, forming the Tier 1 sites.

AUTHOR'S SUBJECTIVE RANKING		
RANK	**SITE**	**TIER**
#1	1	Tier 1: Suitable for HDD
#2	3a	
#3	BG-D2	
#4	3b	
#5	BG-D1	Tier 2: Suitable for HDD with some mitigation measures.
#6	2	Tier 3: Potential for Significant Risks to HDD completion.

Table 10. 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 B.

The matrix results and subjective rankings were broadly similar. Site 1 ranked first or equal first in both. Site BG-D1 varied between the methods because the matrix ranking did not weigh the risk from proximity to offshore cables and pipelines as highly as the subjective ranking.

Site 2 was ranked very low in both methods because it has a high entry elevation with ground collapse risk and it drills 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. Bacton Green Design 2 is a viable HDD Option

The Design 2 alignment bearing at approximately 60 degrees from North is a viable option for a HDD option both as long and short HDD’s.

For the option of a long HDD the route is considered to be less attractive than Site 1 and Site 3a for the following reasons:

- The HDD equipment will need to be positioned beside the B1159 Coast Road, within 25m of permanent residences therefore noise disturbance will be an issue and obtaining permission for 24 hour working could be difficult.
- The HDD equipment is in closer proximity to a greater number of permanent residences than Site 1 or 3a.
- If working hours are restricted to 12 hours per day the option of 4 or 6 HDD’s and the longer HDD’s will require lengthy programmes.
- The entry elevation of 8m ODN results in a longer section of dry borehole after seafloor exit, increasing the risk of ground collapse
- The HDD has a risk of drilling through the underlying chalk which is a major aquifer

In the event that only short HDD’s are to be considered, Bacton Green becomes the most favoured HDD location for the following reasons:

- The short HDD’s could be completed quickly by smaller sized HDD equipment, reducing the impact of noise on neighbours
- Beach access to the exit points is very straightforward (subject to permission for use of the low angle ramp)
- Site access is very good, minimal / no access road is required

15. RECOMMENDATIONS

15.1. Site Selection

Based on the available information Sites 1, 3a and 3b and Bacton Green Design 2 (BG-D2) 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 Bacton Green, 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

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.
- 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
- 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

Drawing 20160901RA/04in Appendix D indicates the position and depth of suggested ground investigation boreholes and geophysical survey areas for Bacton Green. 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.

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 laboratory tests in Table 11are to be undertaken where the quality of the samples allows. Thermal conductivity testing is also likely to be required. Cable specialists should advice on the number and location of samples to be tested.

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

Table 11. Suggested laboratory testing for borehole samples

15.3.4 Marine Geophysics

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

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.

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

CALCULATION OF ENTRY POINT POSITION (FROM EXISTING SHORELINE) AND MINIMUM HDD LENGTH																		
	BATHYMETRY				ELEVATION & SET BACK			COASTAL ACCRETION / EROSION						SHORT OPTION LENGTH		LONG OPTION LENGTH		
SITE	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		NOTES
No.	0m	-3m	-5m	-10m	mODN	10	m	20-50 years	50-100 years	m/yr	m/yr	50	100	50	100	50	100	
BG-D1	250	490	570	8909	9	62		MR	MR	-0.4	-1.25	-50	-100	340	390	580	630	Constrained to max 95m Setback
BG-D2	250	500	610	870	9	62		MR	MR	-0.4	-1.25	-50	-100	340	390	590	640	Constrained to max 95m Setback
1	100	340	450	920	5	49		H	MR	-0.9	-1.5	-60	-120	190	250	430	490	
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	
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 12. Entry position and HDD length calculation.

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APPENDIX B

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
		DIMENSIONAL CONSIDERATIONS					GEOTECHNICAL		ENVIRONMENTAL						ANTHROPOGENIC					CONSTRUCTION LOGISTICS				
Weighted Score using all Criteria	SITE	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		
33	BG-D1	3	1	3	2	3	1	3	1	2	1	2	3	2	3	1	3	2	2	1	1	1	1	1
31	BG-D2	3	1	1	2	3	1	3	1	2	1	2	3	2	1	1	3	2	2	1	1	1	1	1
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
	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 -100	Problematic	Problematic	Possible	Problemati	Problemati	UXO prob rqd	Problemati	Problemati	Med cost	Problemati	Med cost
	KEY	>8	Insufficier	Too narrov	>400	>800	Difficult	Difficult	Avoid	Avoid	High	Avoid	> -100	Avoid	Avoid	High	Avoid	Avoid	UXO rqd	Avoid	Avoid	High cost	Avoid	High cost

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APPENDIX C

Site Visit Photographs

Figure 9. View to northwest from Bacton Gap lane. The B1159 Coast Road on the left, site on the right approximately indicated in yellow.

Figure 10. Residences on opposite side of road to site. The site boundary on the left side of the photograph would be 25m from the houses.

Figure 11. View to the southwest from the coastal edge of the field showing overlooking houses. Indicative site boundary is shown in yellow.

Figure 12. View to the west from the coastal edge of the field showing holiday chalets overlooking the site. The left side of this photograph joins the left side of the previous photograph.

Figure 13. Transformer for underground cables located on the opposite side of the B1159 Coast Road from the site. The transformer can also be seen in Figure 10.

Figure 14. Entrance to site through the gate on the left of picture. Car parking entrance in centre, Bacton Gap lane on right. The B1159 Coast Road is behind the view point.

Figure 15. View W-N-W along the coastal frontage of the field. Design 1 alignment is behind the timber groyne extending into the sea. Design 2 passes beneath the feet of the person walking on the beach.

Figure 16. Low angle access ramp to the beach at the northwestern corner of the field. The location is at the far end of the track in the previous photograph. Design 1 passes beneath this view point.

Figure 17. Timber beach access ramp at Bacton Gap.

Figure 18. View W-N-W along the sea defence wall showing steel sheet piles at the toe. A timber groyne can be seen projecting into the sea in the distance.

Figure 19. Cliff section at the northern end of the beach 20m beyond the low angle ramp. The Glacigenic deposits are silty gravelly SAND. The ground above the cable at the top of the cliff is head deposit or topsoil/made ground

Figure 20. Silty gravelly SAND of the Glacigenic deposits with car keys (5cm length) for scale.

APPENDIX D

Drawings

Drawing No's:

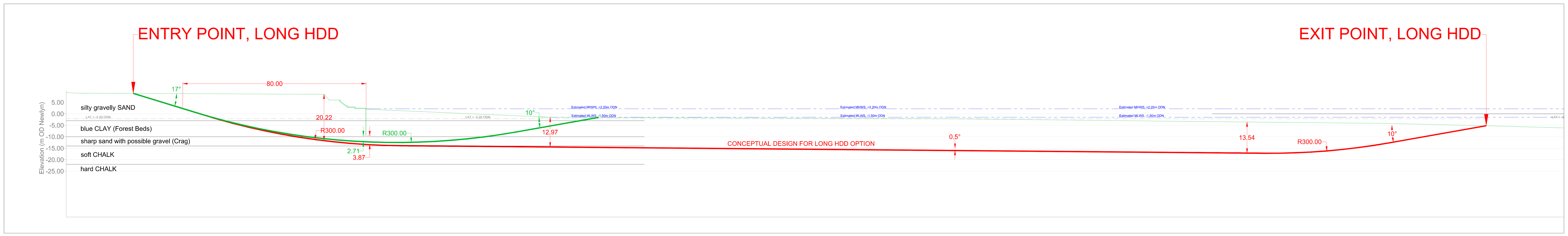
20160901RA-C/01 – Conceptual HDD Designs Bacton Green – Design 1

20160901RA-C/02 – Conceptual HDD Designs Bacton Green – Designs 1 & 2

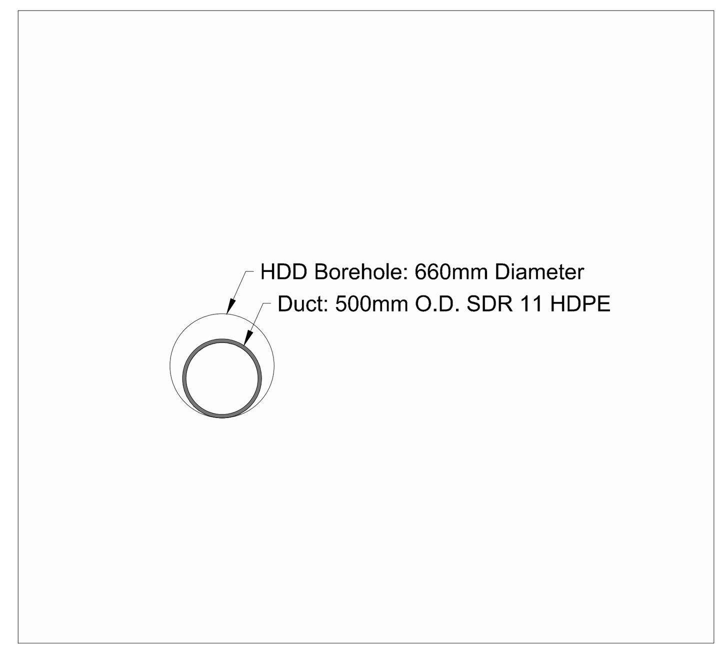
20160901RA-C/03 – Conceptual HDD Site Layout Bacton Green

20160901RA-C/04 – Proposed Ground Investigations Bacton Green

PLAN VIEW



SECTION VIEW



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.

DO NOT SCALE

Rev	Date	Description	By
A	07/10/2016	Draft for discussion	TR

Client: VATTENFALL WIND POWER LTD

Scale	Drawn by	Date Drawn	Sheet Size
AS SHOWN	TR	07/10/2016	A1
Designed by	**Checked by**	**Approved by**	**Date approved**
TR			

Drawing Number: 20160901RA-C/01

Issue: A

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

Drawing Title: CONCEPTUAL HDD DESIGNS BACTON GREEN - DESIGN 1

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Email: admin@riggallandassociates.co.uk

PLAN VIEW

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.

DO NOT SCALE

Rev	Date	Description	By
A	07/10/2016	Draft for discussion	TR

Client: VATTENFALL WIND POWER LTD

Scale	Drawn by	Date Drawn	Sheet Size
AS SHOWN	TR	07/10/2016	A1
Designed by	**Checked by**	**Approved by**	**Date approved**
TR			
Drawing Number			**Issue**
20160901RA-C/02			A

Project Title

EAST ANGLIA NORTH TRANCHE 1 (EAN)
BACTON GREEN HDD FEASIBILITY STUDY

Drawing Title

CONCEPTUAL HDD DESIGNS
BACTON GREEN - DESIGNS 1 & 2

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PLAN VIEW

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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.
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	07/10/2016	Draft for discussion	TR

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

Drawing Number: 20160901RA-C/03

Issue: A

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

Drawing Title: CONCEPTUAL HDD SITE LAYOUT BACTON GREEN

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PLAN VIEW

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. POSITION OF SEA DEFENCES TO BE ACCURATELY 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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TR			

Drawing Number: 20160901RA-C/04

Issue: A

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

Drawing Title: PROPOSED GROUND INVESTIGATIONS BACTON GREEN

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