TRITON KNOLL

REVIEW OF HDD PROPOSALS FOR BURIED CABLE

RISK ASSESSMENT FOR ENVIRONMENT AGENCY

Doc No. 2505-GCG-ENG-Q-RA-2721341-02

28 August 2018

GEOTECHNICAL CONSULTING GROUP

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DISCLAIMER

REVISION HISTORY

Revision	Date	Description
Draft Version 1	3/8/2018	Draft Risk Assessment to inform Internal Project Risk Workshop of 6Aug2018
Draft Version 2	10/8/2018	Updated with input from 6 Aug 2018 Risk Workshop in Papendrecht and follow-up feedback.
Version 1	23/8/2018	Issue to TKOWF for review
Version 2	28/8/2018	Version for issue to EA

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EXECUTIVE SUMMARY

This report presents a risk assessment of the proposed installation of export cables at the landfall for the Triton Knoll Wind Farm (TKOWF). The export cables at the landfall will be installed using the Horizontal Directional Drilling (HDD) method.

The risk assessment addresses the risks that are of interest to the Environment Agency (EA). It has been produced following a risk workshop with participation by TKOWFL, their geotechnical consultant (Geotechnical Consulting Group, GCG) and the Landfall and Offshore Cable Contractor (Boskalis Subsea Cables & Flexibles/ VBMS). Interest by the EA has been focused on risks to the chalk aquifer and abstractors of groundwater from this aquifer.

A conceptual site model is presented, which underpins the risk assessment undertaken. The risks to the chalk aquifer are reduced to As Low As Reasonably Practicable (ALARP) by the methods and processes described in the risk assessment. Residual risks will be listed on the project risk register and will be tracked and managed throughout the detailed design and construction stages. An experienced specialist cable contractor has been engaged. Examples of similar landfall HDD pipelines installed by the contractor are given to illustrate their experience.

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1 INTRODUCTION

Background

The Triton Knoll Offshore Windfarm (TKOWF) is being developed in the Southern North Sea. The site is located off the coast of Lincolnshire and will utilise export cables that make landfall near Anderby Creek in Lincolnshire (Figure 1(a)). The Export cables are required to connect the offshore wind turbine generators (WTGs) to the onshore grid. At landfall, Horizontal Directional Drilling (HDD) is proposed for use in installing underground cables beneath the beach (e.g. Figure 1(b)). The HDD method is a trenchless technology approach that allows cable installation without interference with the surface (sand dunes and beach) and with beach replenishment work that has been ongoing in the area for several years. Two HDD installed cables of 900mm outer diameters and about 900m length, each, are proposed. These will run from an entry pit behind sand dunes on the beach to an exit pit below sea level (Figure 1(b)).

A conceptual design has been developed by the cable contractor, based on existing information. An additional ground investigation (GI) is planned this summer/ autumn to further investigate the HDD alignment. A detailed HDD design will be developed when this GI information becomes available.

Scope

GCG has been commissioned by TKOWF to carry out a review of the HDD proposals. Part of this commission is the preparation of a qualitative risk assessment focused on the interests of the Environment Agency, as previously communicated to the project. This report presents the risk assessment in Sections 3 and 4.

2 GROUND CONDITIONS AND CONCEPTUAL MODEL

The expected ground conditions from the available information are depicted in Figure 1(b). The strata relevant to the HDD works as are the wind-blown sands, Alluvium and Glacial Tills. Beneath all these strata is the Cretaceous Chalk. A detailed description of the ground conditions is given in Appendix 1.

2.1 Windblown sands

These sands form a line of dunes at the rear of the beach typically about 5m high.

2.2 Alluvium

The Alluvial soils and the 'Tidal Flat Deposits' are here considered to be the same deposit, outcropping either side of the overlying coastal dune system. They comprise soft normally consolidated redeposited Glacial Till (i.e. clays and silts with some more recent organic material). Coarser material from the Till may be concentrated at the Alluvium / Till interface in some locations.

2.3 Glacial Till

The Glacial Till is a 'Diamict' – i.e. it is a well graded deposit with a broad range of particle sizes. As a consequence, it has a dense and compact packing, resulting in high strength and low permeability. The Glacial Till found in this part of Lincolnshire is the Skipsea Till Member of the Holderness Till Formation.

In general terms the Skipsea Till is a poorly sorted, low plasticity, stiff silty sandy gravelly CLAY that contains occasional cobbles and boulders. The Till many contain permeable lenses or channel fills of sand, gravel, cobbles and boulders, but these are not likely to be common.

Local historic well data suggests the Till is around 30m thick west of the HDD launch site. This is consistent with the results of geophysical investigations of the alignment (e.g. Figure 1(b)).

There is a possibility that there may be two tills at the alignment site comprising the 30m thick till deposit detected by the geophysical survey. However, the presence of two tills at this location is still disputed in academia. As the sources of coarser material in any lower Till are likely to be similar to those of the upper till (if applicable), the two tills may be very similar. The presence of a second till is relevant to the project because of the contact between the two tills may contain other materials – such as concentrations of boulders, other fluvially sorted deposits (such as sands / gravels) or palaeosoils.

2.4 Chalk

Till-Chalk interface

Where the Chalk / Till interface is exposed north of the Humber and in north Norfolk it generally has low relief. However there are locations where Till filled paleotopography and solution features can be seen (e.g. Flamborough Head). The depth of Quaternary weathering of the top of Chalk is variable. In areas of paleotopographic highs Grade D weathering profiles are typically limited to a few metres. Beneath and adjacent to palaeo-valleys weathering depths can reach tens of metres. A photograph of some exposures of this interface is given in Appendix 1.

The Chalk

The Chalk found beneath the Till is thought to be the Burnham Chalk Formation. In total this would be expected to be more than 100m thick. However the depth to its base isn't known at the site. The Burnham Chalk is characteristically thinly bedded with tabular and discontinuous flint bands and occasional marl seams.

The chalk in this area is designated by the EA as a principal aquifer. That means that it has a high permeability and can provide a high level of water storage, and it may support water supply and/or river base flow on a strategic scale.

2.5 Groundwater

There are two aquifers expected at the site, separated by the impermeable glacial till:

- a superficial aquifer in the beach sands which is connected to the sea, and
- a deep aquifer in the chalk.

The chalk aquifer is connected to the sea offshore.

There are many historic farm wells close to the coast drilled through the Glacial Till to extract water from the Chalk. Notes added to BGS logs of such wells in the 1940's and 50s, when the wells were starting to be replaced by mains water, often state that water levels were close to the ground surface and that hand pumps were often present. Occasionally the well logs suggest that the Chalk aquifer was just artesian. Artesian wells (known locally 'blow wells') are a relatively common feature in the low ground close to the Lincolnshire Wolds.

These well logs sometimes suggest that this water was 'salty'. One log quotes 420ppm of chloride ion concentration (Cl^-) in comparison, seawater is typically circa 19000 ppm). However, typical quoted values of chloride concentrations are less than 100ppm. This saline intrusion into the Chalk aquifer, through its offshore hydraulic connection to the sea is a well-known phenomenon by the Humber and around Grimsby (e.g. see Figure 2).

2.6 The Conceptual Model

A conceptual model for the HDD site is given in Appendix 2. Section A2.1. It shows and discusses potential sources of pollution, receptors and pathways. It can be seen that there are no viable pathways to the receptors and so the risks are minimal. In addition, Springs/ wetland receptors and abstractors are very far from the site and are unlikely to be affected.

3 BASIS OF RISK ASSESSMENT

This is a qualitative risk assessment (Tier 1). It comprises an initial assessment and consideration of the potential pathways, receptors and the level of risk to the groundwater, and groundwater abstractors and springs/ wetlands.

The definitions used in the risk assessment are given in Appendix 2 Section A2.2.

A hazard identification study was undertaken which informed an initial risk assessment. Then, a risk workshop with wide participation was carried out. This provided input into the finalised risk assessment presented in this report. The risk workshop was held on 6th August 2018 and was participated in by TKOWF, GCG and Boskalis/VBMS. Post-workshop input from the potential HDD subcontractor was also considered.

The identified risks will be added to the project risk register for tracking, treatment, monitoring, management and close-out during the detailed design and construction phases.

The risk assessment is based on the likelihood and consequence criteria given in Tables 1 and 2 below. The likelihood and consequences are combined in the risk grading table given as Table 3.

Groundwater abstractors within 2km of the site have been identified from an Envirocheck search carried out on 20 August 2018. A number of databases were searched including the Environment Agency database. Only two abstractors/ potential abstractors were identified and these are more than 1.7km from the site. Details of the identified abstractors are presented in Appendix 2, Section A2.3. These abstractors/ potential abstractors would serve as the potential receptors of saline water in the conceptual model (Appendix A2.1).

An experienced specialist cable contractor has been engaged. Appendix 3 presents a list of similar HDD landfall projects carried out by the contractor, together with some project pictures.

Table 1. Likelihood Criteria

Level	Likelihood	Qualitative Description
5	Almost Certain	Event is expected to occur in most circumstances
4	Likely	There is a high chance that the event will occur in most circumstances
3	Possible	The event is as likely as not to occur in most circumstances
2	Unlikely	There is a low chance that the event would occur in most circumstances
1	Rare	The event is not expected to occur in most circumstances

Table 2. Consequence Table

Level	**Likelihood**
5	Catastrophic
4	Major
3	Moderate
2	Minor
1	Insignificant

Table 3. Risk Grading Table

		Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Level	**Likelihood**	**1**	**2**	**3**	**4**	**5**
5	Almost Certain	5 Low Risk	10 Medium Risk	15 High Risk	20 V High Risk	25 V High Risk
4	Likely	4 Low Risk	8 Medium Risk	12 High Risk	16 V High Risk	20 V High Risk
3	Possible	3 Low Risk	6 Medium Risk	9 Medium Risk	12 High Risk	15 High Risk
2	Unlikely	2 Low Risk	4 Low Risk	6 Low Risk	8 Medium Risk	10 High Risk
1	Rare	1 Low Risk	2 Low Risk	3 Low Risk	4 Low Risk	5 Medium Risk

.

4 RISK ASSESSMENT

The risk assessment is presented in Table 4 which follows

Table 4. Risk Assessment

Item	Activity	Hazard	Cause	Possible Outcomes	Conse-quence	Like-lihood	Initial Risk Rating	Risk Treatments	Residual			comments
									conse-se-quence	Like-lihood	Risk	
EA-1a	HDD Drilling	Saline intrusion into chalk aquifer	Planned boring into chalk aquifer	Contamination of ground water resource, impact on private and public abstractors, impact on springs/ wetlands.	4 Major	3 possi-ble	12 High Risk	• The HDD bore is planned to be in the glacial till and well away from the chalk aquifer (see Figures 1(b) & (c)). The low permeability glacial till and the drilling mud used will ensure the chalk aquifer is not affected. • A seismic refraction survey has been undertaken to define the rocked along the HDD alignment (e.g. Figure 1(b)). Uncertainty related to the rock head position is very substantially reduced. • A minimum clearance will be specified in the design between the HDD design alignment and the chalk aquifer in the ground model. A minimum glacial till cover of 1m will be provided in the detailed design of the HDD. All tolerances on the HDD operations will be provided on top of this min-imum clearance. There will therefore be no planned interception of the chalk aquifer. • Detailed design will consider options to lift the alignment even higher if possible. • The vertical deviation tolerance that will be adopted for design is selected to be conservative. • Additional GI is planned. It will provide more information on the ground conditions at the HDD alignment including: to confirm the soil properties, to confirm rock levels and rock properties, to provide more calibration for the seismic refraction survey data, and to give pore water pressures in both the rock and the overburden soils. • In any case, regional groundwater flow is eastwards from the hills of the Lincolnshire Wolds to the sea. Saline intrusion would occur if GWL was drawn down below sea level in the chalk aquifer onshore (ref [16], Fig 2). The HDD drilling works will not cause such a draw down. The HDD entry point is above mean sea level and with the high mud pressure (hundreds of kPa) saline intrusion through the HDD bore will not occur during drilling even if the chalk aquifer is intercepted. • In addition, saline water exists in the coastal zones due to Pleistocene-age saline groundwater and historic abstractions (Fig 2 and ref [16]). It is likely groundwater in the HDD area will already be saline. The additional GI pro-posed would provide information on the baseline salinity of the water in the area. • **<u>Saline Intrusion Risk Source</u>**: HDD bore filled with seawater • **<u>Saline Intrusion Risk Receptors</u>**: chalk aquifer, abstractors drawing from chalk aquifer, springs/ wetlands. • **<u>Saline Intrusion Pathway:</u>** none. Low permeability glacial till and drilling mud prevent transmission (see Appendix A2.1).	1 Insig-nificant	1 Rare	1 Low Risk	
EA-1b	HDD Drilling	Saline intrusion into chalk aquifer	Accidental boring into chalk aquifer	Contamination of ground water resource, impact on private and public abstractors, impact on springs/ wetlands	4 Major	3 possi-ble	12 High Risk	• See risk treatment for Item EA-1a • Unplanned interception of the chalk aquifer is unlikely due to the mini-mum clearance to the chalk aquifer that will be designed in. • Boring alignment will be accurately monitored during construction using a gyro, and the alignment of the pilot assembly can be corrected to main-tain the design alignment together with a drill tolerance. • Density of the bentonite drilling mud is slightly higher than that of sea water. This means that sea water will not penetrate into the HDD bore, which is filled with bentonite. • See Fig 3(c) for illustrative cartoon and note points made in Fig 3(d) to 3(e) and 4 to show that saline intrusion will be insignificant and can be addressed. • **<u>Saline Intrusion Risk Source</u>**: HDD bore or pipe filled with seawater • **<u>Saline Intrusion Risk Receptors</u>**: chalk aquifer, abstractors drawing from chalk aquifer, springs or wetlands. • **<u>Saline Intrusion Pathway:</u>** none. Inadvertent length of chalk bore would be short and sidewalls of bore in chalk are sealed with mud, and can be sealed by setting a plug, if necessary. This prevents transmission of saline water. After completion of the installation of the product pipe, is still surrounded by bentonite. The bentonite will settle and consolidate under its self-weight to become a soft-firm clay. This together with any convergence of the HDD bore onto the pipe would provide a good seal to prevent penetration of sea water (see Appendix A2.1).	1 Insig-nificant	1 Rare	1 Low Risk	
EA-2	HDD Drilling and long term	Artesian conditions at HDD entry point	Geological conditions	Backflow of water up the drill bore and loss of water from the aquifer, Saline intrusion into aquifer	4 Major	3 possi-ble	12 High Risk	• Saline intrusion is not feasible during HDD drilling (bentonite has a higher density than water and mud pressures can be high, several hun-dred kPa). • After drilling, if the chalk aquifer is intercepted and if artesian condi-tions exist, saline intrusion still cannot occur. This is because flow will be from the aquifer – only very small water loss from the aquifer re-	1 Insig-nificant	1 Rare	1 Low Risk	

								source is possible (see Fig 3(a)). This can be addressed using the methods shown in Figures 3(a), 3(b), 3(e) & 4. • Fig 4 involves using specially designed muds for sealing the ground. These could be polymer enhanced bentonite mud (or other additives to bentonite). Polymers (which have a chain molecular structure) are typically used to seal factures/ joints openings in permeable rock. • Artesian conditions can only occur in the chalk aquifer (due to recharge in the Lincolnshire Wolds, see Fig 2). Artesian conditions cannot occur in the overburden soils. The glacial till is clayey and of low permeability. The Alluvium and wind-blown sands above the glacial till will have a hydrostatic groundwater pressure for a water table sitting on the glacial till. This will not be artesian. • Planned HDD alignment is in the Till (with a safe margin to the chalk, see Risk Item E-1a and Figure 1). A minimum glacial till cover of 1m in addition to all tolerances on the HDD operations will be provided by the design • Unplanned interception of the chalk aquifer is unlikely (see Risk Item EA-1b and Fig 3(b) and (c)). However, if it occurs, the amount of saline intrusion would be very small (see Figs 3(a) to (e) & Fig 4). This small leak can be addressed using the example methods shown in Figs 3 &4. These include use of polymer enhanced bentonite mud or other specialist muds to seal factures/ joints openings permeable zones in the chalk (Fig 4). • It is not known if artesian GW pressures exist in the chalk at the site, though it is thought to be unlikely as the aquifer is now being managed and public abstractors are reported (blue triangles to the east of the site in Fig 2). • The additional ground investigation planned will measure pore pressures in the chalk aquifer and check for artesian conditions.				
EA-3a	HDD Drilling and long term	Loss of water from aquifer	Geological conditions, planned and unplanned boring into chalk aquifer, ingress of water into HDD bore.	Loss of yield of private users (licensed and unlicensed) , Deterioration of wetlands due to reduced spring discharge or lowering of gwl	4 Major	3 possible	12 High Risk	See risk treatment for EA-2 (above), see Appendix A2.1. Also see Figs 3(d) & 4 for possible mitigation scheme. Abstractors and springs/ wetlands are very far away from the site and are very unlikely to be affected (Abstractors >1.7km, see Appendix A2.3; springs >5km see Figure 2)	1 Insignificant	1 Rare	1 Low Risk	
EA3b	HDD Drilling and long term	Loss of water from aquifer	Geological conditions, planned and unplanned boring into chalk aquifer	Continued loss of chalk aquifer water at HDD exit point.	3 Moderate	3 possible	9 Medium Risk	See risk treatment for EA-2 (above), see Appendix A2.1. Also see 3(a), 3(b), 3(e) & 4 for possible mitigation scheme.	1 Insignificant	1 Rare	1 Low Risk	

Notes

1. Risk treatment should reduce the remedial risks to “Low” for the residual risk to be tolerable.
2. A conceptual design has been produced to date for the HDD. Further site investigations and surveys are planned and a detailed design will be produced by the HDD sub-contractor based on the more detailed information. Some risks that have been identified can be mitigated or treated in the detailed design work.
3. Items designated EA-* refer to Environment Agency risks.
4. Abbreviations: GWL = Ground Water Level, GI = Ground Investigation, m bgl= metres below ground level, AL = Alluvium, dia = diameter.

5 REFERENCES

Input Data from TK

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[3] Export Cable Corridor Landfall Geotechnical Design Basis, Date: February 2017, Document Ref: 2505-TKN-OSC-G-FD-0001

[4] Triton Knoll, Onshore Site Investigation - WP1, 2505-TKN-DAT-D-RB- 0002 Factual Report for Triton Knoll Offshore Wind Farm Ltd., Project Number PC166424, November 2016

[5] FUGRO GEOCONSULTING LIMITED, Geotechnical Report, Export Cable Route Measured and Derived, Geotechnical Parameters and Final Results, Triton Knoll Offshore Wind Farm, Site Investigation 2016, UK Sector, Southern North Sea, Triton Knoll Document No.: 2505-FUG-OEC-G-RA-0004-04, Fugro Document No.: J35050-R-7(04), Issue Date: 27 October 2016

[6] Triton Knoll Offshore Wind Farm Project Geotechnical Specification for Beach and Landfall Boreholes, Document No: 2505-TKN-DAT-B-SP-0001 Rev: 01 dated July 2018

[7] Triton Knoll Offshore Windfarm Export Cables (Northern Route) Landfall Alignment Chart 1 of 1 Refraction Results, Version 1 dated 20/7/2018.

[8] Structural Soils Ltd Factual Report on Ground Investigation at Anderby Creek, Report 727689, dated June 2013.

[9] Triton Knoll Offshore Wind Farm Ltd - Onshore Cable Route GI for Priority Locations, AGS file PC166424v1.ags, created 19/12/2016 14:09, size 24.9Mb

Commissioning Documents

[10] GCG Proposal TK-HDD2-2018: Risk Assessment of HDD Proposals for Burial of Export Cable, dated 5/7/2018

[11] GCG Proposal TK-HDD1-2018: review of HDD Proposals for Burial of Export Cable

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[14] The stratigraphy of the Chalk Group in Yorkshire and Lincolnshire BGS Technical Report WA/99/02

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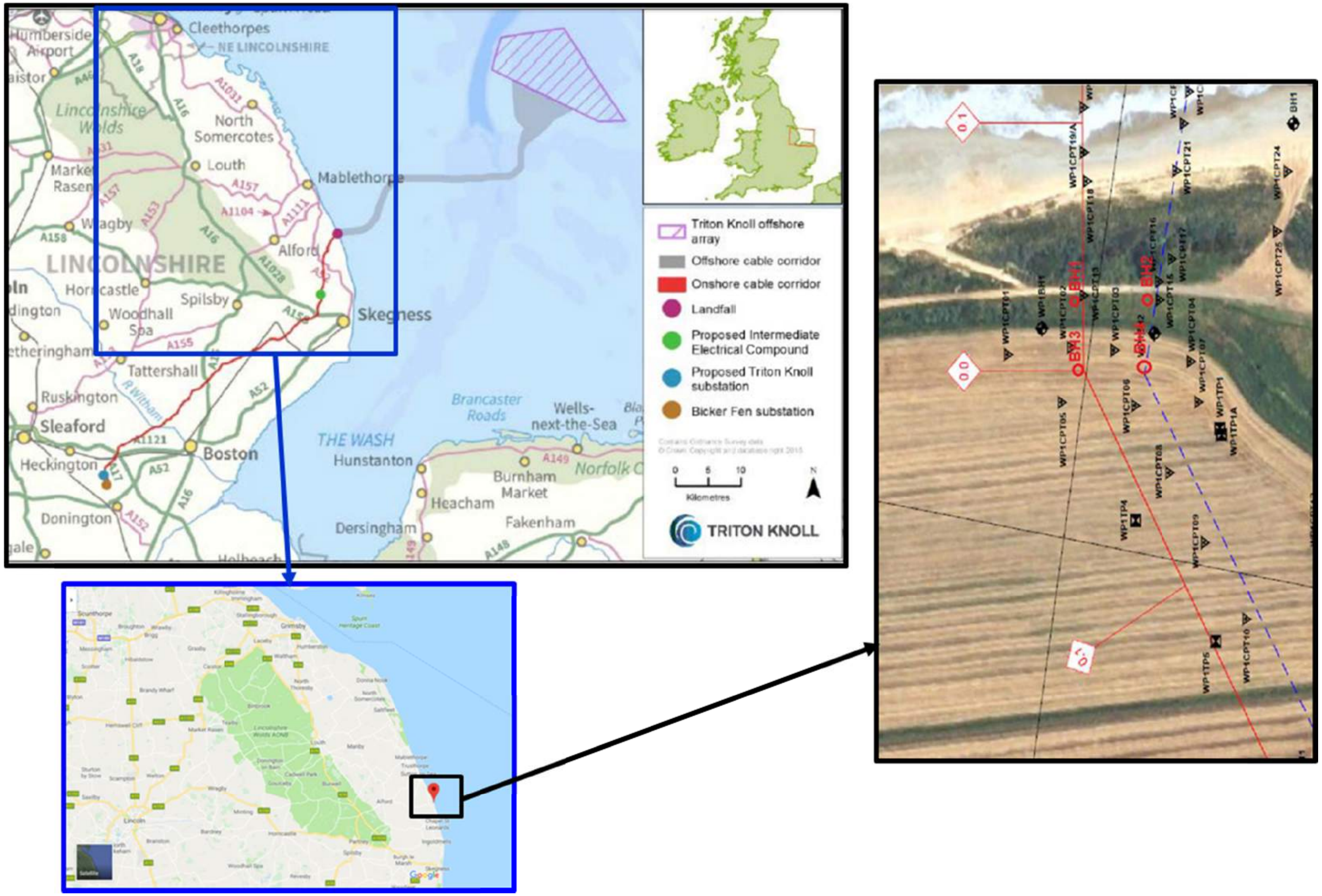
[16] A successful model: 30 years of the Lincolnshire Chalk model. M. J. Hutchinson, R. G. S. Ingram, M. W. Grout and P. J. Hayes. M. J. Hutchinson, R. G. S. Ingram, M. W. Grout and P. J. Hayes. Geological Society, London, Special Publications, 364, 173-191, 23 April 2012

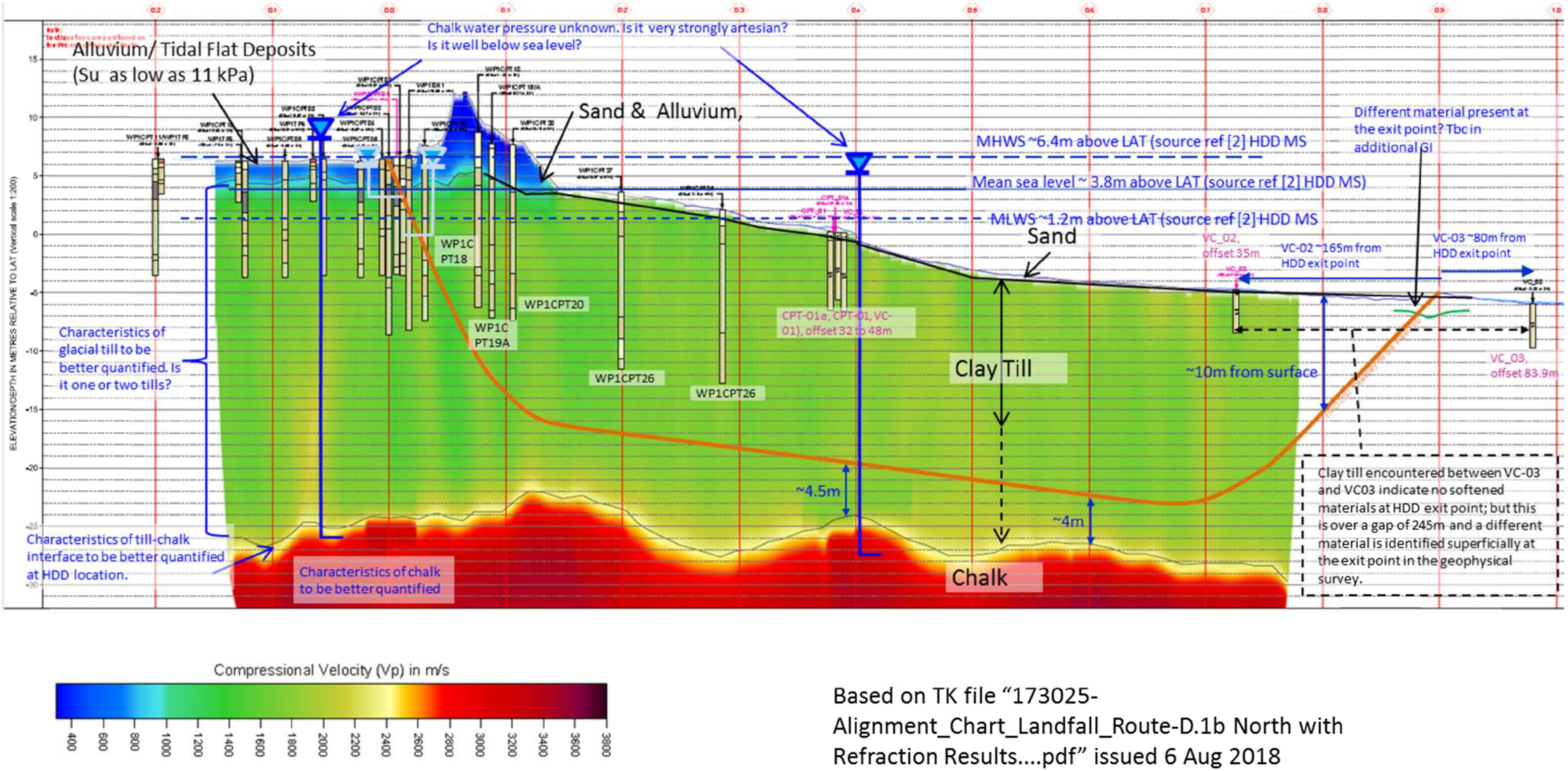
[17] Bell & Foster (1991) "The geotechnical characteristics of the till deposits of Holderness", Quaternary Engineering geology, geological Society Engineering Geology Special Publication No 7, pp 111-118, Foster A, Culshaw M G, Cripps J C, Little J A & Moon C F (eds)

[18] Thewes M (2012) "Slurry shield machines and separation plants", ITACET-SIG & ITA AITES Workshop, "Mechanised Tunnelling in Urban Areas", Rome, 13 – 14 April 2002

FIGURES

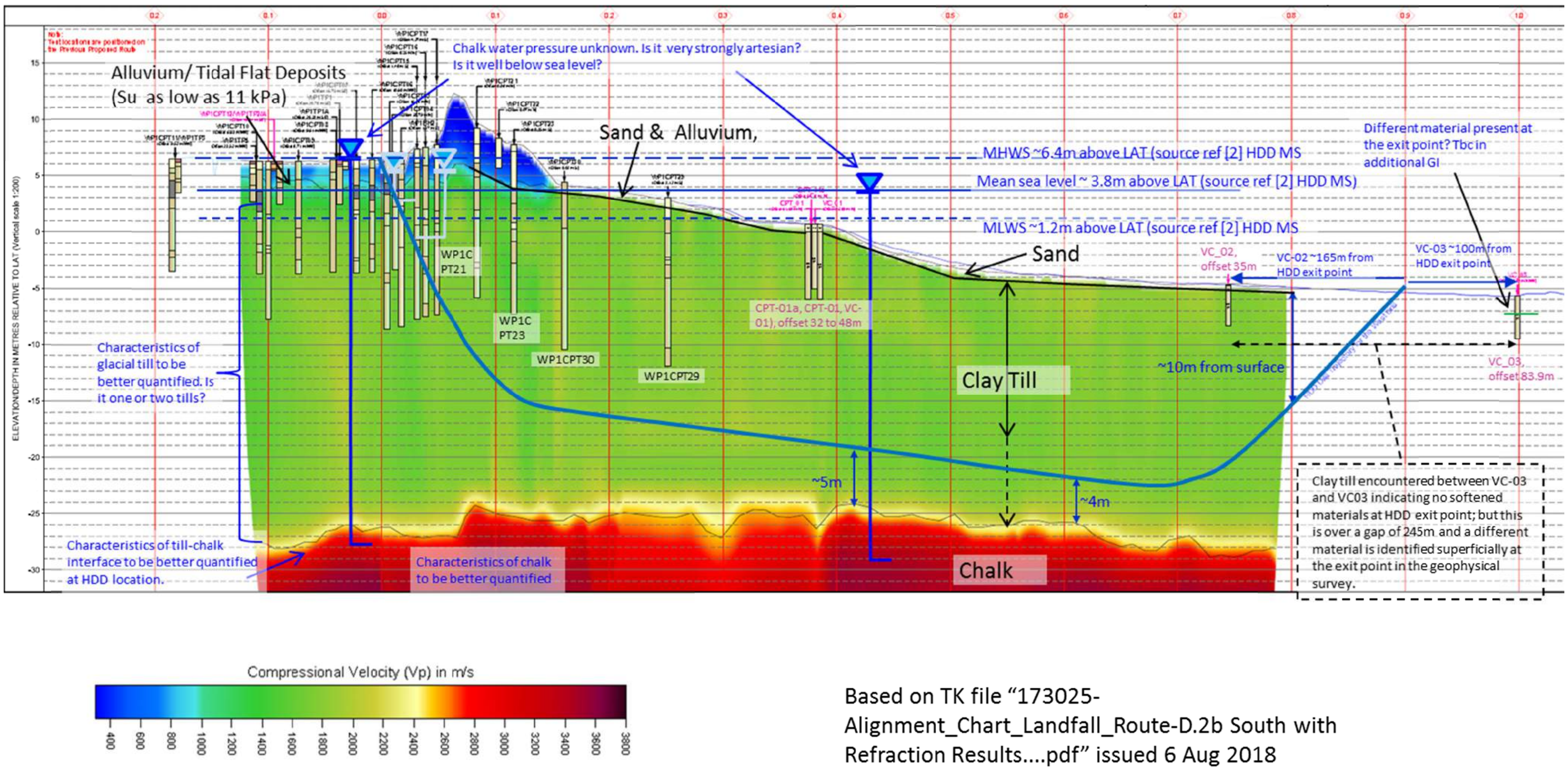


	Triton Knoll Review of HDD Proposals for Buried Cable	**Figure 1(a)**
GCG	**Site Location**	



Based on TK file "173025-Alignment_Chart_Landfall_Route-D.1b North with Refraction Results....pdf" issued 6 Aug 2018

GCG	**Triton Knoll** Review of HDD Proposals for Buried Cable **2018 refraction survey with northern cable HDD alignment, geotechnical interpretation and some areas to be better defined in the additional Ground Investigation** North Cable	**Figure 1(b)**



GCG	**Triton Knoll** Review of HDD Proposals for Buried Cable **2018 refraction survey with southern cable HDD alignment, geotechnical interpretation and some areas to be better defined in the additional Ground Investigation** South Cable	**Figure 1(c)**

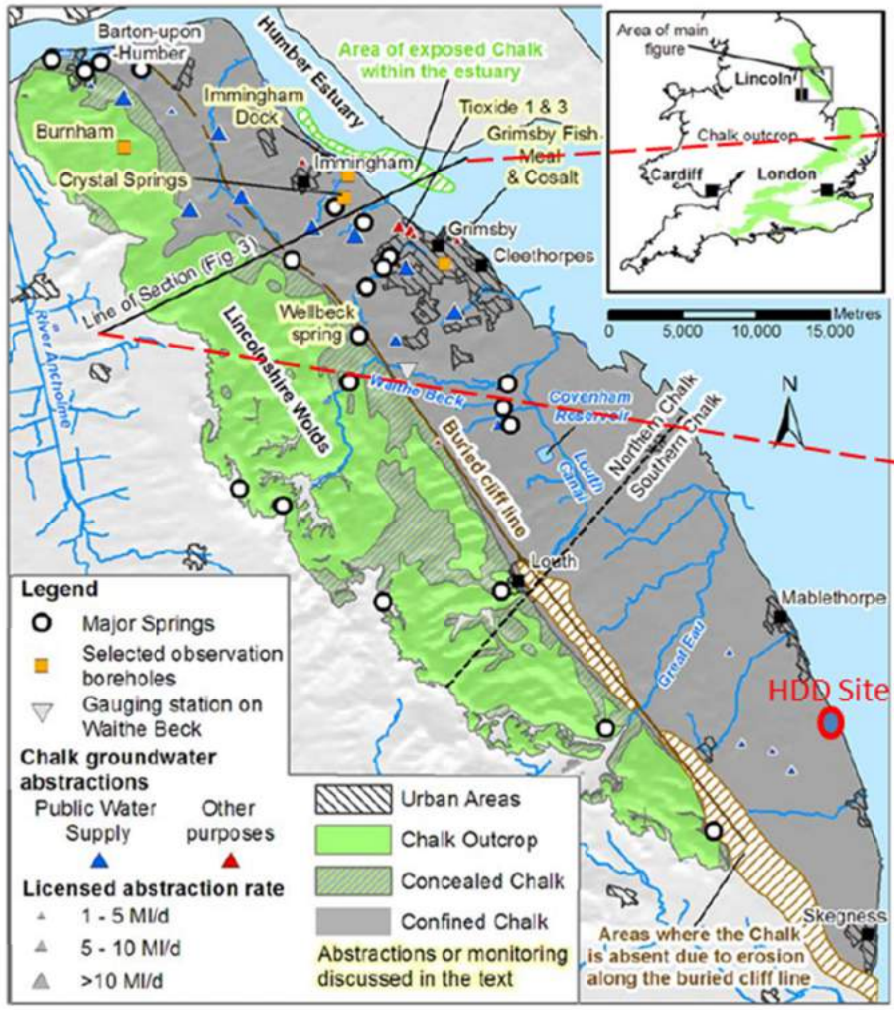


Fig. 1. Location map of the Lincolnshire Chalk aquifer illustrating the main hydrogeological features of the aquifer system, key abstractions and locations discussed in the text. Ml/day, megalitres per day (1 Ml/day is equivalent to 1000 m^3/day).

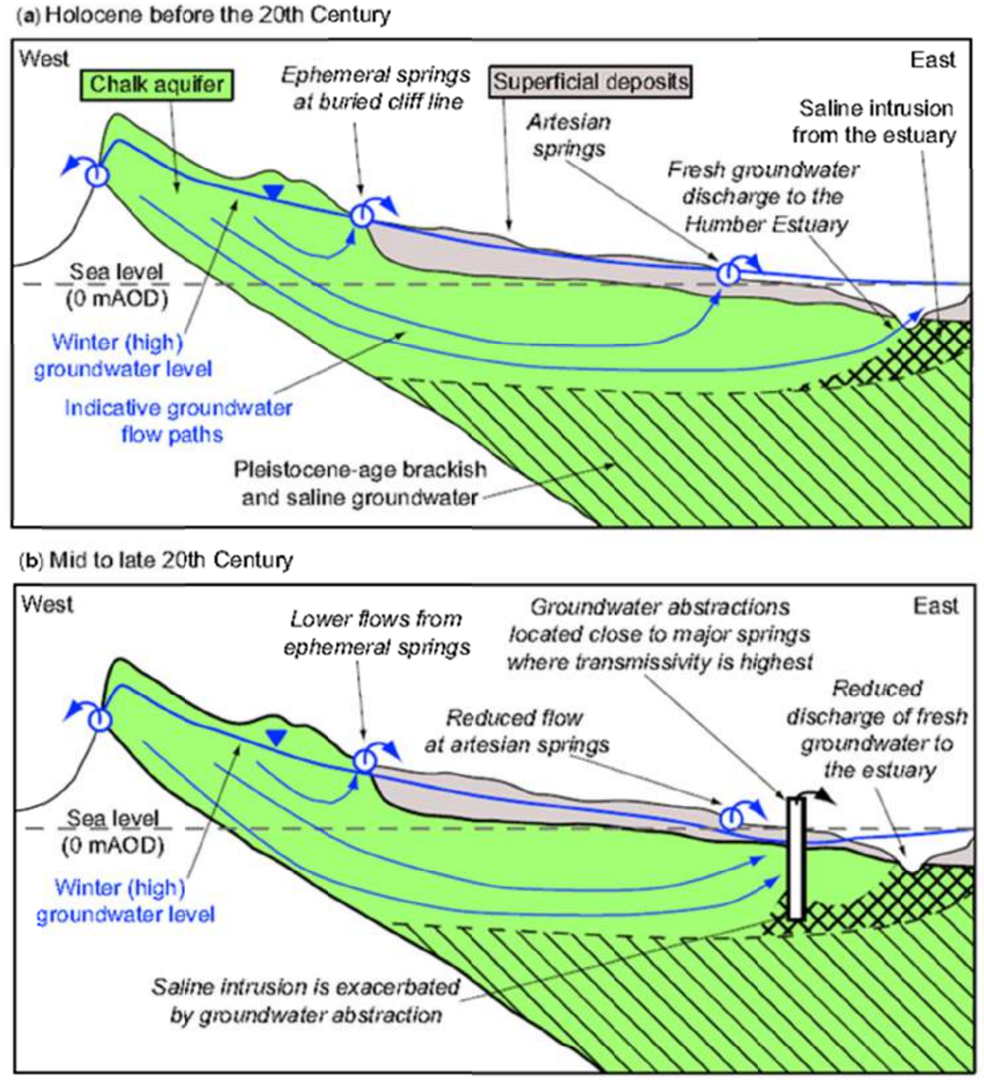
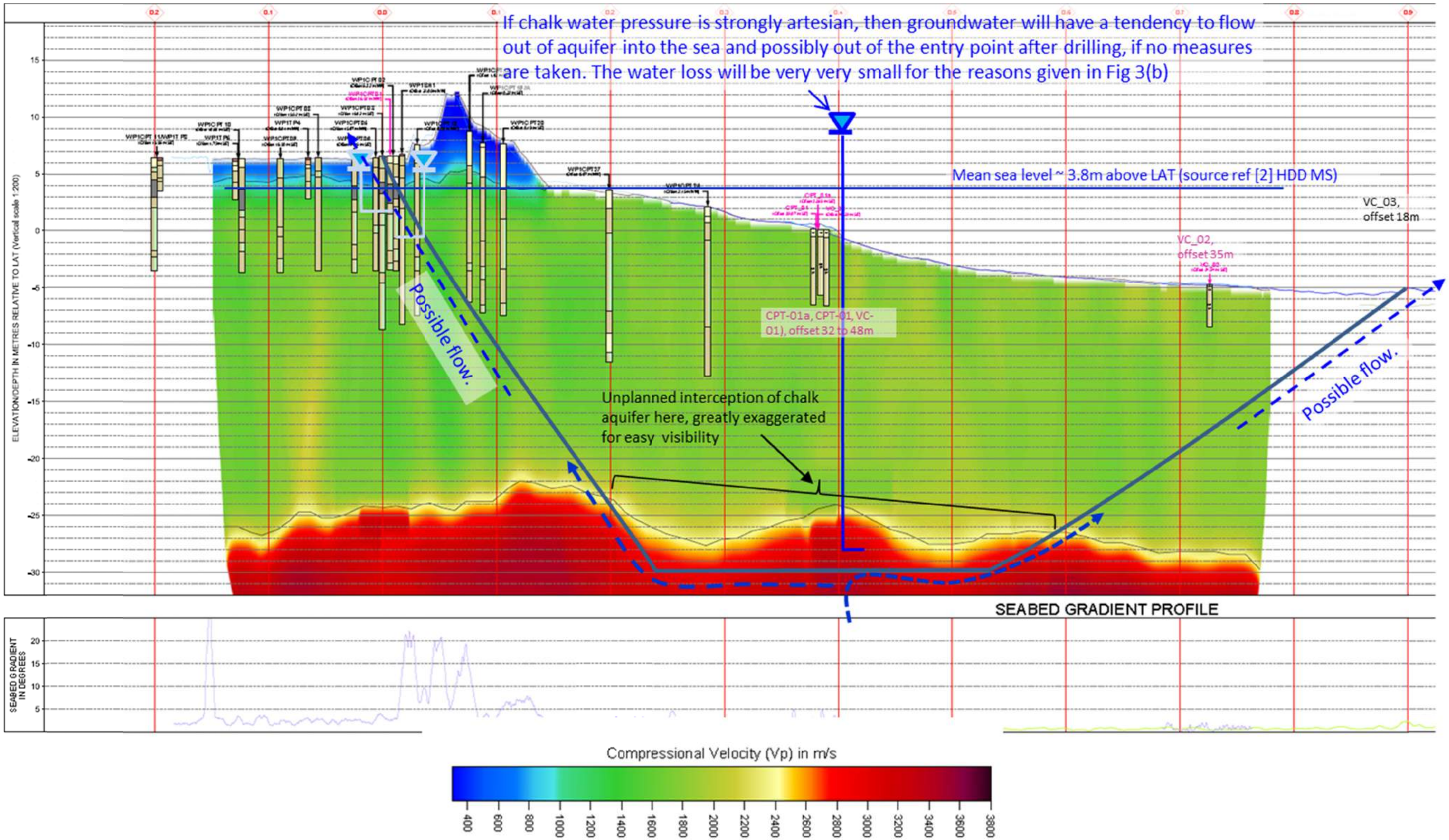


Fig. 3. Schematic conceptual models of the hydrogeology of the Northern Lincolnshire Chalk aquifer (**a**) prior to large-scale groundwater abstraction, and (**b**) illustrating the impacts of groundwater abstraction, which include reduced flows at springs, a decline in fresh groundwater discharge to the Humber estuary and consequently increased intrusion of estuary water into the aquifer (after Hiscock & Lloyd 1992).

Artesian conditions existed before 20th century due to recharge at the hills of the Lincolnshire Wolds. Boreholes drilled in the 1930s in Grimsby had persistent artesian flow. Due to continued abstractions, these became only seasonally artesian in the 1940s. Industrial growth after 1945 and increased water demand meant that artesian conditions were only observed in Grimsby occasionally, such as at weekends when industrial use was lower. By 1960 no overflows were observed at Grimsby. The abstraction rate had equalled the aquifer recharge rate. Also, groundwater levels near the coast had been reduced to below sea level. This combination led to saline intrusion in Grimsby in the coastal areas. Since the 1980s the aquifer has been managed with controlled abstraction to prevent deterioration.

GCG	Triton Knoll Review of HDD Proposals for Buried Cable **Regional groundwater flows in Lincolnshire (extracts of ref [16])**	Figure 2



GCG	**Triton Knoll** Review of HDD Proposals for Buried Cable	**Figure 3(a)**
	Exploring the consequences of unplanned interception of the chalk aquifer – artesian conditions Schematic cartoon illustrating the (exaggerated) conditions	

The amount of freshwater lost from the aquifer to the sea through the HDD bore **will be very small/ negligible** for the following reasons (

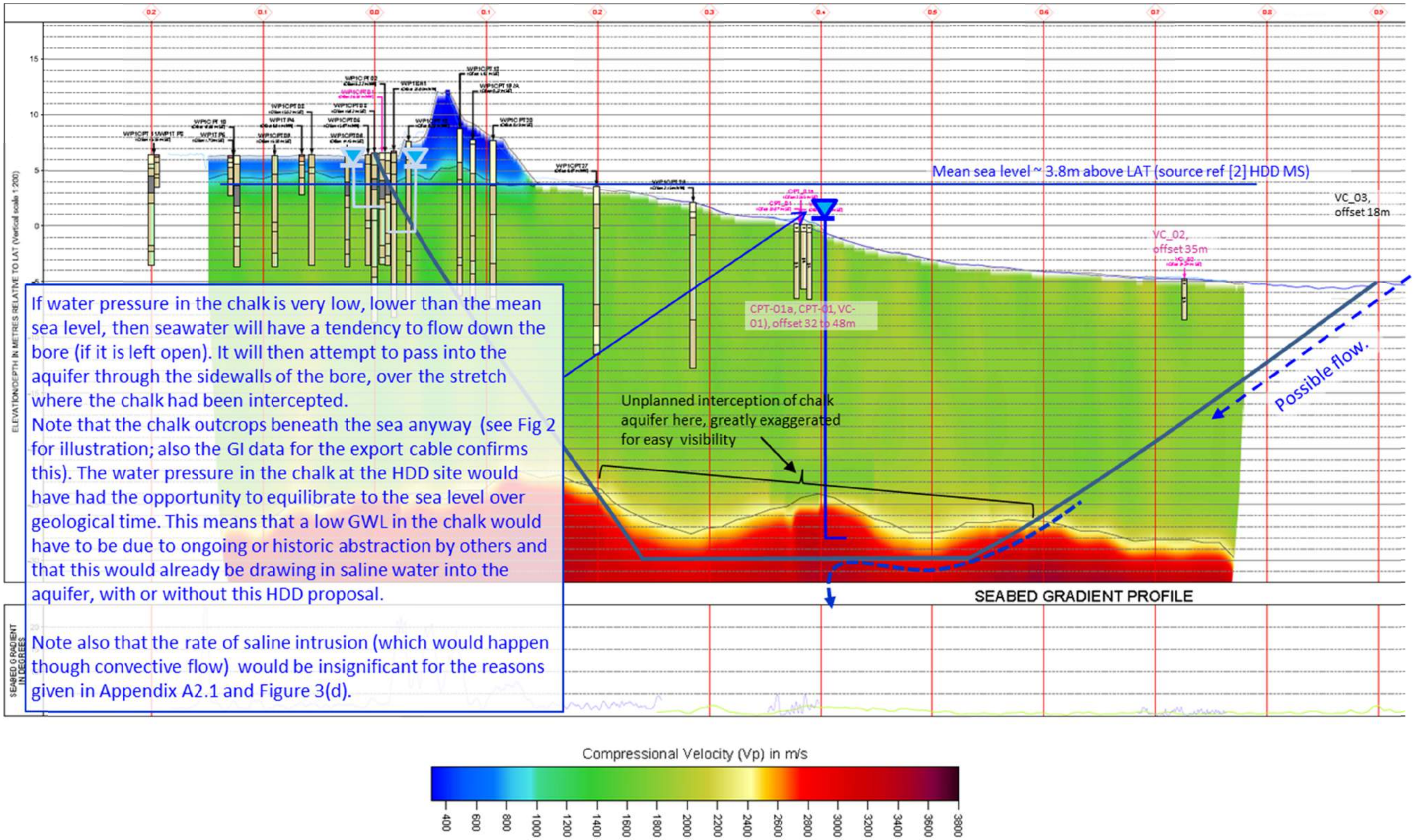
- The flow will be driven by the head difference between the artesian water pressures and the mean sea level. This head difference will be a few meters at most; it will not be tens of meters (see Fig 3(a) for illustration). In any case the new GI will establish the head difference before detailed design and construction.

- The water loss will also be dependent on the length of HDD bore in the chalk aquifer. It is not planned that the bore will enter the chalk aquifer. The bore length in the chalk should be zero, but lets consider the case where the aquifer was penetrated unintentionally. In this circumstance, the HDD operator will take steps to get the bore out of the aquifer as soon as possible and this will keep the chalk length small. The measures that would be taken to get out of the chalk as soon as possible are as follows.

  - We have good information on the location of the chalk rock head and so can avoid the chalk. There is good geophysical survey information on this (Fig 1). The rockhead it shows matches available BGS borehole logs. Additional high quality boreholes are planned and these will confirm and calibrate the geophysical survey. The additional GI will be done soon, before HDD starts.
  - The project will monitor the drilling thrust force, torque, rotation and penetration rates and other parameters during drilling. This will give information about what material is being drilled and can help to identify if the drill bit inadvertently enters the chalk. The project can also monitor the colour of the flush returns at the entry point and with a sieve the nature of the particles returned with the flush.
  - If we are inadvertently in chalk the alignment can be changed quickly, using the minimum radius achievable to exit the chalk. This will allow the bit to emerge from the chalk over a distance of a few meters.
  - The drilling mud used for the HDD will tend to clog up any fractures and discontinuities in the chalk if the chalk has normal permeability. If the chalk is inadvertently encountered in a location where its permeability is high, flush returns will be lost immediately and this will be noticed by the drill crew. Then, using a more viscous drilling mud and sealing polymers, flush loss in the chalk can be sealed (see Fig 4 for some example methods of sealing permeable zones using Loss of Circulation Materials (LCMs)). There is a wealth of experience of sealing against flush loses or sealing bores from the oil and gas drilling industry; that knowledge and associated products are available for HDD work. Much of this experience is directly relevant as it involves drilling in limestones and chalk. Once the flush loss is sealed, the HDD drill bit would then be deviated out of the chalk as soon as possible.
  - If necessary, at pilot stage, it is also possible to trip back the drill bit, set a plug seal in the chalk bore length and then adopt a new alignment that will re-establish the minimum design clearance to the chalk aquifer. This is illustrated in Figure 3(e).

- Separate from the above, the chalk outcrops under the sea in the site area (see Fig 2 for a cartoon illustration). This means that natural losses of freshwater to the sea will be occurring anyway, if artesian pressures exist in the chalk.

GCG	**Triton Knoll** Review of HDD Proposals for Buried Cable **Exploring the consequences of unplanned interception of the chalk aquifer – artesian conditions** Assessment of the magnitude of potential loss of water from the HDD bore into the sea in the event of artesian pressures in the chalk aquifer	**Figure 3(b)**



	Triton Knoll Review of HDD Proposals for Buried Cable	Figure 3(c)
	Exploring the consequences of unplanned interception of the chalk aquifer – ground water level in chalk substantially below sea level Schematic cartoon illustrating the (exaggerated) conditions	

In the event that: the HDD bore inadvertently hits the chalk, and the water level in the chalk aquifer is below mean sea level, saline intrusion into the aquifer from the sea via the HDD bore would be a risk. The amount of saline intrusion **will be very very small** for the following reasons (see Fig 3(c); note also that the chalk aquifer is in hydraulic connection to the sea offshore).

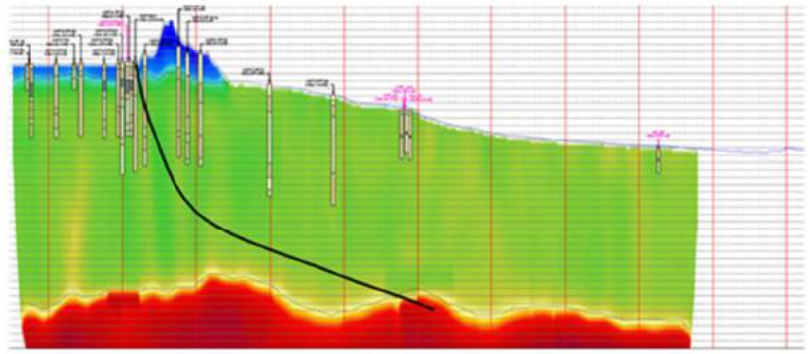
- The flow of sea water from the bore into the aquifer will be driven by the head difference between mean sea level and the groundwater level in the chalk. This head difference will be small, a few meters at most. It will not be tens of meters (see Fig 3(c) for illustration). In any case the new GI will establish the head difference and sense before detailed design starts.
- The rate of potential salt water ingress from the HDD bore into the aquifer will also be dependent on the length of HDD bore within the chalk aquifer. It is not planned that the bore will enter the chalk aquifer. The bore length in the chalk should be zero, but let's consider the case where the aquifer was penetrated unintentionally. In this circumstance, the HDD operator will take steps to get the bore out of the aquifer as soon as possible and this will keep the chalk length small.
- The measures that would be taken to get out of the chalk as soon as possible are as follows.
  - We have good information on the location of the chalk rock head and so can avoid the chalk. There is good geophysical survey information on this (Fig 1). The rockhead it shows matches available BGS borehole logs. Additional high quality boreholes are planned in the further GI to be conducted and these will confirm and calibrate the geophysical survey. The additional GI will be done soon, before HDD starts.
  - The project will monitor the drilling thrust force, torque, penetration rate and other parameters during HDD drilling. This will give information about what material is being drilled and can help to identify if the drill bit inadvertently enters the chalk. The project can also monitor the flush and cutting returns at the entry pit to verify when the bit is inside the chalk aquifer.
  - If the HDD drill bit is inadvertently in chalk, the drill alignment can be changed quickly, using the minimum radius achievable to exit the chalk. This will allow the bit to emerge from the chalk over a distance of a few meters and thereby limit the length of bore in the chalk.
- The rate of salt water ingress from the HDD bore into the aquifer will also be extremely small because the walls of the bore will be sealed for the following reasons.
  - The drilling mud used for the HDD will clog up any fractures and discontinuities in the chalk to prevent flush loss. This is the case if the chalk has normal permeability. If the encountered chalk is of high permeability, then flush returns will be lost and this will be noticed and immediately addressed by the drill crew. They must address it immediately because success of the HDD installation depends critically on avoiding flush loss to ensure that the bore remains supported and open. Flush loss in permeable chalk would be stopped by using a more viscous drilling mud and sealing polymers such as the examples shown in Figure 4. There is a wealth of experience of sealing against flush loses or sealing bores from the oil and gas drilling industry and the knowledge and tools are available for HDD work. Much of this experience is directly relevant as it involves drilling in limestones and chalk. Once the flush loss is addressed, the HDD drill bit would then be quickly deviated out of the chalk to keep the length of inadvertent chalk bore as short as possible.
  - If necessary, at pilot stage, it is also possible to trip back the drill bit, set a plug seal in the chalk bore section, and then adopt a new alignment that will re-establish the minimum design clearance to the chalk aquifer. This is illustrated in Figure 3(e) and will prevent saline intrusion via the HDD bore.

Separate from all the above, it is noted that the chalk outcrops under the sea in the site area (see Fig 2 for a cartoon illustration). This means that natural saline intrusion would be occurring anyway, if depressed water pressure exists in the chalk. Compared to this the possible saline intrusion from the HDD bore will be negligibly small.

Triton Knoll Review of HDD Proposals for Buried Cable	**Figure 3(d)**
Exploring the consequences of unplanned interception of the chalk aquifer – ground water level in chalk substantially below sea level	

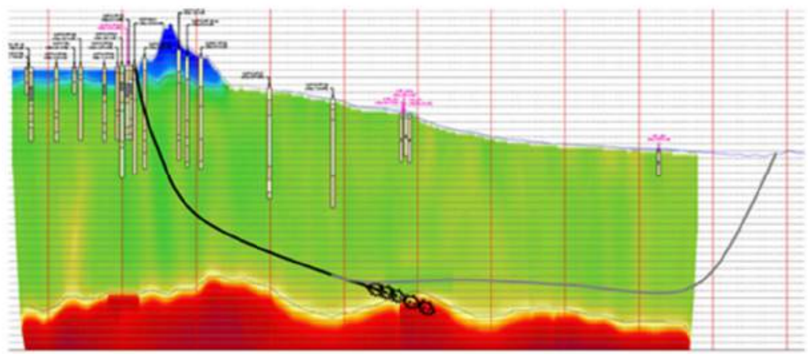
Possible scheme to adopt to seal inadvertent lengths of chalk bore (if necessary) and to complete the HDD bore

Step 1: inadvertent entry into chalk aquifer identified as early as practicable.

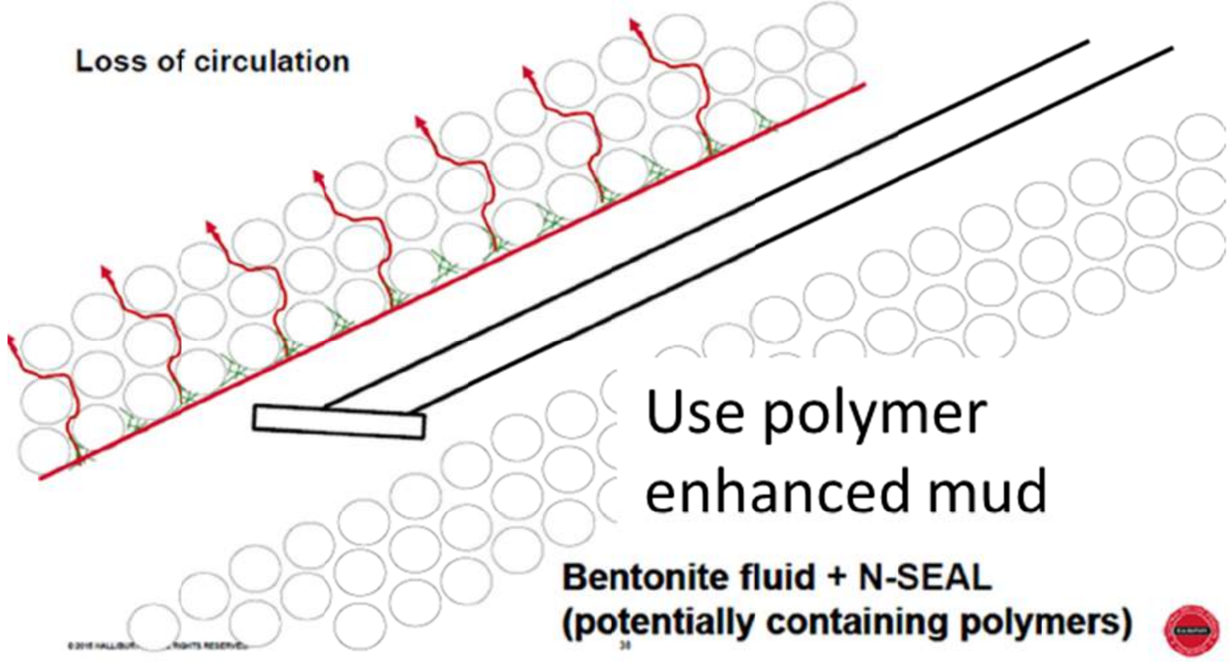


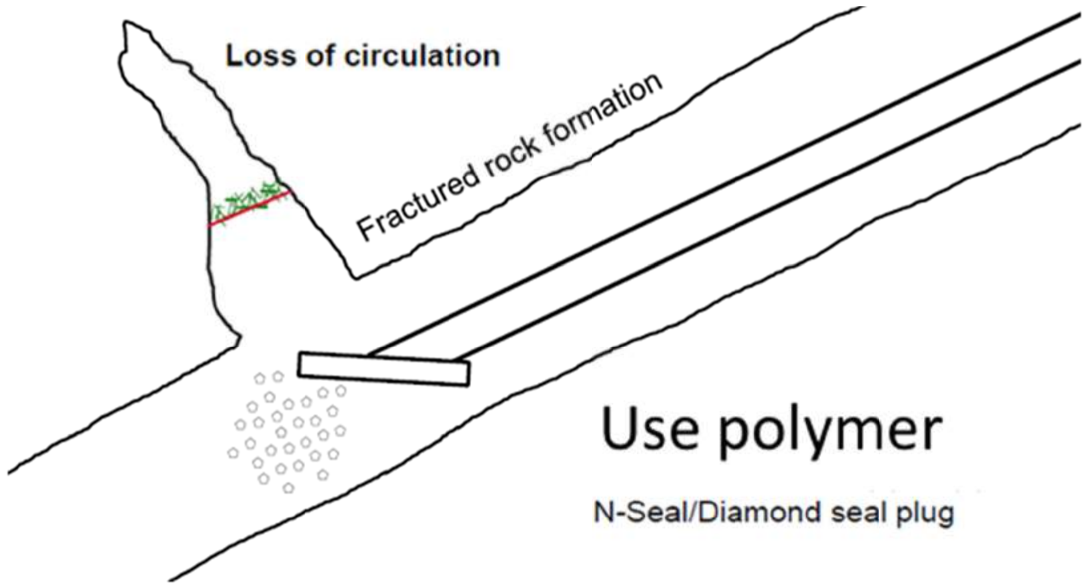
Step 2: set a plug in the chalk bore to seal it, trip back well out of the chalk,

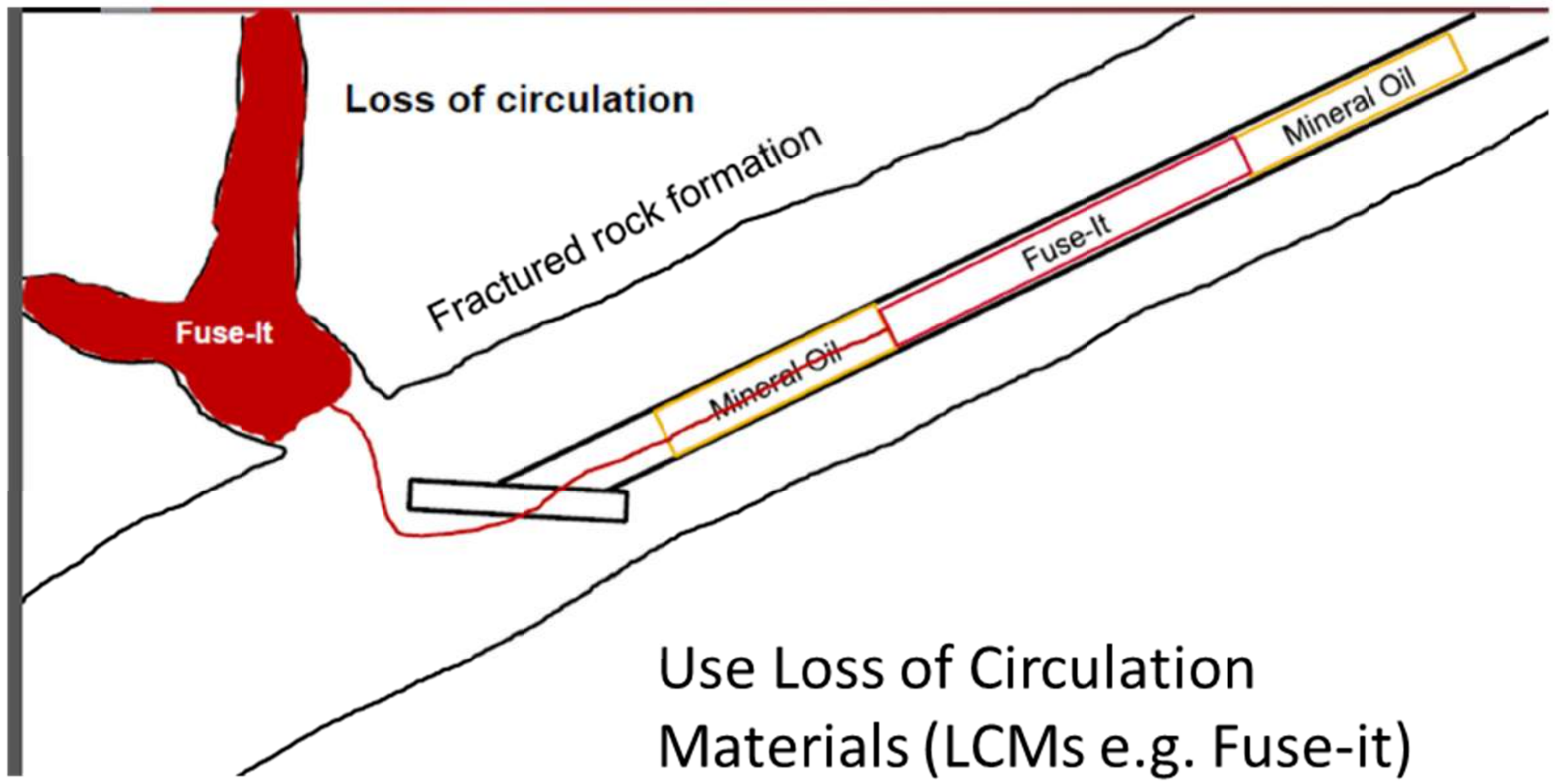
Step 3: change the alignment to maintain the minimum clearance and complete the HDD bore



	Triton Knoll Review of HDD Proposals for Buried Cable	**Figure 3(e)**
	Exploring the consequences of unplanned interception of the chalk aquifer – ground water level in chalk substantially below sea level Possible scheme for sealing the inadvertent lengths of bore in chalk (if necessary)	







GCG	**Triton Knoll** Review of HDD Proposals for Buried Cable	**Figure 4**
	Loss of circulation/ permeable zones - solutions Some examples of for sealing the highly permeable ground	

APPENDIX 1 DETAILS OF GROUND CONDITIONS

A1.1 Introduction

The strata relevant to the HDD works as indicated on the onshore BGS mapping are the Quaternary wind-blown sands, Alluvium and Glacial Tills. Beneath these strata is the Cretaceous Chalk.

A.1.2 Windblown sands

These sands form a line of dunes at the rear of the beach typically about 5m high. They are likely to sit on top of the underlying Alluvium and probably comprise near single sized fine sand.

A.1.3 Alluvium

The Alluvial soils and the 'Tidal Flat Deposits' here are considered to be the same deposit, outcropping either side of the overlying coastal dune system.

As temperatures rose and ice melted at the end of the Devensian 'last Ice age' a combination of sea level rise and glacial isostasy caused the sea to reoccupy the southern North Sea and move the coastline southwards and westwards to produce tidal mudflats in the area between the Wolds and Anderby Creek. These have been extensively reclaimed and drained just inland of the HDD launch point and are slightly lower as a result.

These deposits are essentially soft normally consolidated redeposited Glacial Till (i.e. clays and silts with some more recent organic material). Coarser material from the Till may be concentrated at the Alluvium / Till interface in some locations.

A.1.4 Glacial Till

The BGS offshore mapping indicates the presence of a 'Diamict' (Glacial Till) over Chalk. Diamicts are well graded deposits with a broad range of particle sizes. As a result, they can achieve a very dense and compact packing, resulting in high strength and low permeability.

The Glacial Till found in this part of Lincolnshire is the Skipsea Till Member of the Holderness Till Formation. This Till was created by a Devensian ('last Ice Age') ice sheet flowing down the eastern side of the Chalk hills forming the Yorkshire and Lincolnshire Wolds. The ice source was the east side of the Pennines and southeast Scotland. The Skipsea Till is poorly exposed on the Lincolnshire coast and most of the published data for this Till is based on coastal exposures north of the Humber and at its southernmost extent in north Norfolk.

In general terms the Skipsea Till is a poorly sorted, low plasticity, stiff silty sandy gravelly Clay that contains occasional cobbles and boulders. The Till many contain permeable lenses or channel fills of sand, gravel, cobbles and boulders; these are not likely to be common.

Published analyses of the coarser (>8mm) material in samples taken of this Till north of the Humber indicate that most of this material is derived from the sedimentary rocks that outcrop close to the current east coast south of the Scottish Midland Valley. Cretaceous rocks (Chalk and Flint) typically form around a quarter of the coarser particles. Igneous rocks form a relatively low proportion of these analyses.

Photographic evidence from where these tills are well exposed north of the Humber (where the local underlying geology is similar to that of Lincolnshire) suggests the larger Till particles (cobbles and boulders) are mostly local (Chalk and flint).

Local historic well data suggests the Till is around 30m thick west of the launch site. This is consistent with the results of geophysical investigations of the alignment (e.g. Figure 1(b))

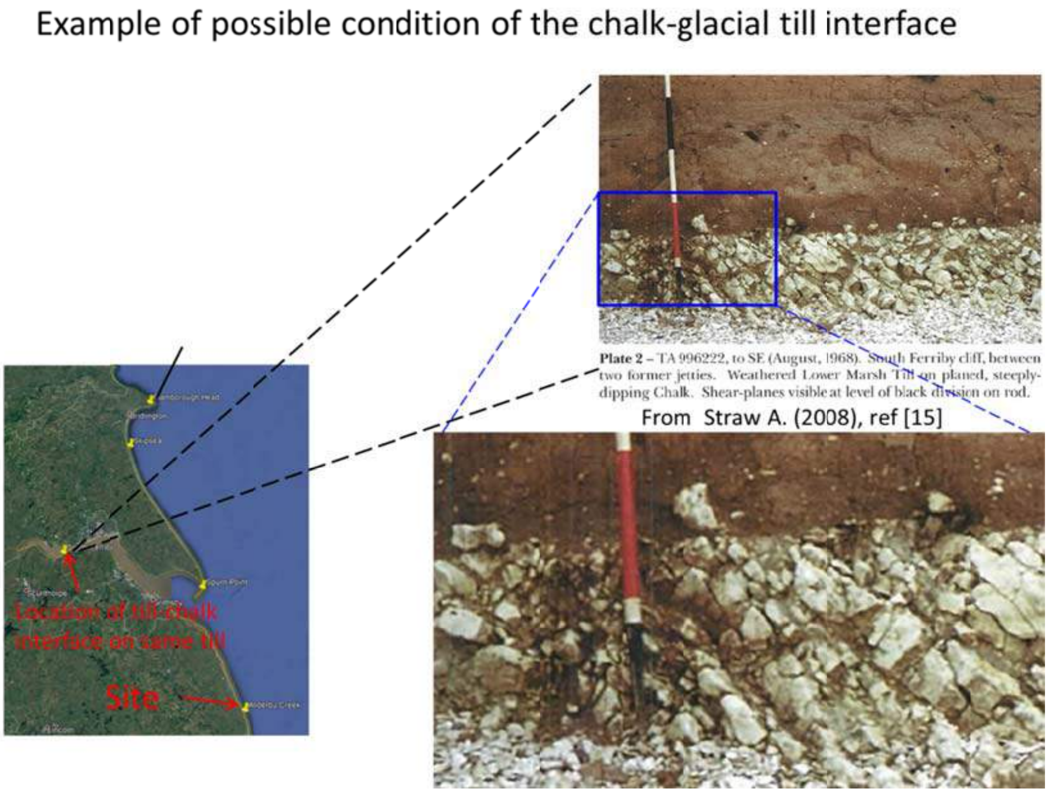
There is little or no local evidence as to whether there is an older Till beneath the Skipsea Till. There is however indirect evidence that this may be the case in the wider area. The presence of this lower Till is disputed in academia. As the sources of coarser material in any lower Till are likely to be similar to those of the upper till (if applicable) the two tills may be very similar. The presence of a second till is relevant because of the contact between the two tills may contain other materials – such as concentrations of boulders, other fluvially sorted deposits (such as sands / gravels) or palaeosoils.

A.1.5 Chalk

a) Till / Chalk interface

Where the Chalk / Till interface is exposed north of the Humber and in north Norfolk it generally has low relief (see Figure below). However there are locations where Till filled paleo-topography and solution features can be seen (e.g. Flamborough Head).

The depth of Quaternary weathering of the top of Chalk is variable. In areas of paleo-topographic highs Grade D weathering profiles are typically limited to a few metres. Beneath and adjacent to palaeo-valleys weathering depths can reach 10's of metres.



b) The Chalk

The Chalk found beneath the Till is thought to be the Burnham Chalk Formation. In total this would be expected to be more than100m thick. However the depth to its base isn't known at the site. The Burnham Chalk is characteristically thinly bedded with tabular and discontinuous flint bands and occasional marl seams. It also contains some zones with large Paramoudra style flints. The base of the unit contains hard chalks and thick closely spaced tabular flints. The base of all of the Chalk is thought to be around -100m OD at the site. If this is the case the base of the Burnham Chalk may be very close (<10m) to the base of the Till.

A.1.2 Groundwater

There are many historic farm wells close to coast drilled through the Till to extract water from the Chalk. Logs for these are available on the BGS website. Notes added to these logs in the 1940's and 50s, when the wells were starting to be replaced by mains water, often state that water levels were close to the ground surface and that hand pumps were often present. Occasionally the well logs suggest that the Chalk aquifer was just artesian. Artesian wells ('blow wells' locally) are a relatively common feature in the low ground close to the Lincolnshire Wolds.

These well logs sometimes suggest that this water was 'salty'. One log quotes 420ppm of chloride iron (Cl^-, seawater is typically circa 19000 ppm). Typical quoted values are chloride concentrations are less than 100ppm. Saline intrusion into the Chalk aquifer is a well-known phenomenon by the Humber and around Grimsby.

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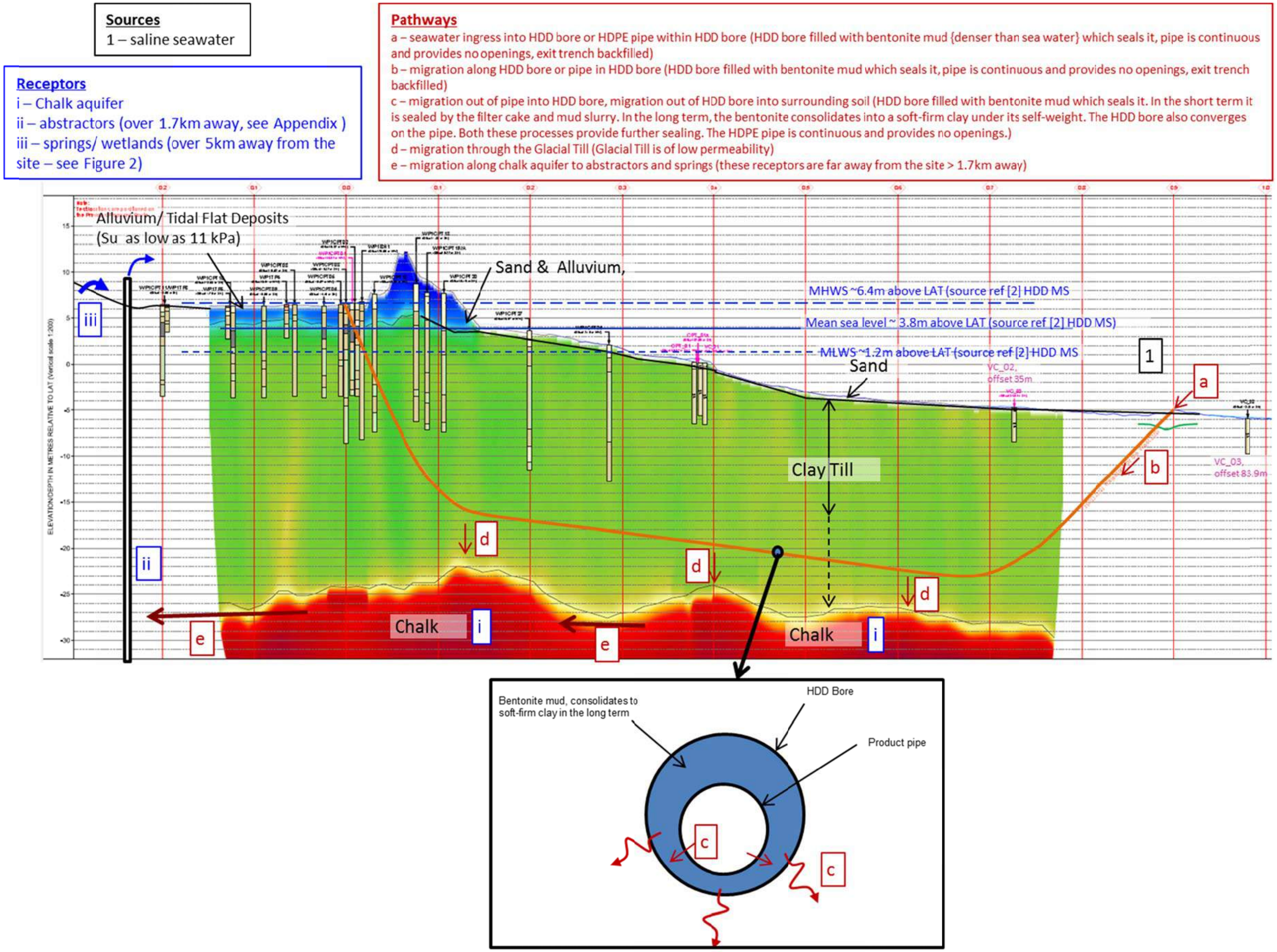
APPENDIX 2 CONCEPTUAL MODEL, DEFINITIONS AND ABSTRACTORS FROM THE CHALK

A2.1 conceptual model

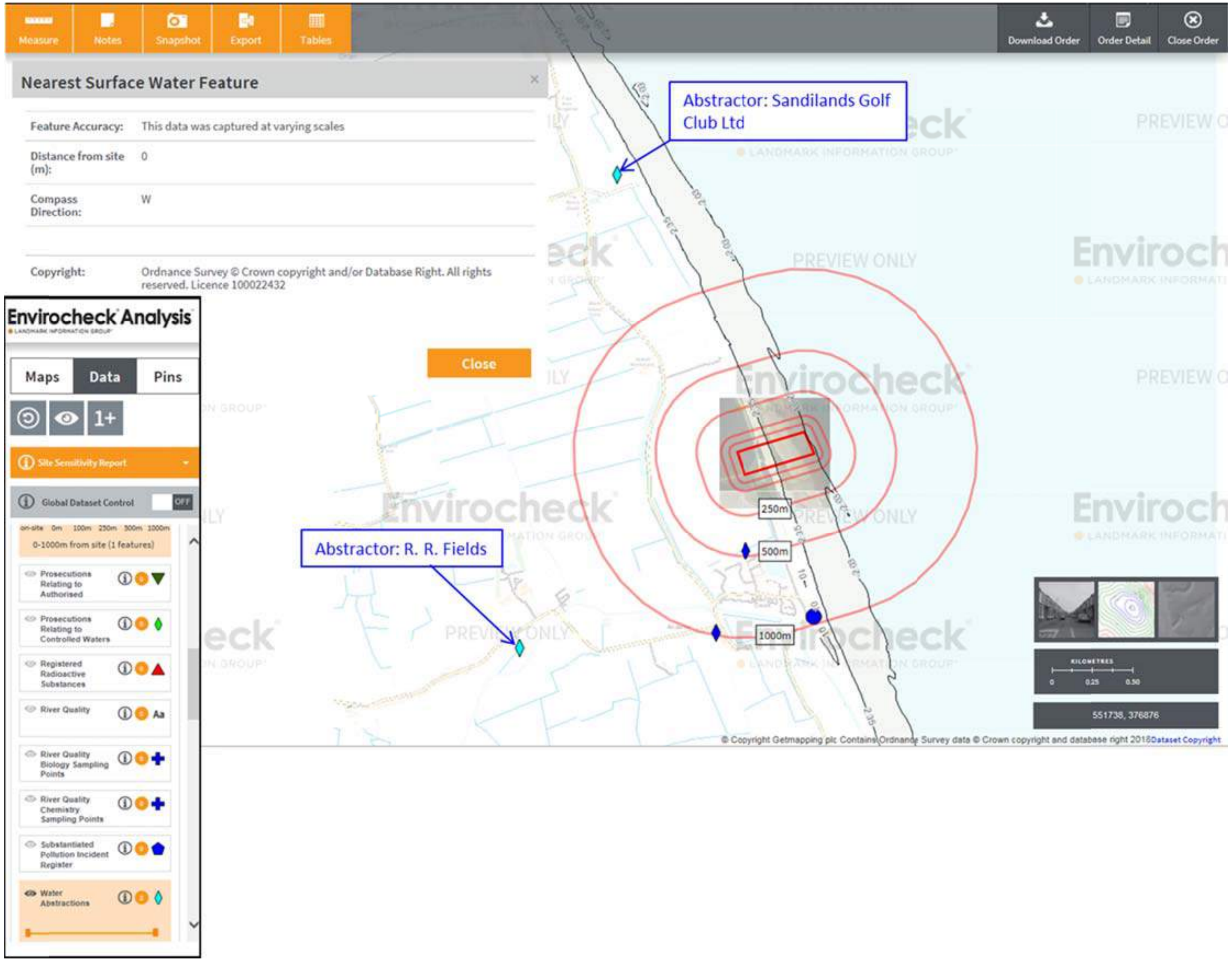


A2.2 DEFINITIONS

- Hazard is a condition that has the intrinsic potential to cause harm
- Likelihood is the chance or probability of something happening.
- Risk is the combination of a hazard and its likelihood of occurrence. It reflects the effects of uncertainty on the project objectives.
- Risk control – any measure of action that modifies risk.
- Risk treatment – a risk modification process that involves selecting and implementing one or more treatment options. Once a treatment has been implemented, it becomes a risk control measure.

Hazard Identification: a structured study has been undertaken to find, recognise, describe and evaluate sources of hazards and the consequential risks that can arise from them. Based on this risk treatment measures have been compiled that would reduce the risk by reducing the likelihood of occurrence and the consequences of the hazard.

A2.3 ABSTRACTORS FROM THE CHALK WITHIN 2KM OF THE SITE



Feature Accuracy:	This data was captured at varying scales
Distance from site(m):	1847
Compass Direction:	NW
Operator:	**Sandilands Golf Club Ltd**
Licence Number:	4/29/15/*G/0086
Permit Version:	100
Location:	Sandilands Golf Club Bore 6
Authority:	Environment Agency, Anglian Region
Abstraction:	Golf Courses: Spray Irrigation - Direct
Abstraction Type:	Water may be abstracted from a single point
Source:	Groundwater
Daily Rate (m3):	Not Supplied
Yearly Rate (m3):	Not Supplied
Details:	L Chalk 7; Status: Perpetuity
Authorised Start:	01 April
Authorised End:	30 September
Permit Start Date:	1st February 1966
Permit End Date:	Not Supplied
Positional Accuracy:	Located by supplier to within 10m

Sandilands Golf Club well (E553,996 N378,694)

Feature Accuracy:	This data was captured at varying scales
Distance from site(m):	1741
Compass Direction:	SW
Operator:	**R. R. Fields**
Licence Number:	4/29/16/*g/063
Permit Version:	Not Supplied
Location:	Borehole, ANDERBY
Authority:	Environment Agency, Anglian Region
Abstraction:	Agriculture (General)
Abstraction Type:	Not Supplied
Source:	Well And Borehole
Daily Rate (m3):	0
Yearly Rate (m3):	2270
Details:	L Chalk 7; Status: Revoked
Authorised Start:	Not Supplied
Authorised End:	Not Supplied
Permit Start Date:	Not Supplied
Permit End Date:	Not Supplied
Positional Accuracy:	Located by supplier to within 10m

R. R. Fields well (E553,406 N375,810)

APPENDIX 3 CASE HISTORIES OF LANDFALL HDD INSTALLATION BY THE CABLE CONTRACTOR (BOSKALIS/ VBMS)

Some examples of landfall HDD installations by Boskalis /VBMS

1. Dudgeon Offshore Wind Farm 2015 (HDD and marine assistance) – 2 x 1150m HDD / 450mm diameter pipe
2. Westermost Rough Offshore Wind Farm 2013 (HDD and marine assistance) – 1 x 1050m HDD / 710mm diameter pipe
3. IFA 2 2018 (Marine assistance) – 6 x 650m / 450mm diameter pipe
4. Rampion Offshore Wind Farm 2016 (Marine assistance) – 2 x 430m / 630mm diameter pipe

Photographs of example project

Rig set up and HDD site

Laid cable – surface

Landfall and HDD site