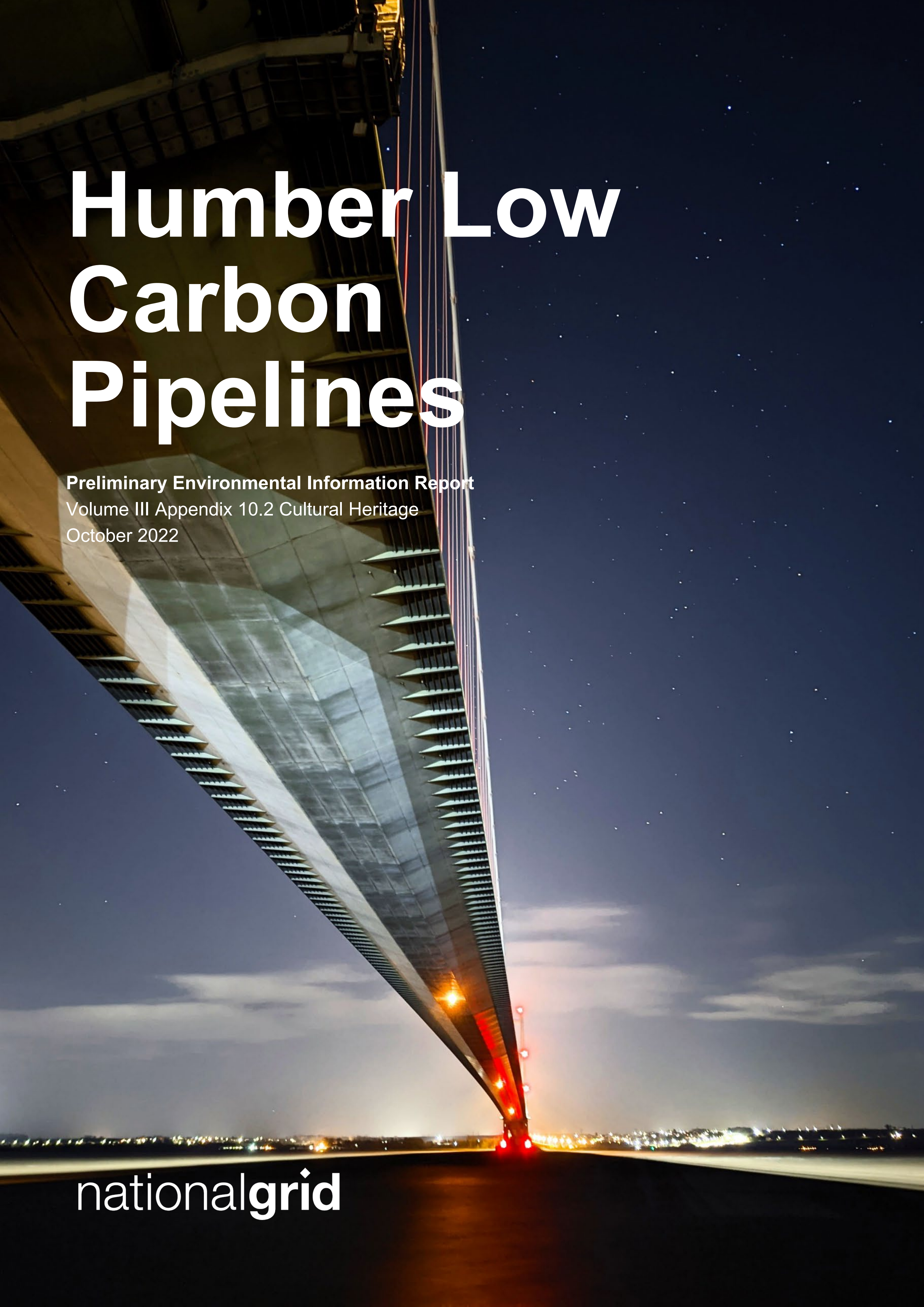
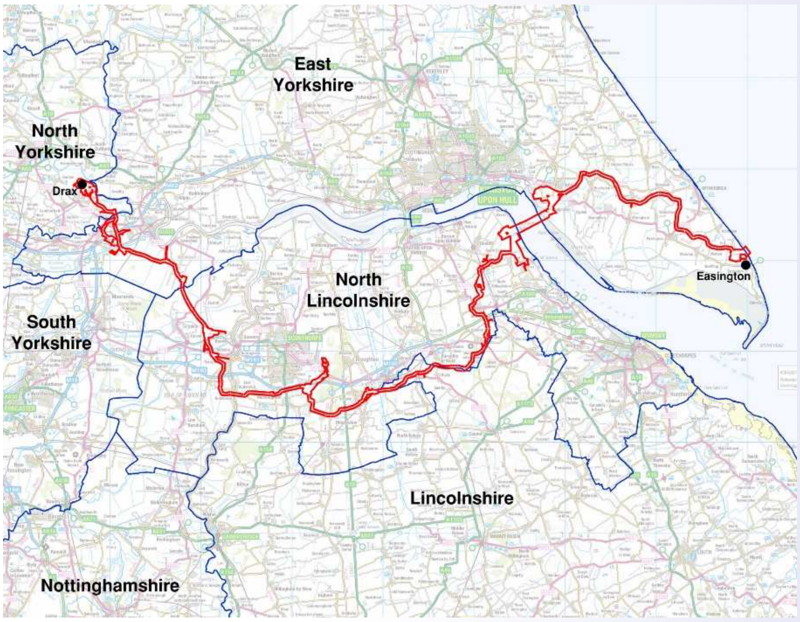


Humber Low Carbon Pipelines

Preliminary Environmental Information Report

Volume III Appendix 10.2 Cultural Heritage

October 2022



Humber Low Carbon Pipelines, North Yorkshire, East Riding of Yorkshire, Lincolnshire, and North Lincolnshire

Geoarchaeological Desk-based Assessment

September 2022

Client: Arcadis

Issue No: V1
Report Number: 2022-3/2215
OA Reference No: L11446
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Humber Low Carbon Pipelines, North Yorkshire, East Riding of Yorkshire, Lincolnshire, and North Lincolnshire

Geoarchaeological Desk-based Assessment

Written by Mairead Rutherford

With illustrations by Anne Stewardson

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Summary

Oxford Archaeology (OA) North was commissioned by Arcadis, to undertake a preliminary geoarchaeological desk-based assessment (GDBA) of the route of the Humber Low Carbon Pipelines (HLCP; henceforth, the Project), located across parts of Yorkshire and Lincolnshire. The working is being undertaken on behalf of National Grid Carbon Limited (NGCL) ('the Applicant') (NGCL is part of National Grid Ventures (NGV), the competitive division of National Grid plc, responsible for both developing and operating a portfolio of low-carbon renewable businesses in the United Kingdom (UK) and United States (US)). This assessment aims to provide a baseline high-level review, broadly characterising the topography, bedrock geology, and associated superficial sediment sequences likely to be encountered across the Project, through a review of regional models of landscape evolution, LiDAR data, geological mapping, and the distribution of historical borehole data. Overall, the assessment aims to provide an initial qualitative evaluation of geoarchaeological potential prior to more detailed deposit modelling, anticipated to be informed by a programme of project-specific geotechnical ground investigation, to inform further archaeological strategies. The information provided by this report should be considered in conjunction with a separate archaeological desk-based assessment currently being produced by Arcadis. The Project is a Nationally Significant Infrastructure Project (NSIP) as set out in the *Planning Act* 2008, comprising the construction of dual pipelines, to transport carbon dioxide (to facilitate carbon capture, usage and storage (CCUS)) and hydrogen, together with associated above ground installations (AGIs).

The Project stretches for *c* 120km from Easington in eastern Holderness, across the Humber Estuary, parts of the Lincolnshire Wolds, the Ancholme valley, Lincoln Edge, the lower Trent Valley, the Humberhead Levels and the lower Vale of York (Drax, North Yorkshire). The Humber area was once part of the continental landmass of Doggerland and became separated following the Post-Glacial inundation of the North Sea. Sea-level rise and fall has impacted the sediment packages all along the coastline and up the estuary, therefore it is more logical in terms of landscape evolution, to discuss the Project from the coast landwards, i.e. from east to west.

The broader area, within which several river valleys are located, is known for its rich floodplain archaeology, with evidence of fish traps, log boats, rafts, historical mills and bridges, all recovered from post-glacial sand and gravel deposits, sealed beneath thick fine-grained alluvium. Low-lying broad river valleys, which provide access to riverine resources, have previously produced evidence of both ritual and settlement activity.

The geoarchaeological assessment has shown that there is scope across the area for potential preservation of pre-Devensian and Devensian (Palaeolithic)

deposits, as well as post-glacial and Holocene (Mesolithic to Post-Medieval) deposits. Previous historical borehole data are available, but sparse, across the site, and are of some value, for example, in the lower Trent area. Other borehole data are of little value, as they lack specific criteria such as altitude records and do not differentiate superficial deposits where identified. The better-quality data could contribute to the development of a deposit model for the area; however, further data should be obtained from project-specific ground interventions, and consideration given to positioning interventions in areas likely to yield geoarchaeological information.

Acknowledgements

OA North is grateful to Daniel Evans of Arcadis for commissioning this piece of work. The report was written by Mairead Rutherford and edited by Liz Stafford. GIS support was provided by Hannah Leighton and the illustrations were completed by Anne Stewardson. The project was managed for Oxford Archaeology by Stephen Rowland.

1 INTRODUCTION

1.1 Scope of work

1.1.1 Oxford Archaeology (OA) North was commissioned by Arcadis to undertake a geoarchaeological desk-based assessment (GDBA) of the route of the Humber Low Carbon Pipelines (HLCP; henceforth, the Project), located across parts of North Yorkshire, East Riding of Yorkshire, North Lincolnshire, and Lincolnshire. The working is being undertaken on behalf of National Grid Carbon Limited (NGCL) ('the Applicant') (NGCL is part of National Grid Ventures (NGV), the competitive division of National Grid plc, responsible for both developing and operating a portfolio of low-carbon renewable businesses in the United Kingdom (UK) and United States (US)). The Project crosses a landscape that is both archaeologically rich, topographically diverse, and also dynamic, as it straddles several river valleys, their confluences, and the geologically and historically significant Humber Estuary. The GDBA is the first element of a multi-stage approach to characterise the deposits traversed by the Project, especially those that might seal previously unidentified archaeological remains. As such, the GDBA presents an initial qualitative review of the available data and provides a preliminary framework for understanding the burial environments that have the potential to preserve archaeological and palaeoenvironmental remains at multiple spatial and chronological scales. Accordingly, the work will follow previous geoarchaeological and palaeoenvironmental work for Holderness and the Humber Wetlands, and divides the Project footprint into five main physiographic regions, from east to west.

1.1.2 A particular focus of the work will be on deposits associated with existing and former river courses, floodplain valleys, lakes, and meres, where Pleistocene and Holocene deposits may be well preserved. These initial lithostratigraphic data will be based largely on published data for the Humber Estuary, existing BGS (British Geological Survey) borehole records and an assessment of superficial deposits mapped by the BGS across the Project.

1.1.3 The archaeological potential, based on the sediment profiles present within each region, will be assessed, and zones of poorer coverage highlighted. Following completion of the geoarchaeological assessment, a phase of proportionate and targeted fieldwork may be appropriate, potentially combined with geotechnical ground investigations. Data resulting from interventions during this phase would be used to build a project specific deposit model, to investigate deposit sequences across the landscape of the Project in more detail.

1.2 Location

1.2.1 The Project is a c. 120km twin pipeline positioned between a landfall location at Easington on the Holderness coast of the East Riding of Yorkshire, extending to Drax Power Station, Selby, North Yorkshire, in the west (Fig 1). The pipelines cross the tidal River Trent and the Humber Estuary. Other major rivers crossed by the Project include the River Ancholme and the River Aire. Several becks including East Halton Beck, Kettleby Beck and tributaries of Bottesford Beck, as well as numerous drainage channels crisscross the Project area. To facilitate presentation of the Project geographically, location maps have been produced from Holderness to Drax and are labelled throughout the text, following Fig 2 (inset maps a-h). The Humber area was once part of the continental landmass of Doggerland and became separated following the post-glacial inundation of the North Sea. Sea-level rise and fall has impacted the sediment packages all along the coastline and up the estuary, therefore it is more logical in terms of landscape evolution, to discuss the Project from the coast landwards, i.e. from east to west.

1.2.2 The GDBA is primarily concerned with deposits contained directly within the HLCP Proposed Order Limits surrounded by a 500m-wide buffer zone. Reference will also be made, however, to relevant deposits as well as previous geoarchaeological and palaeoenvironmental studies occurring adjacent to, but outside, this boundary.

1.3 Topography

1.3.1 The 120km-long pipeline is divided into five geographical/physiographic sections, from east to west (Fig 3):

- Holderness;
- Humber Estuary;
- Lincolnshire Wolds;
- Lower River Trent Valley and Ancholme Valley;
- Humberhead Levels and the Vale of York.

1.3.2 ***Holderness***: Holderness is a coastal lowland of the East Riding of Yorkshire. To the north and west lie the Yorkshire Wolds and Hull Valley, to the south is the Humber Estuary, and to the east is the North Sea (Figs 2-3). The Project passes westwards from Easington on the coast, running north of Patrington, south of Halsham, north of Burstwick and south of Hedon, to Paull on the Humber Estuary. The topography of the central and eastern part of Holderness is generally low, and gently undulating (c. 10-20m OD), whereas in southern Holderness the landscape is generally below c. 10m OD (Tweddle 2000). Localised wetland areas have formed around small meres in the east. The relatively higher ground in the east forms the main watershed which drains inland via a network of natural streams modified as artificial channels (Van de Noort and Ellis 1995).

1.3.3 ***Humber Estuary***: the Project crosses the Humber Estuary to the east and south of Kingston-upon-Hull and north of Immingham (North Lincs). The estuary essentially separates the Yorkshire Wolds to the north from the Lincolnshire Wolds to the south (Figs 2-3). The Humber Gap formed as a result of geological faulting (Gaunt *et al.* 1992), creating an area of weakness that has been exploited and enlarged by the Rivers Ouse and Trent and their tributaries to form the Humber Estuary (Frederick *et al.* 2001; Figs 4-6). The area is a flat, low-lying, estuarine environment.

1.3.4 ***Lincolnshire Wolds***: the Lincolnshire Wolds are of Cretaceous Chalk bedrock and form a distinctive area of rising ground to the west of East Halton Beck, southwards to Kirmington and over the Wolds across Bigby Top (the highest point within the Project, at 97m OD; Figs 2-3).

1.3.5 ***Lower River Trent Valley/River Ancholme Valley***: the Lincoln Edge (an upstanding ridge of Jurassic rock rising to c. 80m OD) separates the lower Trent Valley to the west from the Ancholme Valley to the east (Figs 2-3). The eastern boundary of the Ancholme Valley is defined by the scarp slope of the higher ground of the Lincolnshire Wolds. The town of Brigg (North Lincs) sits on a gravel spur of the Wolds that juts out into the Ancholme Valley. The River Ancholme was artificially diverted and straightened in the seventeenth century, so that it joins the Humber in a straight line, resulting in an Old River Ancholme and a New River Ancholme (Van de Noort and Ellis 1998).

1.3.6 To the west, the lower Trent Valley is bounded by the higher ground (c. 30m OD) of the Isle of Axholme (Figs 2 and 7). The River Torne crosses the Project to join the Trent via engineered channels, the Three Rivers, at Keadby. The floodplain of the lower reaches of the Trent, downstream from Gainsborough, is broad and dominated by fine-grained sedimentation, with the river channel showing lateral stability (Baker 2007). In order to reduce the risk of flooding and to improve agricultural productivity, the height of the ground has been raised through a process known as warping. At high tide sediment-laden estuarine waters would be directed onto embanked areas close to the estuary via a system of sluices and channels, permitting warp deposits to settle out of the pooled water prior to its release (Ellis 1990).

1.3.7 ***Humberhead Levels/Vale of York***: the Humberhead Levels describe an area of low ground around and west of the head of the Humber Estuary (Figs 2-3). Rising ground formed by ridges of Permian rocks (the eastern Pennines foothills) lie to the west with the southern extent of the Levels coinciding with a low ridge of Triassic rocks, including resistant rocks of the Isle of Axholme, beyond which lies the Trent Valley. To the north, the low gradient merges with the Vale of York (Gaunt, 1994; Van de Noort and Ellis, 1999, Gaunt *et al.* 2004).

1.3.8 The Vale of York is a large area of lowland situated between the Yorkshire Wolds to the east and the Pennines to the west (Figs 2, 3, and 8). The southern boundary is marked by the rivers Humber, Ouse, and Aire. There has been extensive artificial embankment of these major rivers and application of warping in order to reduce flooding.

1.4 Geology – a broad overview

1.4.1 The bedrock strata dip eastwards such that progressively younger strata are present further east and rocks of an older age are present towards the west (BGS 2022). The bedrock at Holderness and across the Lincolnshire Wolds, comprises Chalk of various formations (of progressively older age westwards, including the Flamborough Chalk Formation (Fm), Burnham Chalk Fm and Ferriby Fm. Further west, from the Ancholme Valley across the Lincolnshire Edge, bedrock comprises rocks of younger to older Jurassic age (including the Kimmeridge Clay Fm, the Oxford Clay Fm, and the Whitby Mudstone Fm). Rocks of Early Jurassic and Triassic age, comprising largely mudstones of the Scunthorpe Mudstone Fm, Penarth Group, Charmouth Mudstone Fm, and Mercia Mudstone Group, are recorded west of Scunthorpe, across the Trent Valley and the Isle of Axholme. The Humberhead Levels and Vale of York south of Goole, are underlain by older rocks of the Sherwood Sandstone Group, of Triassic to Late Permian age. Superficial deposits, mapped by the BGS across the Project, show thick deposits of alluvium associated with major river valleys. These data are presented in detail in *Section 3.5*.

1.5 LiDAR analysis

1.5.1 Environment Agency LiDAR data illustrating topography (hillshade) have been compiled across the Project. There is patchy LiDAR coverage over parts of the Project, for example, areas of Holderness, and where the Project crosses the area of the Lincolnshire Wolds, south and south-west of East Halton Beck. The LiDAR data are presented in detail in *Section 3.3*.

1.6 Archaeology

1.6.1 The detailed archaeological baseline across the Project is presented in the *Archaeological Desk-based Assessment* (Arcadis forthcoming), so the following sections present only the briefest of synopses to contextualise the geoarchaeological work. Following deglaciation after the Late Glacial Maximum (LGM; c. 15-26 cal BP), humans dispersed into Britain during the Windermere interstadial (Upper Palaeolithic), albeit that there is occasional evidence for earlier activity. The nearest finds are from outside the Project area, but include two hand-axes, of Lower or Middle Palaeolithic age, from Lee Moor, Stanley (West Yorks; PRN3813; WYAAS 2016), whilst the limestone caves of Creswell Crags (north Nottinghamshire) contain Britain's only known Upper Palaeolithic cave art. Kirmington (North Lincolnshire) adjacent to the Proposed Order Limits, is one of the few sites in Britain where Palaeolithic remains are believed to have been found beneath glacial deposits and were determined to represent elements of a Clactonian assemblage (Lower Palaeolithic, early part of the Hoxnian Interglacial; *c* 424-374k years cal BP; Burchell 1931; 1935; Bridgland and Thomas 1999). However, White (1999) has argued that it is plausible that some (if not most) of these finds are not really artefacts, but the products of abrasion/collision in a high-energy environment.

1.6.2 Lake edges would have been attractive site for occupation, so there is potential for littoral deposits of proglacial Lake Humber (which occupied the western half of the Project; Fig 4), to contain Late Upper Palaeolithic archaeological material. Indeed, Palaeolithic remains, including a flint artefact, were found on Lindholme Island, a morainic ridge of sands and gravels formed by the terminal Late Devensian moraine within Lake Humber, and just beyond the western end of the Project (Bateman *et al.* 2001; Pettitt 2018).

1.6.3 The current, or Holocene Interglacial Period (11,700 cal BP), records camps and settlement sites from the Early Mesolithic onwards, the site at Star Carr on the shores of glacial Lake Flixton being a hugely significant Early Mesolithic archaeological site, located in the Vale of Pickering, to the north of the Humber (outside the Project). In Holderness, to the north of the Project, evidence of occupation is derived from the Mesolithic lakeside platform of Round Hill and the Bronze Age settlement at Barmston Drain, which was located on the sediments of a Late Glacial mere (Fletcher and Van de Noort 2007). From the Humberhead Levels, a Bronze Age trackway has been reported from Thorne Moors and a Neolithic trackway at Lindholme (on Hatfield Moors; Chapman and Gearey 2013).

1.6.4 Many important finds have been reported from the Humber basin, in particular, the discovery of Prehistoric boats at North Ferriby (Van de Noort and Ellis 1998) and the Brigg raft from the Ancholme Valley, dating to the Bronze Age/Iron Age transition

(McGrail 1990). The past two decades or so have seen a considerable amount of archaeological work associated with Infrastructure projects through Holderness and North Lincolnshire (for example Abramson 1996; Burgess and Daniel 2018; Evans 2016; Glover *et al* 2016; Humber Field Archaeology 2006; Malone and Williams 2010; NAA 2000; OA North 2012; 2022; Savage 2013; Zant and Gregory forthcoming; Zant and Howard Davis in prep).

1.6.5 These have revealed a wealth of sites with activity from the Mesolithic Period to the Post-Medieval Period, with sites of Iron Age and Roman date being particularly well represented, including evidence for agriculture and salt making. An Iron Age settlement at Ulceby, adjacent to the Project corridor is particularly noteworthy, as the artefacts include an Iron Age metalwork hoard, containing horse bridal fittings, gold torcs, and a bracelet, as well as large numbers of Iron Age coins dating to the first century BC (Farley 2012).

1.6.6 Within the peatlands, to the west and south of the Project, at Lindholme (Hatfield Moors), a wooden 'corduroy' trackway and platform, were built in a single phase towards the end of the Neolithic Period, around 2730-2450 cal. BC (Chapman and Gearey 2013). The trackway and platform were constructed from pine and birch, probably sourced from locally growing woodland and are associated with a lithics assemblage (*ibid*). Three bog bodies have been recovered from Hatfield Moors, from the vicinity of Hatfield Chase. A date in the late third or fourth century AD has been suggested for one, whilst another was described as a male dressed in 'Saxon' clothes (*ibid*; Turner and Scaife 1995). A detailed account of the palaeoenvironmental history of the site and these peatlands is presented in Chapman and Gearey (2013).

2 AIMS AND METHODOLOGY

2.1 Research Context

2.1.1 A firm basis for research on many archaeological projects is provided by the Regional Research Frameworks initiative devised by Historic England and the Association of Local Government Officers. The Project traverses two regions and, whilst the framework for Yorkshire is currently being compiled, the *East Midlands Historic Environment Research Framework* (EMHERF; Research Frameworks 2022) is available online. It contains themes that have relevance to this geoarchaeological project, both within and beyond the immediate bounds of the East Midlands. Given the breadth of the present piece of work, the following have been selected from Cooper's overarching research themes (2006, reproduced in the current EMHERF; Research Frameworks 2022):

- *Pleistocene and Holocene climatic change (as evidenced, for example, by palaeochannel deposits);*
- *changes in sea level, the configuration of sea and land, the drainage network and the spatial extent of wetlands;*
- *the impact of [and relationship with] human activity upon soil development and geomorphic processes (notably alluviation, colluviation and aeolian deposition);*
- *exploitation and settlement of diverse ecological zones (including study of the pivotal highland-lowland contrast);*
- *the role of rivers as movement corridors*.

2.1.2 In addition, and particularly pertinent, is Howard's assertion that understanding the long-term landscape evolution and the development of models that place the sedimentary deposits within a securely dated chronostratigraphic framework is a prerequisite for any archaeological project (Howard 2020, in Research Frameworks 2022). Other, more specific initiatives for the Prehistoric Period include:

- *How can we enhance the Historic Environment record dataset for study of the Palaeolithic Period?*
- *Enhance understanding of the environmental background to Mesolithic activity;*
- *Characterise the regional and local evidence for Mesolithic activity*;
- *Investigate the topographic locations of Mesolithic activity foci;*
- *Investigate the transition from the Mesolithic to Neolithic;*
- *Target sites with Late Mesolithic and Early Neolithic stratigraphy and well-preserved organic remains to provide a chronological framework and understand exploitation of different landscape zones;*
- *Investigate landscape contexts of rural settlements* (Research Frameworks 2022).

2.1.3 Further research themes and priorities can be discussed with the curatorial bodies responsible for the areas traversed by the Project.

2.2 Aims

2.2.1 The GDBA is one of the first elements of an iterative, multi-stage process and, as such, has four very basic aims:

i. to identify areas (e.g. wetland ecotonal zones) considered to have high potential to preserve archaeological remains stratified within sediment sequences based on palaeotopography and to consider associated environments of deposition and taphonomy;

ii. to provide baseline data which may contextualise a future first-stage deposit model. This will be based on Ground Investigation (GI) data and will contribute to a more detailed understanding, both locally and more regionally, of sediment sequences and geomorphological features and their archaeological potential;

iii. beyond predicting the potential location of buried archaeological remains during evaluation, this GDBA is intended to provide the baseline data that will be used to develop an integrated archaeological and palaeoenvironmental landscape model for the duration of the project. This model will be subsequently enhanced throughout a staged programme of archaeological works, culminating in a detailed understanding of cultural and natural landscape relationships;

iv. in the longer term, to contribute to a better understanding of the value of geoarchaeological work in the regional planning process.

2.2.2 Within the parameters of the GDBA, those aims are addressed through the following tasks:

a) review published geoarchaeological and significant palaeoenvironmental data relevant to the Project;
b) provide mapped geological and superficial data relevant to the Project, to characterise the sediments;
c) examine topographical and LiDAR data to identify features such as palaeochannels and gravel islands;
d) assess availability of British Geological Survey (BGS) borehole/trial pit interventions that could be used to construct a geoarchaeological model. This initial desk-based visual assessment will be able to identify whether there are any high- to medium-priority zones where the data are of sufficient quality and density to be incorporated into a more detailed sub-surface deposit model alongside borehole data from previous infrastructure projects as well as Project related GI data when they become available;
e) highlight any geoarchaeologically significant zones or deposits, in order to target superficial deposits in areas that may hold potential for recovery of archaeological remains and could be prioritised during a future watching brief on GI works;
f) highlight areas of uncertainty that lack lithostratigraphic data (either superficial mapping and/or BGS GI data) and LiDAR data, and to make recommendations

that would result in greater data coverage, in order to develop a more comprehensive deposit model.

2.3 Methodology

2.3.1 A review of geoarchaeological and palaeoenvironmental studies relevant to the Project includes reference to published data and information sourced from academic studies (theses) and grey literature. The main database for survey of the superficial and bedrock geology is largely based on BGS (2022) mapping, with greater but localised detail available from the Humber Wetlands volumes. Indeed, the work of the Humber Wetlands Group throughout the 1990s and, in particular, the volumes on Holderness, the Humberhead Levels, the Ancholme and Trent Valleys and the Vale of York (Van d Noort and Ellis 1995; 1997; 1998; 1999), has provided substantial geoarchaeological and palaeoenvironmental data for reference in the current study. The Holocene evolution of the Humber Estuary has been the subject of both the NERC (Natural Environmental Research Council) funded LOEPS (Land-Ocean Evolution Perspective Study) and LOIS (Land-Ocean Interaction Study) projects (Shennan *et al.* 2000a, b and Metcalfe *et al.* 2000), that interpreted geoarchaeological and palaeoenvironmental data from a series of boreholes as well as from additional cores taken by the Universities of Durham and Hull, from both the inner and outer estuary. Lithological data, interpreted from BGS borehole interventions along the lower Trent Valley, are available from publications of the Trent GeoArchaeology Group (Challis 2000). In the lower Vale of York, Kirby (1999) used a database of over 100 borehole records to reconstruct the floodplain depositional environments in the lower Aire valley.

2.3.2 Historic BGS borehole data occur across the Project; however, the distribution is generally sparse and much of the data are denoted as confidential. All of the boreholes within or adjacent to the Proposed Order Limits have been assessed, and those of stratigraphic value for production of a future deposit model are listed in *Appendix A*. Limited and localised geoarchaeological data are also available from some previous developer-led infrastructure investigations that have been undertaken within the vicinity of the Project, especially its eastern end. Examples in Holderness include the Easington to Paull Pipeline (OA North 2012; Zant and Howard Davis in prep), Easington to Salt End (Burgess and Daniel 2018), the Tunstall to Salt End Scheme (Evans 2016) and AOC's Dogger Bank Offshore Windfarm (R Newman *pers comm*). Of those, only the latter, well to the north of the HLCP, included a specific GDBA and deposit model comparable to the Project. Borehole samples were taken as part of the mitigation programme for the Feeder 9 Replacement Pipeline Tunnel at both Paull (OA North 2021; Zant and Gregory forthcoming) and Goxhill (North Lincs; OA North 2016; 2022; Zant and Gregory forthcoming). In North Lincolnshire, data are also available for borehole transects that cross the Project south of Goxhill, at East Halton Skitter (NAA 2000) and outside the Project, to the west of Scunthorpe, at both Keadby (Timpany 2012; Headland Archaeology 2013; 2018; SSE Thermal 2021; Trent and Peak Archaeology 2021; York Archaeological Trust 2022) and the proposed North Lincolnshire Green Energy Park (AOC 2021). New data including borehole data may also be available for the lower Trent valley and for Kettleby Beck (A Williams *pers comm*).

2.3.3 Detailed 3D modelling of geological and superficial deposits is available for the Holderness area but limited in extent, as it stops south of Hornsea (Burke *et al.* 2015). Limited data are available from the BGS Selby 3D superficial deposits modelling (Burke *et al.* 2017), the south-eastern part of which is adjacent to the western extremity of the Project. The glacial evolution of the Vale of York is mapped by Ford *et al.* (2004).

2.3.4 Topographical maps and LiDAR images have been scrutinised, where available, to identify features that could mask or seal potentially important archaeological remains, including preliminary identification of possible topographic highs as well as palaeochannels.

3 Results

3.1 Introduction

3.1.1 An understanding of the impact of the cyclical glacial chronostratigraphy through the Pleistocene and into the Early Holocene is important, for these processes have shaped the landscape traversed by the Project and, consequently, the setting for past human activity. The first section outlined below is, therefore, a quick review of the chronostratigraphy relevant to the Project. The origins and demise of proglacial Lake Humber are also briefly reviewed, as sediments relevant to wetland edge environments, e.g. lake margins, are known to have played a significant role in Early Prehistory. The Humber Estuary and associated wetlands have been subject to fluctuations in sea level since the end of the last ice age, impacting the sedimentary history of the region; therefore, a brief review of the sea-level history is also outlined.

3.1.2 A series of maps for the study area accompany the text showing geological data (Figs 9a-h), superficial (Drift) deposits (Figs 10a-h) and topographical (LiDAR-hillshade) data (Figs 11a-h), and are presented for each of the four geographical areas. This is followed by a comprehensive review of significant geoarchaeological data and background palaeoenvironmental data. These data, together with geoarchaeological evidence from previous studies, in addition to relevant BGS borehole data, are then used to infer the likely geoarchaeological potential for each of the areas (*Section 4*).

3.2 Chronostratigraphy, glaciations, and sea-level change

3.2.1 The generalised chronostratigraphic context of the region's principal archaeological periods is outlined (Table 1). The base of the Holocene is placed at 11.7 cal. BP, following Gibbard and Hughes (2021), with the archaeological designations for the Pleistocene following Hosfield *et al.* (2017).

<table>
<tr><th>EPOCH</th><th>ARCHAEOLOGY</th><th colspan="4">CHRONOSTRATIGRAPHY</th></tr>
<tr><th></th><th></th><th colspan="2">STAGE</th><th>AGE in years cal BP</th><th>MARINE ISOTOPE STAGE (MIS)</th></tr>
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<tr><td>Dimlington Stadial (LGM)</td><td>26-15k</td></tr>
<tr><td rowspan="3">Later Middle Palaeolithic</td><td>Upton Warren Interstadial</td><td>c 43 – 40k</td></tr>
<tr><td>Early Devensian</td><td>c 110 -60k</td></tr>
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<tr><td colspan="2">Hoxnian Interglacial</td><td>424-374k</td><td>11</td></tr>
<tr><td colspan="2">Anglian Glaciation</td><td>478-424k</td><td>12</td></tr>
<tr><td>Lower Palaeolithic</td><td colspan="2">Cromerian 'complex'</td><td>750-478k</td><td>13-19</td></tr>
</table>

Table 1: Generalised correlation of British Pleistocene and Holocene stratigraphy

3.2.2 The following definitions explain terms used in the text:

- Glacial Stage – a cold phase during which major expansion of ice sheets and glaciers occurred;
- Interglacial – a temperate interval during which temperatures were as high or higher than at the present day;
- Stadial – a short cold sub-stage, following an interstadial, when local ice advance occurred;
- Interstadial – a relatively short period of climatic improvement during a cold stage, when temperatures may not have reached those of the present day;
- 'Complex' – stratigraphically complex periods during which colder (glacial) and warmer (interglacial) intervals have been reported;
- LGM – Last Glacial Maximum – the maximum extent of the last glaciation in Britain (Dimlington Stadial; Evans *et al.* 2001);
- Lateglacial (including the Windermere Interstadial and Loch Lomond Stadial).

3.2.3 ***Glacial stratigraphy and proglacial Lake Humber (Fig 4)***: the Pleistocene glacial history of the UK is complex, with advance and retreat of several ice sheets (Table 1). The climate oscillated between colder (glacial) and warmer (interglacial) stages. The ice action resulted in erosion and modification of the existing landscape. The effects of persistent freeze-thaw action in ground not covered by ice but in areas adjacent to the ice sheets (periglacial) also resulted in deposition of a variety of glacial sediments, further modifying the pre-existing landscape.

3.2.4 During the colder Pleistocene periods, sea levels were lower than today, and the Humber area was located on the western margins of 'Doggerland,' an area of dry land linking eastern England to the continent (Fig 5; Bicket and Tizzard 2015). For the greater Humber region, the most significant ice advance was that of the Late Devensian and during that last ice age, the Humber wetlands were covered by the North Sea ice lobe, that extended down the North Sea Basin as far as North Norfolk, depositing Till and glaciofluvial sands and gravels across the region (Fig 4). Following the final retreat of ice, there was rapid incision of the river valleys down to contemporary sea-level, creating steep-sided valleys up to 9m wide, now infilled with Holocene sediments (Van de Noort 2004).

3.2.5 Glacial deposits associated with the Dimlington Stadial icesheet (MIS 2) remained east of the Lincolnshire Wolds (Fig 4); however, the possibility of earlier Devensian ice (MIS 4) in this part of the Lincolnshire Wolds contributes to the complex and less well understood glacial stratigraphy of this area (Straw 2019; Howard 2022). The Devensian ended about 11,700 cal. BP, marking the beginning of the Holocene, or recent period. Sedimentary deposits reflect erosion and deposition in a varied succession of environments during much milder climatic conditions within the Holocene. Fluvial deposits occur in almost all valleys or river courses and are still forming. These include a wide range of deposits, including clays, silts, sands, and gravels. Peat deposits also accumulated during the Holocene after the glaciers retreated and may occur both in local topographic lows in floodplain and estuarine environments, and as broader expanses of blanket bog over areas of high ground.

3.2.6 Mapping the advances and retreats of the British and Irish ice sheets has revealed that, during the Last Glacial Maximum (LGM, or Dimlington Stadial), North Sea ice lobes and the Vale of York ice lobe formed ice dams. These resulted in a series of proglacial lakes in the lowlands of eastern England; the damming of the Humber Gap by the North Sea ice lobe resulting in the creation of Lake Humber (Fig 4; Bateman *et al.* 2015; 2018; Buckland *et al.* 2019). The Vale of York Ice expanded briefly (*c* 18.7 +/- 0.63k years ago), across Lake Humber into South Yorkshire and North Lincolnshire, prior to retreating and leaving the Escrick and York moraines (Fig 8; Bateman 2015).

3.2.7 Excavations at Finningley, near Ferrybridge (West Yorkshire), revealed lacustrine sediments of former Lake Humber which were dated by OSL (optically stimulated luminescence) to *c.* 14,650 BC, with evidence that the lake was silted up by *c.* 9150 BC (Late Devensian to Early Holocene; Buckland *et al.* 2019). The pattern of drainage of the lake is complex and is thought to have persisted at least until *c.* 14,500 BP at its maximum extent (Fairburn and Bateman 2016). Proglacial Lake Humber would have been a significant feature in the Late Devensian landscape and, after drainage, would have remained as an extensive regional wetland area, providing a wide range of resources.

3.2.8 Following ice sheet retreat and the infilling of Lake Humber, braided drainage channels initially formed across the floor of the former lake, with levées of sand and silt along the margins. Wind erosion resulted in the deposition of aeolian sands (coversands), with development of extensive dune systems particularly in the south and east of the Vale of York, with much of this activity dated to the period of climatic deterioration during the Loch Lomond Stadial (van de Noort and Ellis 1999; Table 1). At this time, sea level was lower than at present, and rivers incised rapidly, cutting deep channels.

3.2.9 Alluvium was deposited along the length of the channels as sea level began to rise. The alluvial deposits contained material deposited from tidal estuarine environments by tidal action, as well as alluvium transported downstream by rivers and tributaries (van de Noort and Ellis 1999). River locations represent prime areas chosen as key locations by Prehistoric people and organic alluvial sequences have the potential to yield high-resolution palaeoenvironmental data suitable for landscape reconstruction as well as radiocarbon dating, or inorganic sediments suitable for OSL dating.

3.2.10 ***Sea-level changes***: the LOIS project, which followed the LOEPS project (*Section 2.3.1*), produced palaeogeographical reconstruction maps of the Humber Estuary through the Holocene, for the Early Mesolithic Period to the Bronze Age (Shennan *et al.* 2000a; Metcalfe *et al.* 2000). Shennan *et al.* (2000a) utilised sea-level index points, based on lithological and palaeoenvironmental data, to reconstruct the evolution of the North Sea coastline and the data suggested that, during the Early Mesolithic Period, the coastline of north-east England was only a little to the east of its present position.

3.2.11 Around 10,000 cal. BP, the North Sea coastline comprised a western embayment extending south to the latitude of Flamborough Head, so the Humber coastline at this point was modelled at 10m+ above mean sea level (Shennan *et al.* 2000a, Metcalfe *et al*. 2000). By 9000 cal. BP, the western embayment had extended further south to a position just off that now occupied by Spurn Point. Its eastern extent produced a shallow estuary to the south of the Dogger Bank, with the area around the Humber Estuary modelled to be around 10m above mean sea level.

3.2.12 By 8000 cal. BP, the North Sea connected to the English Channel via a narrow strait and, by 7500 cal. BP, the model suggests all the estuaries of the east coast were subject to tidal influence. By 6000 cal. BP, the Dogger Bank was totally submerged (Shennan *et al.* 2000a; Metcalfe *et al.* 2000).

3.2.13 More detailed palaeo-reconstruction data specifically for the Humber Estuary (Metcalfe *et al.* 2000, 112; figs 5 and 6), show that, by *c* 8000 cal. BP, estuarine conditions existed in a relatively narrow channel within the outer estuary, with sea level about 17m below present. The reconstructions, based on pollen, diatom, and radiocarbon data from freshwater peats, provide evidence for extensive eutrophic wetland palaeoenvironments within the estuary, with a mosaic of hazel-oak fen wood, sedge fens, open standing water, and some evidence for possible, short-lived marine incursions. From about *c* 7000 cal. BP, deposit sequences in the outer estuary record the transgression of intertidal environments across previously eutrophic wetlands, with the limit of intertidal sediments roughly at the Ancholme's confluence with the main Humber channel (Metcalfe *et al.* 2000). After *c* 6000 cal. BP, the transgression continued up to the inner Humber Estuary. These changes had an impact on the hydrology within the inner estuary, with impeded freshwater drainage causing ponding, waterlogging, and paludification (the conversion of forest to peatland). Reconstructed palaeogeographic maps show the general areas influenced by the main tidal incursion but do not, however, show the narrow tidal reaches of individual rivers (Metcalfe *et al.* 2000).

3.2.14 Sea level continued to rise until the Early to Middle Iron Age, followed by a phase of marine regression during the Late Iron Age and Roman Period, allowing settlement to expand into areas previously too wet (Long *et al.* 1998). Many sites were abandoned as a result of renewed sea-level rise during the early fourth century AD but, on higher ground, there remained some settlement into the Early Medieval Period (Fleming and Royall 2019). Low-lying areas adjacent to the Humber and the lower reaches of its tributaries remained as wetlands until the Medieval Period (due to susceptibility to inundation caused by estuarine and/or riverine flooding, and a water table that was close to the surface). From then on, widespread changes occurred due to artificial drainage, land reclamation, and land-use changes (Metcalfe *et al.* 2000).

3.2.15 The relative sea-level curve for the Humber Estuary (Metcalfe *et al.* 2000; Shennan *et al.* 2000) shows sea levels beginning to rise from *c.* 8000 cal. ka BP (Fig 5). Post-Glacial sea-level rise in the Early and Mid-Holocene would have caused the movement of people from the low-lying areas of continental shelves; the consequences of the post-glacial inundation of the North Sea, including the loss of 'Doggerland' (Coles 1998) is directly relevant to the early prehistory of the East Riding of Yorkshire and North Lincolnshire.

3.3 HLCP route-wide mapping

3.3.1 ***Holderness (Figs 9a-b; 10a-b; 11a-b)***: the bedrock geology underlying the Project across Holderness is Chalk of the Flamborough Fm (Late Cretaceous; Figs 9a-b). It is covered by superficial deposits of Pleistocene and Holocene age, which comprise largely Glacial Till with alluvial sediments occurring along present and former river courses (Figs 10a- b). The Kelsey Hill Gravel Beds, of Pleistocene age, occur along the

Project route. Lacustrine sediments, indicative of meres that may have developed in former kettle holes in the Till, and which may contain deposits suitable for palaeoenvironmental data, are also present. Artificial deposits including road and flood embankments, backfilled pits and quarries, as well as artificially created drainage channels, act to conceal the natural landscape. LiDAR and contouring images for Holderness are patchy across the eastern part of the–Project, but where present, differentiate higher from lower ground, coinciding with deposits of Kelsey Gravel Beds and alluvium or tidal flat deposits (Figs 11a-b).

3.3.2 ***Humber Estuary (Figs 9c; 10c; 11c)***: as it crosses the river from Holderness, the Project is underlain by Chalk of the Flamborough Fm. West of the Humber crossing, the Project is underlain by older Chalk of the Burnham Fm and Weldon Fm (Late to Middle Cretaceous; Fig 9c). The mapped superficial deposits either side of the Humber in the area of the Project include beach and tidal flat deposits (Fig 10c). LiDAR images correspond with that superficial geology, in that mudflats are evident along the Humber, with ground levels rising slightly inland (Fig 11c).

3.3.3 ***Lincolnshire Wolds (Figs 9d, 10d, 11d)***: the area of the Lincolnshire Wolds crossed by the Project comprises bedrock of the Burnham Chalk Fm and the Weldon Chalk Fm, of Cretaceous age (Fig 9d). Between East Halton and Killingholme (North Lincs), alluvial sediments are recorded along with small areas of peat and Head deposits (Fig 10d). The Project, as it traverses in a southward direction, is largely underlain by Till (Fig 10d). Between Ulceby to the west and Kirmington (North Lincs) to the east, the Project traverses a greater variety of superficial deposits, including Till and glaciofluvial deposits as well as interglacial beach deposits of sands and gravels, and Head deposits, which through processes of slopewash and solifluction (mass movement in cold climates), may bury significant sequences (Fig 10d).

3.3.4 Potential palaeochannels may be present within the alluvial and tidal flat deposits at the estuary end of the East Halton Beck (Fig 11d). The higher ground of the Lincolnshire Wolds, with views to East Halton Beck and beyond, are also clearly visible (Fig 11d). No LiDAR data are available for the Project to the north and south of Kirmington (Fig 11d).

3.3.5 ***Lower Trent and Ancholme valleys (Figs 9e-f; 10e-f; 11e-f)***: the geology comprises clays and limestones of the Jurassic Kimmeridge Clay Fm, Oxford Clay Fm, Kirton Cementstone Beds, Charmouth Mudstone Fm, then, westwards, the Scunthorpe Mudstone Formation (mudstones and interbedded limestones, encompassing rocks of Late Triassic to Early Jurassic age), followed westwards by rocks of the Triassic Penarth Group (Gp) and the Mercia Mudstone Gp (Figs 9e-f).

3.3.6 As the–Project traverses south and west across the Ancholme Valley it traverses superficial deposits of alluvium, glaciolacustrine sediments, peat, Head and blown sands of the Sutton Sand Fm (Figs 10e). Boreholes located within the-Project, adjacent to the Kettelby Beck (e.g. SE90NE177), record clays and sands infilling a channel of the old river Ancholme.

3.3.7 West of the Ancholme Valley and east of the Trent, the-Project runs south and then north and then branches north and south-west of Scunthorpe (North Lincs; Fig 10f). In some areas, Jurassic bedrock of the Lincoln Edge is exposed (high ground in Figs 10e-f). In other areas, the Project crosses deposits of the Sutton Sand Fm (Fig 10f). Head deposits are recorded further west (Fig 10f). The Bottesford Stream, east of the Trent, flows parallel to the Project, but a tributary is crossed by the Project as the lower ground of the Trent valley merges into the slopes of the Lincoln Edge (Fig 10f). Where the Project crosses the Trent, either side of West Butterwick (North Lincs), two main superficial deposits are recorded – either warp or alluvium. Occasional small peat deposits are also present (Fig 10f). Further north, the Project traverses deposits mapped as either warp or alluvium.

3.3.8 LiDAR hillshade contouring clearly shows the Ancholme Valley situated between areas of higher ground, the Lincolnshire Wolds to the east and Lincoln Edge to the west (Fig 11e). These areas of higher ground may have provided routeways away from alluvial or swampy ground. Possible palaeochannels of the Kettleby Beck are visible (Fig 11e). LiDAR hillshade views of the stretch of the Trent crossed by the Project show possible palaeochannels on the western side of the river (Fig 11f), with the higher relief of the Lincoln Edge to the east of the river, providing areas of drier ground.

3.3.9 ***Humberhead Levels/Vale of York (Figs 9g-h; 10g-h; 11g-h***): the geology comprises Triassic rocks of the Mercia Mudstone Gp and the older, Sherwood Sandstone Gp (Figs 9g, h). The superficial deposits across the eastern part of the Project show dominantly warp and alluvial deposits. In places, the Project is underlain by coversands of the Breighton Sand Fm (Figs 10g-h). This deposit extends westwards across the Vale of York and is described as a sand unit with a black peat to clayey sandy peat base (BGS). The superficial deposits at the western end of the Project include the Hemingbrough Fm, representing deposits of proglacial glaciolacustrine sediments (Figs 10h).

3.3.10 The LiDAR Hillshade image shows the engineered drainage systems that cut the Project at the low-lying western end. Palaeochannels that appear to cross the Project southeast of Pauper's Drain (Fig 11g), may represent former channels of the Old River Don (Whitehouse *et al.* 2001). The meandering nature of the River Aire, which cuts across the Project before it joins the River Ouse, is apparent (Fig 11h) and is associated with several potential palaeochannels. A palaeochannel of the River Ouse is also visible at the western end of the Project (Fig 11h).

3.4 Regional geomorphology, landscape models, and research

3.4.1 ***Holderness***: the hummocky sand and gravel terrain of Holderness is interpreted as an ice-marginal series of outwash fans, deposited sequentially at the margin of the receding North Sea ice lobe at the end of the Dimlington Stadial (Evans *et al.* 2001). BGS mapping of the Holderness region produced a 3D model of geological and superficial deposits; however, the study does not include the Holderness area south of Hornsea (Burke *et al.* 2015). These data show thick accumulations of Holocene deposits across Holderness, including tidal flat deposits along the Humber Estuary and alluvium deposits along river courses. Pleistocene features include a palaeoshoreline that runs north from Hessle on the Humber Estuary, curving eastwards to the coast at Sewerby. This feature has been attributed to the Ipswichian Period (an interglacial period dating to the early part of the Late Pleistocene, approximately 115-230K BP and equivalent to oxygen isotope stage 5e).

3.4.2 An extensive buried cliff in the Chalk bedrock runs west of Hull towards Bridlington and is exposed at Sewerby. Although outside the Project area, the palaeocliff provides evidence that the pre-Devensian landscape was a marine erosion surface or 'wave-cut platform' in the Chalk, and represents the shoreline during a period when the inferred relative sea level was approximately 2m above present OD (Catt 2007). This feature is important because it is incised by several deep channels that are likely to have formed during major sea-level lowering at the onset of the last or previous glaciations. It thus pre-dates the glacial deposits in the area and could represent depositional sites into which late Pleistocene and Holocene sediments accumulated (Burke *et al.* 2015). As part of a wider complex of coastal landforms, a similar channel in the Immingham (North Lincs) area reached depths 80m below OD (Berridge and Pattison 1994).

3.4.3 The cliff site at Dimlington, originally situated near to Easington but now lost to coastal erosion, is the type site for the Late Pleistocene stadial (LGM) cold phase, approximately 15-26 ka, during the Devensian glaciation. The cliff geology comprises a series of Till deposits, with Basement Till overlain by the Dimlington Silts (which contained organic remains) and two Late Devensian Tills (Skipsea and Withernsea). Radiocarbon dates of the organic remains in the Dimlington Silts provide a maximum age of 18.2-18.5 ka BP for the advance during the Late Devensian of the North Sea ice lobe of the British Ice Sheet, which deposited the named tills (Evans *et al.* 2001).

3.4.4 Complex glacigenic features seen in the Holderness area record abrupt changes in geological process, ranging between glaciolacustrine (glacial lake deposits), glaciofluvial (glacial river deposits) and subglacial (till) environments (Burke *et al.* 2015). River valleys across the coastal plain typically follow channels that were probably cut through the glacigenic deposits by meltwater from the ice sheets. Areas of the Project cut across deposits of clays, silts, and peat that form a tidal-flat sequence, following deglaciation and sea-level rise during the Holocene. As the sea level rose to its present level, alluvium and peat filled the channels. Some of the fine-grained sediments include 'warp', artifically deposited silts and clays formed in the last two or three centuries by controlled flooding to raise the land level and improve the quality of agricultural land, and which is difficult to separate from the underlying natural deposits (Burke *et al.* 2015).

3.4.5 Of relevance to the current study is the archaeological investigation along the route of an underground electricity cable in southern Holderness (Easington to Salt End; Burgess and Daniel 2018). That work showed that former settlement patterns at the eastern and western ends of the Project were influenced by topography, with almost all sites situated on relatively high ground, predominantly on hills or ridges (above the 5m contour). The data have been interpreted to suggest that the distribution of sites corresponds with the changing location of the Humber shoreline, possibly defining the fringes of habitable land since the later Iron Age (*ibid*).

3.4.6 ***The broader area of the Humber Wetlands***: a phased geoarchaeological model of the landscape evolution of the area impacted by the–Project south of the Humber (excluding Holderness) is based on previous work by Van de Noort and Ellis (1997; 1998; 1999) and earlier work by Gaunt (1975; 1981; 1987; 1994; Gaunt *et al.* 1971) and Dinnin (1997a). Six key stages of geoarchaeological activity are identified and, in chronological order, comprise:

- Lake Humber phase;
- Braided river phase;
- Aeolian sand phase;
- Channel incision phase;
- Channel aggradation phase;
- Aggradation of river floodplains.

3.4.7 The evolution and drainage of proglacial Lake Humber has been outlined in *Sections 3.2.6 - 3.2.7*. As Lake Humber drained, the resulting deposits of lacustrine clays, silts, and sands formed the '25 foot Drift' – or the Hemingbrough Glaciolacustrine Fm (BGS 2022). This large expanse of loose, unconsolidated sediments forms most of the floodplain of the southern part of the Vale of York (Burke *et al.* 2017).

3.4.8 Between the end of proglacial Lake Humber and the Early Holocene, ridges of sand or levées developed over the emergent lake plain, created by braided river channels (Gaunt 1994; Van de Noort and Ellis 1998; 1999). The distribution of the deposits reflects the meandering water courses; the levées were subject to periodic reworking, resulting in blown sand and dune deposits (Gaunt 1987). Dating evidence for the aeolian deposits suggests that reworking occurs from around *c* 12,480+/-1130 years to 10,040+/-790 years BP (based on thermoluminescence dating of the sands), and continued into the Early Holocene in the area around Scunthorpe (North Lincs), with renewed dune formation during the late Iron Age and the Roman and Early Medieval Periods (Buckland 1982; Van de Noort and Ellis 1998). Across the Project, these blown sands are represented by the Sutton Sand Fm.

3.4.9 A phase of channel incision followed braided channel and levée formation, and may have overlapped, in part, with aeolian re-working (Van de Noort and Ellis 1998). This was considered to be a brief phase of landscape development, beginning in the Late Devensian and continued until equilibrium was reached between river base level and sea level, during the Early Holocene. Continued sea-level rise towards OD resulted in deposition of fining up sequences. This aggradation would have been influenced by both impeded freshwater runoff and estuarine incursion (Van de Noort and Ellis 1998).

3.4.10 During the Early and Middle Holocene, a high-energy fluvial system existed in the lower reaches of the Trent – which included much of the drainage of the Humberhead Levels, for example, the Old River Don, which joined the Trent at Adlingfleet, Trent Falls (East Riding of Yorkshire; Van de Noort and Ellis 1998). The Old River Don cuts the Proposed Order Limits north of a line between Crowle and Eastoft (North Lincs; Whitehouse *et al.* 2001). Capture and abandonment of active river channels may have led to the development of backswamp areas, in which alluvium and peat deposits could have accumulated. One such example, is the palaeochannel of the Trent at Bole Ings, south of Gainsborough (Lincs; Dinnin 1997b; Dinnin and Brayshay 1999). The identification of layers of alluvium, distributed across the floodplain areas, is important, as these deposits may include accumulations of organic sediments that have the potential to preserve both cultural and environmental remains. Peat and organic deposits, when found within these sedimentary packages, could facilitate precise dating of specific pre-Holocene and Holocene palaeochannels.

3.4.11 A combination of impeded runoff, overbank flooding, and paludification led to the development of extensive, time transgressive, floodplain peats during the Later Prehistoric and Early Historic Periods. Floodplain mire peats and alluvium, with more localised peat development occurring in marginal dune locations, would have characterised the Trent floodplain from the mid-Holocene onwards (Van de Noort and Ellis 1998). Accelerated erosion and alluviation was occurring in the Humber wetlands during the later Iron Age to Roman Period (Van de Noort and Ellis 1999), and continued until the introduction of drainage, perhaps as early as the Roman Period, and warping in the Post-Medieval Period (Van de Noort and Ellis 1998).

3.4.12 ***Humber Estuary***: data from two small developer-led studies from the southern part of the Estuary, at Goxhill (outside the Project, on the northern edge of the Lincolnshire Marsh), and from the northern part of the Estuary, at Paull (outside but adjacent to the Proposed Order Limits, on the Holderness coast; OA North 2021; Zant and Gregory forthcoming), provide geoarchaeological data along a line parallel to the northern edge of the Project and ranging from the Early Mesolithic to Neolithic Periods. Peat deposits spanning the Early Mesolithic to Late Neolithic reflect sea-level changes that ultimately resulted in the creation of the present-day coastline, and the submergence of the Prehistoric woodland landscape of the Humber Estuary. The earliest Mesolithic date from Paull is 7569-7482 cal. BC (8434±25 BP; humic acid fraction, SUERC-76296) to 6776-6642 cal. BC (7866±23 BP; humic acid fraction, SUERC-76291).

3.4.13 ***Lincolnshire Wolds***: south-west from Immingham, the Project runs adjacent to a site designated as a geological SSSI: at Kirmington a thick sequence of superficial deposits comprises glacial, estuarine, and freshwater sediments filling a fossil valley cut into the Chalk (Bridgland and Thomas 1999). The estuarine and freshwater sediments are attributed to interglacial conditions and include flint-rich gravel that has yielded putative Palaeolithic artefacts, as well as a thin peat from which pollen has been extracted (Bridgland and Thomas 1999; Bridgland *et al.* 2014). Straw (2018) has argued that the gravels are of Ipswichian age and represent beach sediments, deposited at the head of the deep Immingham Channel. Interglacial beach deposits are mapped by the BGS within the Project corridor (Fig 10).

3.4.14 On the south side of East Halton Beck, lithological data from three transects of 44 boreholes identified a sequence of Holocene sediments from a large intertidal channel (NAA 2000). During the Early Bronze Age, a rise in sea level resulted in development of mudflats, with pollen and diatom data interpreted to suggest these areas supported saltmarsh vegetation, with development also of reedswamps and accumulation of peat deposits. Glacial Till deposits may have represented higher ground (islands) within this setting, providing a potential focus for archaeological remains.

3.4.15 ***Lower Trent and Ancholme Valleys:*** although the upper and middle Trent Valley floodplains have been the subject of years of research (e.g. Howard 2004; 2005; Howard *et al.* 2008; 2011), the lower reaches of the floodplain have received less attention. Palaeochannel mapping of the lower Trent north of Gainsborough has revealed very few surface-visible palaeochannels, as a consequence of thick deposits of alluvium masking the sub-surface topography (Baker 2007). GIS-derived mapping of the Lower Trent, as part of the Trent Valley GeoArchaeology survey, identified the broad character of the deposits across the Trent, distinguished into sand and gravel, peat and clay/silt alluvium (Fig 6; Challis 2002). Alluvial deposits are characterised by vertical accretion and stratified sequences of fine-grained sand, silt, clay, and peat. The relatively simplistic data are based on digitized borehole records, rather than generated by a specialist package such as RockWorks. These data resulted in a generalised profile across the Lower Trent Valley, based on a digital elevation model (Figs 6 and 7). Challis (2000) also identified peat deposits, some of which may be associated with depressions in the sand and gravel surface close to the present channel of the Trent and which may be indicative of palaeochannels of the Trent. These features may not be visible at the present floodplain because they are masked by later alluvial deposits.

3.4.16 A deposit model has been developed for the Keadby Power Station 2 and Wind Farm site, an area east of the Trent and close to the Proposed Order Limits (Timpany 2012; Trent and Peak Archaeology 2021; SSE Thermal 2021). The deposit model identified bedrock of the Mercia Mudstone Gp at varying depths of approximately - 9.5m OD to -17m OD. Overlying the bedrock, alluvial deposits of sand and clay up to 10-15m thick, were present. Bands of peaty alluvium were recorded in the uppermost layers of alluvium at approximately 0.55m OD to -1.55m OD, with the thickest deposits present eastwards towards the River Trent.

3.4.17 Dating of deep peat from core 1 at Keadby Wind Farm, at -3.88m to -4.20m OD resulted in interpretation of an Early Holocene age for the peat (Headland Archaeology 2013). Pollen from the peat recorded the spread of juniper and dwarf birch, suggesting cold conditions at the end of the Lateglacial Period and the very early opening of the Holocene (Headland Archaeology 2013; SSE Thermal 2021, section 4.5.6). A second undated peat was recorded at -3.12m to -3.52m OD. An upper peat unit, which appears to occur consistently across the area surveyed, was dated from two cores, and gave consistent Late Neolithic dates for inception and Iron Age dates for peat termination (*ibid*). A further thin layer of peat above the dated Iron Age peats was also recorded but undated.

3.4.18 Data from the geoarchaeological study (including interventions data from previous geotechnical surveys east of Keadby 2 Power Station as well as boreholes from Keadby Wind Farm), have been used to interpret a former channel of the Trent (palaeochannel) running north-east/south-west beneath the footprint of Keadby 1 Power Station (Le Quesne 2015) and it is likely that the area between the palaeochannel and the Trent may have existed as a sand island (eyot; SSE Thermal 2021, section 4.6.7). A deposit model based on data from a geoarchaeological hand auger survey (Keadby 3 Low Carbon Gas Power Station; Trent and Peak Archaeology 2021) found that sand deposits (likely to be the Sutton Sand Fm) contained isolated pockets of deeper organic accumulations within hollows in the sand surface. These organic deposits have been interpreted as reflecting an encroaching floodplain which may have developed at the site after the Iron Age. The deposit model was also interpreted to suggest that pre-Iron Age land surfaces may be preserved beneath the organic and warp deposits and that the sands might also mask earlier remains (Trent and Peak Archaeology 2021). The stratigraphy was recorded as bedrock of the Mercia Mudstone Gp overlain by sands (Sutton Sand Fm), in turn overlain by peat deposits and alluvium/warp. Peat deposition is believed to have occurred in the Late Neolithic and therefore there is potential for a buried pre-Neolithic land surface to exist beneath this. The peat deposits will be subject to palaeoenvironmental and radiocarbon assessment and will form part of an updated geoarchaeological assessment of the site area (York Archaeological Trust 2022).

3.4.19 South of Gainsborough (and outside the Project) the palaeochannel sequence from Bole Ings was found to contain an important sedimentological and palaeoenvironmental record (Dinnin and Brayshay 1999). Boreholes in this area have indicated a maximum of *c.* 9m of Holocene alluvium, including peaty silty-clay deposits, spanning an age range from the Early Mesolithic Period to the Bronze Age.

3.4.20 The appearance of the lower Trent floodplain during the Bronze Age and Iron Age has been described by Knight and Howard (2004) as a rich wetland area with channels flowing across the valley floor. Continued clearance of woodland from the floodplain and gravel terraces as well as adjacent upland areas would have resulted in a more open landscape. This landscape would then have been prone to soil erosion and re-deposition of both colluvium and alluvium. The main channel would have remained active but minor streams and abandoned channels fringed by reed swamp would have accumulated under low-energy conditions.

3.4.21 Deforestation and intensified land use, which began during the Iron Age and continued during the Roman Period, lead to an increase in sediment load of regional river systems (including the Trent and Ancholme) and subsequent deposition of thick deposits of fine-grained alluvium across the floodplain during the latter part of the Roman Period (Tweddle 2001). A marine transgression started around *c.* 800-500 cal. BC and continued into the Roman Period. Terrestrialisation, possibly linked to falling sea levels or lower amplitude tidal regimes, was renewed during the first to fourth centuries AD and this event is seen in the Ancholme Valley, the Lower Trent Valley, and the Humberhead Levels (Van de Noort and Ellis 1998).

3.4.22 Attempts at flood alleviation from around 1485 AD to the present day have resulted in a network of drainage channels across the lower Trent Valley, resulting in the loss of the natural wetland environment. Channel re-direction and building up of blankets of alluvium (warp) are clearly present on maps of the area and warp is mapped as a distinct unit by the BGS (Fig 10f).

3.4.23 The Early Holocene Ancholme valley would have been characterised by a single channel and a flat valley floor. Fine sand overlying lacustrine clays probably originated from fluvial reworking of aeolian sands of probable Late Devensian age. The low-lying floodplain or Ancholme Levels reaches altitudes as low as 1m OD to the north and south-east of Brigg, and this area of former tidal wetland consisted of saltmarshes, reedswamps, and alder carrs, with shallow streams following meandering courses, prior to drainage which commenced in the thirteenth century (Van de Noort and Ellis 1998).

3.4.24 In the Ancholme valley, a lower gradient and overall discharge would have resulted in a lower energy environment than in the Trent Valley. In this part of the Project, sea-level rise would have impacted on floodplain aggradation, with sediment accumulation resulting from incursion of brackish water that entered the Ancholme from the Humber (Van de Noort and Ellis 1998).

3.4.25 ***Humberhead Levels/Vale of York***: the Project corridor extends to include part of the Vale of York, a large area of lowland between the Yorkshire Wolds to the east and the Pennines to the west. A schematic model (Fig 8) of the glacial evolution of the Vale of York shows bedrock, overlain by fluvioglacial outwash and valley fill deposits (Ford *et al.* 2004). These are in turn overlain by proglacial glaciolacustrine deposits of the Hemingbrough Fm, overlain in places by fluvial/aeolian sands of the Breighton Sand Fm and aeolian sands of the Sutton Fm. These named deposits are mapped by the BGS within the Proposed Order Limits (Fig 10h).

3.4.26 The Humberhead Levels and the Vale of York are drained by several main rivers including the River Aire, which traverses the Project between Newland and Airmyn. The Aire joins the Ouse just north of Airmyn and, in the Early Holocene, both rivers occupied courses similar to those of today (Gaunt 1987; van de Noort and Ellis 1999). Two transects were undertaken by van de Noort and Ellis (1999), at Airmyn on the Ouse, to the north, and at Carlton Towers on the Aire, to the south. Although both transects are outside the Project boundaries, they bracket the geoarchaeological deposits and palaeoenvironmental history either side of this part of the Project.

3.4.27 The sequence interpreted from the results of the Airmyn transect at Asselby suggest that fluvial sands underlie the sequence at *c.* 9m depth below ground level (bgl) and represent reworked sands, deposited as levée and floodplain sediments, as rivers were initiated across the emergent floor of Lake Humber after *c.* 11,000+/-200 BP (N-810) to 10, 469+/-60 BP (SRR-870; Gaunt *et al* 1971; Gaunt and Tooley 1974; Jones and Gaunt 1976; Gaunt 1994; Van de Noort and Ellis 1999). Channel aggradation may have occurred as early as 7500-6300 cal. BC (8500-7500 BP) with material from the base of the floodplain at Airmyn suggesting a later date of 5330-4900 cal. BC (6200+/-80 BP; GU-5761). The lateral spread of peat was determined to have occurred from the mid-Later Mesolithic Period through to the Early Bronze Age. This date probably coincides with cessation of incision and the upper range of wetland development in this region (van de Noort and Ellis 1999).

3.4.28 The lithostratigraphy of the Carlton transect has been interpreted to represent low-energy fen-carr environments coupled with sporadic alluvial inundation phases. However, the central part of the floodplain, at Carlton Marsh, has been reworked by high-energy fluvial activity during the Holocene, limiting the potential for recovery of archaeological and palaeoenvironmental artefacts and ecofacts. The earliest date for organic sedimentation at this location is placed as *c.* 5000-4000 BC (Later Mesolithic).

3.4.29 A database of over 100 borehole records was used to reconstruct the floodplain depositional environments in the lower Aire valley (west and south of the Project). A clayey wood peat was found overlying the pre-Holocene subsurface, grading into clays of estuarine origin (Kirby 2001). The data reflect the interplay between wetland and estuarine environments, controlled, in part, by fluctuating sea levels during the Holocene.

3.4.30 The Humberhead peatlands of Thorne (including Crowle and Goole moors) and Hatfield, which lie to the south of the Project corridor, are remnants of the once extensive range of raised mires and wetlands that formed in the region *c* 6,000 years ago (Whitehouse *et al.* 2001). The mires formed on laminated clays and silts that infilled proglacial Lake Humber, during the Late Devensian. On Hatfield Moor, windblown sands overlie these deposits (Gaunt 1994), and the two Moors are separated by the riverbed of a previous branch of the River Don (Gaunt 1975; Whitehouse *et al.* 2001), part of which is crossed by the Project between Crowle and Eastoft, with potential for palaeochannels that might retain organic sediments of archaeological significance.

3.4.31 Lindholme Island, in the centre of Hatfield Moors, is an area of dryland, and is one of several discontinuous deposits of sand and gravel, stretching south-east from near Selby to the southern part of the Isle of Axholme. The sands and gravels were deposited as an ice marginal morainic sediment during the high-level phase of Lake Humber (Whitehouse *et al* .2001).

3.5 Regional palaeoenvironmental and vegetation succession

3.5.1 ***Holderness***: there are several important studies from Holderness that provide a palaeoenvironmental context, of which the most significant are those of Beckett (1975; 1981), Gilbertson (1984), and Tweddle (2000). Throughout the Lateglacial and Early Holocene, low sea levels resulted in the exposure of the North Sea Basin, and Holderness and the Lincolnshire Marsh formed part of a low-lying plain linked directly to the continental mainland (Tweddle 2001).

3.5.2 Insect and plant macrofossil evidence from the immediately pre-Late Devensian ice advance deposits at Dimlington show a cold tundra landscape (Penny *et al.* 1969; Tweddle 2001). The earliest part of the Lateglacial has been dated in Holderness as spanning *c.* 13,045 +/-270 radiocarbon years BP (Birm-317) and 11,200 +/-220 radiocarbon years BP (Birm-406; Beckett 1975). Pollen records from Holderness, notably from The Bog at Roos (Beckett 1975, 1981), Gransmoor (Walker *et al.* 1993) and Skipsea Withow Mere (Hunt *et al.* 1984) provide a comparatively well-known Lateglacial vegetational and environmental history.

3.5.3 Pollen from four small infilled kettleholes provide palaeoenvironmental data for the Early Mesolithic to Early Neolithic Periods (Tweddle 2000; 2001). This vegetational history includes recognition of the hazel and alder rises, the expansion of elm and oak, and a date for the elm decline at Gransmoor, northern Holderness, of 4038-3772 cal. BC (5099±50 BP; SR-229; Beckett 1975). Pollen data from the Bog at Roos, closer to the Project route, suggest that during the Early Mesolithic Period, a mixed oak/hazel/elm woodland dominated the catchment between *c.* 8605-8012 cal. BC (*c.* 9101±85 BP (AA-33290) and *c.* 6470-6238 cal. BC (*c* 7525±65BP; AA-32292). The data showed little evidence for disturbance to the canopy during this period, including low microcharcoal counts and no evidence of anthropogenic interference with the vegetation (Tweddle 2000).

3.5.4 Although some palaeoenvironmental data are available for the mid/late Holocene on Holderness, dating control is lacking. The impacts of people on the landscape became clearer and more widespread through the late Holocene, with woodland clearance attributed to increased activity in the area, especially in the Bronze Age, with sustained land-use throughout the Iron Age interpreted from pollen sequences from The Bog at Roos (Tweddle, 2001).

3.5.5 During the Late Iron Age/Roman Period, the sediments and pollen from sites along the Easington to Paull pipeline route through southern Holderness all suggest a coastal floodplain environment, subject to freshwater conditions, but also probably influenced by relative proximity to marine conditions (OA North 2012; Zant and Howard Davis in prep). Flooding may have led to the creation of some shallow, freshwater ponds. Prior to the introduction of artificial drainage in the Early Modern Period, the landscape on Holderness contained many wetland areas (Fletcher and Van de Noort 2007).

3.5.6 ***Humber Estuary***: limited palaeoenvironmental data spanning the Early Mesolithic to Early Neolithic Periods are available from deep boreholes analysed from specific sites at Paull and Goxhill, following developer-led projects (OA North 2016; 2021; Zant and Gregory forthcoming). Rackham *et al.* (2011) found pollen evidence that rising sea levels with localised flooding of either fresh or brackish water, impacted the northern margins of the Humber Estuary from the later Neolithic Period (2670-2900 cal. BC (4200±40 BP; Beta-255935)).

3.5.7 At Kingston upon Hull, peats that formed during the the Late Mesolithic Period (6076-5639 cal. BC (6970±100 BP; IGS-C14/99)), at 9.15m OD and -11.58m OD (Van de Noort and Ellis 2000), were overlain by an estuarine transgressive episode after *c.* 6000-5000 BC (6890±100 BP; IGS-C14/100; *ibid*). The transgression progressed up-estuary with intercalated peats indicative of a fine balance between intertidal and freshwater sedimentary environments; the probable maximum extent of intertidal deposits occurred *c.* 1500-1000 cal. BC (*c.* 3000 BP) and numerous sites in the Humber Estuary record the removal of intertidal sedimentation after this date (Metcalfe *et al.* 2000).

3.5.8 During the Iron Age, sea level had regressed in the Humber Estuary (Long *et al.* 1998). Closer to Paull, Rackham *et al.* (2011) found that halophyte elements of the pollen and plant macrofossil assemblages continued right through to the Late Iron Age, with evidence of freshwater marsh elements in the later Roman Period and the start of the Early Medieval Period. A major increase in wetland fen communities is recorded during the middle of the Early Medieval Period (Rackham *et al.* 2011).

3.5.9 ***Lincolnshire Wolds***: the palynology of the pre-Devensian (interglacial) history of the area is limited to a thin peat band contained within estuarine silts close to Kirmington in the Lincolnshire Wolds. The study has been interpreted to suggest the local vegetation was dominated by reedswamp and saltmarsh communities. Woodland containing abundant oak, pine, and alder, with lower frequencies of spruce, holly, elm, and hazel-type occurring. The overall assemblage characteristics, when compared with other sites in the UK, led to an interpretation of a possible Hoxnian interglacial age for the sequence (Watts 1959). Work by Gale and Hoare (2007) suggested that estuarine silts and a thin peat bed containing limited temperate pollen of undifferentiated age, separated tills assigned to the Anglian (bottom of the Middle Pleistocene) and the Late Devensian (Late Pleistocene). Palaeoenvironmental reconstructions for the Wolds is very limited for the Lateglacial and Holocene, as there is an absence of reliable pollen data (Tweddle 2001).

3.5.10 ***Lower Trent Valley and Ancholme Valley***: the pollen and plant remains from a deposit from Messingham (Carrott *et al.* 1997), south of the Project, correlate with a beetle study from beneath coversands (Buckland 1982) that described cold, typically Lateglacial sedge-dominated fen conditions. A radiocarbon date from a peat bed at the base of 3m of coversands at Messingham produced a date of 10,280+/-120 BP (Birm-

349; Buckland and Dolby 1973). There is a possible association between a Late Upper Palaeolithic end scraper and macroscopic willow (*Salix*) charcoal at this site (Buckland 1984; Tweddle 2001).

3.5.11 The most detailed palaeoenvironmental work from the lower Trent is from outside the Project corridor. Investigation of the Bole Ings palaeochannel, located just inside Nottinghamshire to the west of the Trent, recovered data spanning the Early to Later Holocene Period (Mesolithic to Early Iron Age; Dinnin and Brayshay 1999). The data have been interpreted to suggest alder-dominated low-energy floodplain/backswamp environments, with wetland margins along the riverbank and gravel islands/ridges on the floodplain, providing habitats for pine woods as well as mixed deciduous woodland. Disturbed habitats during the Early Holocene are linked to hydrological changes (for example, waterlogging), possibly in response to rising sea level and floodplain aggradation (*ibid*).

3.5.12 The Elm Decline has also been identified at Bole Ings (*ibid*). Later evidence, associated with possible tree clearance in the wider landscape, includes a Bronze Age decline in lime (dated 2140-1740 cal. BC (3579±70 BP; BETA-75271)) that has been associated with a peak in microcharcoal particles and, together, have been interpreted to signify anthropogenic forest disturbance beyond the floodplain, but with no evidence of disturbance to the dense alder carr occupying the floodplain (*ibid*). Land beyond the floodplain was subject to arable and pastoral agricultural activity, dated 1120-540 cal. BC (2690±100 BP; BETA-75270), and has been interpreted as evidence to support exploitation of areas such as the gravel terraces during the Early Iron Age (*ibid*).

3.5.13 Marine diatoms in basal sand deposits of a deep palaeochannel at Brigg (North Lincs), in the Ancholme valley, suggest that, during the Lateglacial or very Early Holocene, the Ancholme was a tidal inlet of the Humber (Van de Noort and Ellis 1998). The earliest dates for the onset of mire development in the Ancholme Valley are Late Mesolithic, with peat development confined to low-lying areas adjacent to the incised palaeo-Ancholme. By the end of the Neolithic Period, much of the valley floor was covered in woody fen-carr, with mire expansion continuing during the Bronze Age and reaching its maximum extent at the Late Bronze Age/Iron Age transition. Evidence of small-scale clearance at Brigg during the Early Bronze Age has been inferred from pollen analyses dated 2580-2330 cal. BC (3940+/-45 BP (OxA-7091); Van de Noort and Ellis 1998).

3.5.14 There is evidence of a marine flooding event in the Middle Bronze Age, which resulted in saltmarsh development near the channel which was fringed by coastal reedswamp, with fen-carr along the valley edges (Van de Noort and Ellis 1998). The increasingly waterlogged conditions were conducive to preservation of a trackway and boats (*ibid*). The Brigg raft was found within a grey clay deposit that separated two peat layers and was dated to the Bronze Age/Iron Age transition (McGrail 1990).

3.5.15 ***Humberhead Levels/Vale of York***: the Humberhead Levels merge northwards to the Vale of York, the southern limit of which is formed by the Rivers Aire and Humber (Van de Noort and Ellis 1999). An early palaeoenvironmental record is available from south of Rawcliffe (East Riding of Yorkshire), where organic sediments recovered from boreholes near Langham yielded pollen indicative of an Ipswichian age (Gaunt 1974). The deposits are interbedded with clays, sands, and gravels and rest directly on Sherwood Sandstone bedrock. The deposits are overlain by lacustrine deposits of Late

Devensian age (*ibid*). Freshwater and saltmarsh habitats have been inferred, together with evidence of estuarine tidal conditions, as a result of sea-level rise during the early part of the interglacial. This area is adjacent to, but outside the Proposed Order Limits.

3.5.16 In the lower Aire Valley, pollen and diatom data were interpreted to suggest that peat inception due to waterlogging led to the spread of fen carr wetland vegetation on the valley bottom during the Early Holocene (Kirby 2001). This was followed by encroachment of estuarine conditions into the upper reaches of the Humber, which resulted in the creation of large tidal lagoons, such as that at Goole, where a brackish tidal lagoon existed permanently during the Early to Middle Mesolithic Period (*ibid*).

3.5.17 By the Middle Mesolithic, alder fen carr expanded throughout the Humber lowlands (Long *et al.* 1998; Metcalfe *et al.* 2000). During the mid- to late Holocene, diatom data were interpreted to support the return of estuarine conditions to the lower Aire valley, with deposition of estuarine alluvium and tidal creek networks eroding parts of the main floodplain peats (Kirby 2000). During the Bronze Age/Iron Age transition, peat was again deposited as sea levels once again fell.

4 GEOARCHAEOLOGICAL POTENTIAL

4.1 Introduction

4.1.1 This chapter integrates the data presented in the previous chapters to consider the geoarchaeological potential within the Project. That potential is expressed in terms of:

- the possible presence of archaeological remains that may lie sealed by, or within, sedimentary facies;
- areas with good stratigraphic sequences that could contribute to a deposit model (either in the case of existing BGS data, or where GI works could be undertaken).

4.1.2 The data is considered first in general and within the broad context of the Project (*Section 4.2*; Table 2), then more specifically for each of the five main regions traversed by the Project (*Section 4.3*).

4.2 General potential of the sedimentary facies

4.2.1 This section considers and summarises the broad potential for encountering archaeological remains within the various environments and sedimentological sequences that are often found at numerous locations along the Project. The deposits are summarised in Table 2, with a more detailed commentary in *Sections 4.2.2 - 4.2.8*.

Sediment Unit	**Environment of Deposition**	**Archaeological Potential**
Topsoil	Modern agricultural ploughsoil.	Could contain redeposited pottery or lithic material brought to the surface through ploughing and sub-surface disturbance.
Warp	Modern flooding for soil improvement. Mapped by the BGS south of the Ouse and Humber, within the Project and across the River Trent near West Butterwick.	Has the potential to seal *in-situ* Historic and Prehistoric archaeological remains.
Colluvium	Potential Modern and Ancient soil movement associated with agriculture and vegetation clearance (hillwash/ploughwash). Soil creep, slope/sheet wash, rill and gully erosion. Low to moderate energy.	Potential to contain re-deposited pottery and lithic material from Historic and Prehistoric activities on higher ground/slopes and to seal land surfaces, Historic and Prehistoric archaeological remains.
Tidal flat deposits	Holocene sedimentation of sands, silts and clays in coastal settings. Mudflats, sandflats, saltmarsh and tidal creeks. Moderate to high energy.	Has the potential to seal *in-situ* Historic and Prehistoric archaeological remains in waterlogged conditions. May preserve evidence of former saltmarsh and creek systems, and earlier freshwater environments at depth (see below). Seasonal activity (timber structures and fish traps, evidence of salt-making?)
Alluvium/ Fluvial deposits	Holocene alluviation associated with overbank flooding and migrating river/stream channels, backwater areas. Low to high energy.	Has the potential to seal *in-situ* Historic and Prehistoric (former dryland?) archaeological remains in waterlogged conditions, although reworking and

Sediment Unit	Environment of Deposition	Archaeological Potential
		erosion may be associated with coarse grained channel facies (sands and gravels). Timber structures may be preserved, particularly at the margins of channels or marginal ecotonal zones adjacent to buried islands or at floodplain edges.
Peat/ Organic Alluvium	Periods of stabilisation or channel migration that result in encroachment of vegetation. Low energy.	*In-situ* Prehistoric potential in waterlogged conditions (organic preservation - timber structures).
Head	Head deposits may occur on lower slopes and the base of valleys, as a result of mass wastage, solifluction, sheet wash. Head deposits generally reflect poorly sorted sands and gravels, often the product of reworked glacial and fluvioglacial sediments (BGS mapping includes colluvium/ploughwash).	Palaeolithic or Prehistoric potential. May seal land surfaces. Gravelly facies may contain reworked artefacts from higher upslope.
Pleistocene/ Holocene Aeolian and riverine deposits	Aeolian coversands/riverine alluvial sand, silt, and clay deposits, undifferentiated. Named deposits, e.g. Sutton Hill Sand, Breighton Sand Fm.	Palaeolithic and/or Prehistoric potential. May seal land surfaces.
Pleistocene glaciofluvial deposits; river terrace sands	Undifferentiated Pleistocene sands and gravels. Named Pleistocene units, e.g. Kelsey Hill Gravels.	Palaeolithic potential. Reworked artefacts.
Pleistocene glaciolacustrine sediments	Sands, silts, and clays associated with infilling proglacial Lake Humber, undifferentiated. Named glaciolacustrine deposits, e.g. Hemingbrough Fm [25-foot-Drift].	Palaeolithic potential. *In-situ* stratified artefacts at marginal locations, ecotonal zones.
Pleistocene Till	Deposits of sands and gravels deposited by and underneath glaciers.	None. Rarely may mask underlying Palaeolithic archaeology.
Pleistocene Interglacial beach deposits	Sands and gravels representing former (pre-Devensian) shoreline deposits. May include estuarine deposits which may include organic rich sediments.	Palaeolithic potential. Artefact and ecofact assemblages that are more likely to have been reworked, but may include some *in situ*.
Bedrock	Geological strata (dominantly mudstones of Early Jurassic – Late Triassic age in west, with Middle and Upper Jurassic clays and limestones further east, followed eastwards by Chalk of Cretaceous age.	None.

Table 2: Summary of facies types and inferred general archaeological potential

4.2.2 *Bedrock:* in the development area, this comprises mudstones of Triassic to Early Jurassic age in the western part of the development with progressively younger rocks of Middle and Upper Jurassic age further east and with Chalk deposits of Cretaceous age described from the East Riding of Yorkshire and Holderness (Figs 9a-h).

4.2.3 *Pleistocene deposits*: these deposits cover a range of sediments, including potentially earlier Pleistocene estuarine and beach deposits, for example, at Kirmington (North Lincs), and mapped (BGS) as occurring within the Project. Named units such as the Kelsey Hill Gravels Beds are recorded on Holderness as upstanding ridges (eskers) surrounded by either alluvium or tidal flat deposits. Throughout the Lateglacial and Early Holocene, low sea levels resulted in the exposure of the North Sea Basin, and Holderness and the Lincolnshire Marsh formed part of a low-lying plain linked directly to the continental mainland (Tweddle 2001). It is, therefore, possible that these deposits could contain evidence of Palaeolithic activity. Bones of animals such as horse, deer, mammoth and bison, have been recorded from the Kelsey Hill Gravels from the area around Keyingham (Whittaker 2001). Deposits such as Till, glaciofluvial sands and gravels, and Head, may mask or seal underlying deposits that could contain Palaeolithic archaeological and environmental remains.

4.2.4 The silting up and draining of proglacial Lake Humber led to early accumulations of sediments along the river valleys, for example, at the western end of the Project, where the Hemingbrough Fm is extensively mapped. This deposit is composed of laminated clay, silt, and sand, largely unconsolidated, and forms much of the floodplain of the southern Vale of York. Along the Trent Valley, fast-moving braided channels resulted in the formation of the Trent Valley terrace sequence and associated gravel islands. The gravel islands could have played a key role in the development of human settlements, as these islands may have been a focus for human activity on the otherwise low-lying river valleys. Where the Project crosses the Trent, these sequences are likely to be covered in thick deposits of alluvium and warp. Elsewhere, undifferentiated Pleistocene sands and gravels are mapped as glaciofluvial deposits.

4.2.5 Windblown sand deposits or coversands, including the Breighton Sand Fm, are mapped by the BGS at the western end of the Project (Figs 10h-g) and, further east, extensive deposits of sands of the Sutton Fm, are present across the Project between Messingham and Scawby (North Lincs; Fig 10f). Dating of these units is imprecise; localised re-activation of these sediments has occurred during the Holocene and up to the present day (Bateman and Buckland 2001). It is likely, therefore, that any archaeological remains contained within these deposits may be reworked; nevertheless, recovery of such finds would be important in this region, which is largely devoid of Palaeolithic materials, and consequently, any finds could be significant. Aeolian deposits have the potential to conceal buried land surfaces.

4.2.6 *Holocene alluvial and peat deposits*: during the Early Holocene, as the sea level began to rise, thick swathes of alluvium were deposited within the floodplain of the Humber and the rivers that flow into it. Extensive areas of alluvium are mapped by the BGS across the Project, across all the main river valleys (natural alluvium is masked by warp across the Trent Valley). Alluvial deposits may seal potentially *in-situ* Historic and Prehistoric (former dryland?) archaeological remains in waterlogged conditions, although reworking and erosion may be associated with coarse grained channel facies (sands and gravels). Timber structures may be preserved, particularly at the margins of channels or marginal ecotonal zones adjacent to buried islands or at floodplain edges. Peat deposits are present as intercalated deposits within an alluvial system and are present in substantial thicknesses in places where alluviation has not eroded the wetland sedimentation. Small pockets of peat are mapped at surface level across parts of the Project; however, these deposits may be degraded from exposure and drainage.

4.2.7 *Holocene colluvial deposits*: colluvium deposits represent Holocene slope deposits associated with de-vegetation and agricultural practices. They have the potential to bury land surfaces and earlier deposits that could be associated with worked lithics.

4.2.8 *Warp*: the main area of warp deposition, mapped by the BGS, occurs extensively across the Trent valley, in particular. This deposit will conceal the shape of the natural landforms it covers, as well as masking former land surfaces of archaeological potential (e.g. palaeochannels and/or gravel islands).

4.3 Specific areas of potential within each zone of the Project

4.3.1 ***Holderness (Figs 9a-b; 10a-b; 11a-b):*** BGS boreholes across the area of interest are generally of limited value, as several of these record quite old data and often lack critical values (for example, altitudinal data). However, several boreholes in the vicinity of Paull, at the western end of Holderness, probably contain sufficient data that could form part of a data package for inclusion in a deposit model (*Appendix A*).

4.3.2 The Project cuts across an area mapped as alluvium by the BGS, between Hollym (to the east) and Hedon (to the west; Fig 10a-b). Areas of potential former wetlands, since drained, may be represented by alluvial and peaty sediments and may contain evidence of former areas of human impact. Striking examples from the north of Holderness include sites such as West Furze, where a trackway spanning the Neolithic Period to Bronze Age was uncovered, or the Mesolithic lakeside platform of Round Hill, or Barmston Drain, where a Bronze Age settlement was located on the sediments of a Lateglacial mere (Fletcher and Van de Noort 2007).

4.3.3 Another area of alluvium between Halsham (east) and Burstwick (west) is bordered on either side by the Kelsey Gravels Beds (Fig 10b). The Kelsey Gravels form a series of parallel, low, north/south trending sinous ridges, probably eskers (ridges deposited by meltwater from a retreating glacier or ice lobe) with numerous peat-filled kettle holes on the ridge surfaces (Eyles *et al.* 1994; Thomson and Evans 2001). Pleistocene bones and shells have previously been recovered from the Kelsey Hill Gravels near Keyingham (Whittaker 2001). Small areas that are adjacent to, or within the Project have been mapped as lacustrine sediments surrounded by deposits of till. These features may retain organic sediments, of palaeoenvironmental value (Fig 10b).

4.3.4 Throughout the Lateglacial and Early Holocene, low sea levels resulted in the exposure of the North Sea Basin, and Holderness and the Lincolnshire Marsh formed part of a low-lying plain linked directly to the continental mainland (Tweddle 2001). Tidal flat deposits on the western side of Holderness, adjacent to the Humber crossing and along the Project routeway, are juxtaposed with deposits of the Kelsey Sand and Gravel Beds, forming upstanding areas surrounded by tidal flats, which may have been areas attractive to early communities (Fig 10b).

4.3.5 ***Humber Estuary (Figs 9c; 10c; 11c***): data are available from BGS boreholes across the Humber, but these are located immediately north of, rather than within, the Project (Fig 9c; *Appendix A*). These all show similar stratigraphic sequences, with alluvium overlying Chalk bedrock at between *c.* 15-20m (bgl), with peaty deposits recorded from boreholes at the western end of the crossing. These data could form part of the dataset for generation of a deposit model. Geoarchaeological data are available from small-scale projects either side of the Humber, at Paull and Goxhill, that could contribute to development of a deposit model (Oa North 2021; 2022; Zant and Howard Davis in prep; Zant and Gregory forthcoming). Areas of alluvium and peat deposits may contain or mask archaeological deposits. Peat deposits can provide valuable palaeoenvironmental data as well as suitable material for radiocarbon dating.

4.3.6 ***Lincolnshire Wolds (Figs 9d; 10d; 11d)***: superficial deposits mapped along the Project to the west of East Halton and Killingholme (North Lincs) show accumulations of alluvium and peat as well as Head deposits (Fig 10d). These deposits could reflect areas of potential wetlands that may contain evidence of former human impact. Head deposits could either seal former land surfaces or may contain artefacts reworked from older deposits. The interglacial beach deposits and associated strata in the vicinity of Kirmington may potentially contain archaeological Palaeolithic material, either artefactual and/or palaeoenvironmental, and are also of potential geoarchaeological significance (Fig 10d). Analysis of such deposits in this part of the country may potentially help to answer strategic objectives of the East Midlands Research Agenda, in particular, how the Historic Environment Record dataset for study of the Palaeolithic Period could be enhanced.

4.3.7 ***Lower Trent and Ancholme Valleys (Figs 9e-f; 10e-f; 11e-f)***: data for geoarchaeological deposit modelling are available from BGS boreholes, in particular, either side of the River Trent. Data from historical boreholes to the west of the Trent (for example, borehole SE80NW39 located on the M180 in the middle of the Project) record 7.5m of peat less than 1m below the surface, with bedrock recorded at 8.7m. Peat and alluvial sequences are also recorded in several other boreholes to the west of the Trent, within the Proposed Order Limits. To the immediate east of the Trent, the sedimentary record from borehole SE80NW35 is of alluvial sediments, but a little further to the east, borehole SE80NW46 contains approximately 5m of very soft peaty clay and brown peat. The data from these specific boreholes, near West Butterwick (North Lincs), either side of the Trent, would be of sufficient quality to contribute to a deposit model for this part of the Project (Fig 9f).

4.3.8 Borehole and hand-auger BGS data are also available for the area of the Project north of Messingham (North Lincs; Fig 9f). Hand augering has shown localised pockets of peat appear to be preserved at relatively shallow depths, for example, at approximately 1-2m below the surface. The interventions are generally too shallow to record a full stratigraphic sequence. Few BGS interventions are available for the part of the Project that crosses the Ancholme Valley (Fig 9e) and location of GI boreholes in this area would be a useful addition to development of a deposit model for the Project.

4.3.9 The Sutton Sands Fm coversands, which are mapped extensively across the Project between Scawby and Scunthorpe (North Lincs; Fig 10f) may mask or contain Prehistoric artefacts. A peat deposit underlying coversands at the Black Walk Nook pit at Messingham Quarry was found to contain a flint end scraper, providing evidence of human presence in the area during the Lateglacial Period (Bateman 2001).

4.3.10 Alluvium, peat, and Head deposits may contain and/or conceal Prehistoric archaeological remains. Peat deposits cross the Project, south of Brigg, where the Kettleby Beck divides in two in an easterly direction (Lincs; Fig 10e). The Beck itself flows parallel to the Project (to the west) and deposits of alluvium are present, with potential also for palaeochannels to be preserved (Fig 11e). Brigg (North Lincs) is located on a former inlet of the Humber and is significant for discovery of the Brigg raft, found in clay deposits separated by two peat layers (McGrail 1990).

4.3.11 LiDAR hillshade (Fig 11e) clearly shows slightly higher ground either side of the Kettleby Beck; similarly, further west, a tributary of the Bottesford Beck is crossed by the Project within the foothills of the Lincoln Edge (Fig 11f). Areas of higher ground close to water courses may have been attractive to Prehistoric communities.

4.3.12 Deposits of warp and alluvium, representing extensive deposits either side of the Trent, (Fig 10f), could conceal Prehistoric archaeological remains as well as geoarchaeological features such as palaeochannels or sand islands (as ridges of former river terraces). Areas of peat close to or at the surface, may be indicative of larger, possibly undisturbed peat sequences concealed beneath warp or may represent remnants of previously more extensive peatlands.

4.3.13 ***Humberhead Levels/Vale of York (Figs 9g-h; 10g-h; 11g-h)***: data are available for approximately 20 BGS interventions within this part of the Project, predominantly from the area around Drax (North Yorks; Fig 9h); however, elsewhere along this part of the Project, BGS borehole data are sparse. The data record probable glaciolacustrine sediments close to the surface (the Hemingbrough Glaciolacustrine Fm, with bedrock at *c.* 20m bgl). The Hemingbrough Glaciolacustrine Fm is composed of laminated clay, silt, and sand, deposited in proglacial Lake Humber, that developed in front of the Vale of York ice lobe (Burke *et al.* 2017; *Section 3.2.6*). An exception to this sequence is the record from SE62NE130, within the Proposed Order Limits, near Long Drax, which records alluvial sediments overlying approximately 7m of peat and organic clay, with weathered sandstone bedrock at 18.69m bgl (*Appendix A*). These data could be used to contribute to a deposit model for this part of the Project. The Hemingbrough Glaciolacustrine Fm silts and clays have the potential to retain archaeological data including palaeoenvironmental data (in organic sequences) in this deposit, which represents the infilled sediments of proglacial Lake Humber (Fig 10h).

4.3.14 Deposits of warp and alluvium (Fig 10g) could conceal Prehistoric archaeological remains. Areas of peat may be indicative of larger, possibly undisturbed peat sequences concealed beneath warp. These sequences could provide important palaeoenvironmental data. LiDAR for the area west of Eastoft shows probable palaeochannels crossing the Project, which may represent channels of the Old River Don (Fig 11g), known to follow a route between Crowle and Eastoft (East Riding of Yorkshire; Whitehouse *et al* 2001). Capture and abandonment of active river channels may have led to the development of backswamp areas, in which alluvium and peat deposits could have accumulated. This is an area of very low BGS cover, so data from GI works would help build a deposit model for this part of the Project. Further west, where the Project crosses the River Aire, LiDAR again shows potential palaeochannels (Fig 11h). The Breighton Sand Fm coversands may mask or contain Prehistoric artefacts across parts of the Vale of York, although artefacts contained within these deposits could be reworked (Fig 10h).

5 Conclusion

5.1 Key points

5.1.1 The Project traverses a considerable transect across a landscape that is both diverse and complex in its geomorphology, sediment history, and geoarchaeological potential. The findings have been discussed in considerable detail in previous sections, and here are summarised as bullets:

- mapping of superficial deposits by the BGS has recorded swathes of alluvial/tidal sediments across large parts of the Project, representing (in part) low-energy environments depositing organic silts and clays, and sometimes peat, suggesting potential wetland margin locations with vegetated palaeoenvironments. Alluvial zones may preserve relict palaeochannels systems and ecotonal zones which may have acted as a focus for activity in the past e.g., for hunting, fishing, transport, or other reasons. The waterlogged nature of the sediments offers the potential for preservation of organic remains which may include timber structures as well as palaeoenvironmental archives suitable for landscape reconstruction;
- mapping floodplain channels and topography across the Project and the integration of these data with LiDAR, has demonstrated that features likely to be of archaeological importance can be identified. During this qualitative GDBA, several potential palaeochannels have been identified, adjacent to or within the Proposed Order Limits, for example, part of the possible former watercourse of the River Don (Fig 11g);
- a large geographical area traversed by the Project represents part of the modelled extent of former proglacial lake Humber (Bateman *et al.* 2018; Baker *et al.* 2013; Fig 4). The potential, therefore, exists for the survival of Prehistoric remains at, or near, possible former water edge/wetland environments within the development area, but these are likely to be buried underneath thick deposits of alluvium;
- lacustrine deposits, present within the Project, and at Holderness, could represent accumulation of organic deposits, perhaps, for example, representative of former lakes that formed in kettle-holes in Glacial Till deposits. These deposits have the potential to contain valuable palaeoenvironmental data;
- deposits of sands and gravels (including Head and colluvium) can also mask underlying archaeological remains. Interglacial beach deposits at Kirmington may reveal a series of deposits with potential evidence of former palaeoenvironments, sealed beneath the Late Devensian gravels;
- river terrace deposits, although not specifically mapped as such across the Project, may represent, in subdued topography, potential topographic highs, subtle ridges, or sand islands that may have been attractive to Prehistoric people. The Project crosses the Rivers Trent, Ancholme, Don, and Aire, and passes just south of the Ouse, potentially in areas where gravel islands may occur but where they might be buried beneath deposits of alluvium and warp;
- sites within the lower reaches of river valley systems are complex because both fluvial and estuarine processes may have influenced deposition and erosion.

Likewise, areas adjacent to former ice sheets (e.g. the lower Vale of York), may have a complicated stratigraphy, due to repeated surging and waning of ice, resulting in multiple periods of deposition, often difficult to separate, correlate and date. It is, therefore, of critical importance that a robust chronological framework is established for the Pleistocene and Holocene deposits along the route of the Project, in order to build a reliable deposit model;

- BGS borehole data across the Project are largely historical and of limited use in construction of a deposit model. The records often lack altitudinal data and have been sited to focus on bedrock geology rather than superficial deposits. In many cases, the spread of boreholes is too far apart to produce a meaningful deposit model representative of the subsurface deposits. There are, however, several areas (mentioned in the text) where BGS borehole coverage is reasonable and would provide sufficient data to supplement new data acquired from future GI investigations. Similarly, data from previous GI interventions from developer-led projects could provide supplementary data to generate a more detailed deposit model across the Project.
- humans were often drawn to watercourses, springs and wetland-edge environments (ecotonal zones). Deposits can seal buried land surfaces associated with well-preserved archaeological features, structures or in-situ artefact assemblages, and areas of higher ground or islands could have been favoured for settlement;
- the region covered by the Project includes areas that lie outside, and on the edges of, the main drainage pattern. Areas such as this were often used as communication routes between lower-lying and higher ground. Within them deposit sequences and archaeological sites could have been protected from the effects of fluvial erosion and well-preserved remains do not necessarily have to be buried at great depths to survive.

5.2 Summary of potential

5.2.1 The geoarchaeological and palaeoenvironmental potential of the deposits traversed by the Project is briefly summarised in Table 3 below. This is further differentiated into zones of high-, medium-, or low potential, based on the extent and nature of the deposits found within the site area. It should be noted that this potential is often specific to discrete regions of these zones (e.g., palaeochannels, valley systems, mires etc), rather than the area in its entirety.

5.2.2 Deposits of geoarchaeological potential reflect sediment accumulations that could be considered for further work, for example, targeted ground investigation work or geoarchaeological survey across key sequences. Deposits of palaeoenvironmental potential are more likely to contain organic sediments that may hold prime data for establishing chronological and vegetational histories. The distinction between high-, medium-, and low potential, is based on the extent and nature of the deposits found within the site area. These distinctions also take into consideration the potential for these zones to have acted as foci for past human activity and for the evidence of such activity to be preserved.

Zone traversed by HLCP	Feature/Deposit	Field of Potential					
		Geoarchaeology			Palaeoenvironmental		
		High	Med	Low	High	Med	Low
Holderness	Till			x			x
Holderness	Kelsey Hill Gravels		x	x		x	x
Holderness	Alluvium	x	x			x	x
Holderness	Peat		x		x	x	
Holderness	Tidal Flat		x			x	x
Humber Estuary	Peat		x	x	x	x	
Humber Estuary	Alluvium	x	x			x	x
Lincolnshire Wolds	Peat		x	x	x	x	
Lincolnshire Wolds	Head			x			x
Lincolnshire Wolds	Interglacial Beach deposits	x	x			x	x
Lower Trent & Ancholme	Coversands (Sutton Fm)	x	x			x	
Lower Trent & Ancholme	Alluvium	x	x			x	x
Lower Trent & Ancholme	Peat		x	x	x	x	
Lower Trent & Ancholme	Head			x			x
Lower Trent & Ancholme	Warp		x	x		x	x
Humberhead & Vale of York	Glaciolacustrine (Hemingbrough Fm)			x			x
Humberhead & Vale of York	Coversands (Breighton Fm)		x			x	x
Humberhead & Vale of York	Alluvium	x	x			x	x
Humberhead & Vale of York	Peat		x	x	x	x	
Humberhead & Vale of York	Warp		x	x		x	x

Table 3: Summary of geoarchaeological/palaeoenvironmental potential

5.3 Consideration of further work

5.3.1 The Project would be a substantial undertaking, involving a multi-stage scheme of archaeological investigation and with each stage informing the scope of the next. Within that context, the following sections provide an overview of a limited scope of early-stage work that could be undertaken to test the findings of the geoarchaeological desk-based assessment and to provide data for deposit model construction.

5.3.2 In the first instance, a watching brief on planned Ground Investigation (GI) geotechnical interventions (e.g., borehole, window samples, and test pits) would provide direct observations of the sediment sequences and offer the opportunity to record any evidence of buried land surfaces and associated cultural activity. These data, combined with the better-quality BGS records, could form the basis for a first-stage deposit model specific to the Project. Opportunistic sampling may provide some material for range-finding radiocarbon dating and palaeoenvironmental assessment, although detailed assessment is normally carried out latterly through targeted purposive investigations (see below). For geoarchaeological modelling purposes, high-priority targets for the watching brief should include waterlogged alluvial/wetland zones (including tidal flats and expanses of peat/ lacustrine deposits) and valley areas which may include Holocene colluvium, as well as coversands. Edge environments may contain shallower sequences where construction impact may be considered greater, and these should be targeted for direct observation for identification of stratified archaeological horizons, in addition to deeper sequences in the locations of directional drilling at crossing points (e.g. roads and watercourses). Lower priority areas for geoarchaeological purposes would include areas where the Project crosses glacial deposits (e.g. Till), or where the BGS maps bedrock only on areas of higher ground.

5.3.3 Comprehensive LiDAR coverage would also help to identify features in the land surface that could relate to former environments. LiDAR coverage is absent where no colour is evident on the LiDAR Hillshade maps Figs 11a-h). It is unlikely that data from GI interventions alone would provide sufficient density of sub-surface data to fully address geoarchaeological potential. Targeted purposive borehole/test pits surveys (to fill gaps in the GI work) in areas considered to be high potential (i.e., through sediment sequences including alluvial/peaty, colluvial and aeolian deposits), would potentially provide additional stratigraphic data and material for palaeoenvironmental assessment and radiocarbon dating, to aid the development of the deposit model. Purposive boreholes/testpits may be carried out alongside GI works, or more commonly integrated with phases of archaeological evaluation trenching once a preliminary first stage model based on GI interventions has been constructed. The quantity of these interventions would depend on the results of the deposit modelling in the context of the developing wider programme of investigation and mitigation, but also a careful consideration of the value and relative effectiveness of other techniques (Historic England 2015; 2020).

6 BIBLIOGRAPHY

Abramson, P, 1996 Excavations along the Caythorpe Pipeline, North Humberside, Yorkshire *Archaeol J*, 68, 1-88

AOC, 2021 *Solar 21: Geoarchaeological watching brief and deposit model report*, unpubl rep

Arcadis, 2022 (forthcoming) *Archaeological Desk-based assessment, Humber Low Carbon Pipelines*, unpubl rep

Baker, S, 2007 *The palaeochannel record in the Trent Valley UK: contributions towards cultural heritage management* [Online] Available at: https://intarch.ac.uk/journal/issue20/3 (accessed June 2022)

Bateman, M D, Evans, D J A, Buckland, P C and seven others, 2015 Last glacial dynamics of the Vale of York and North Sea lobes of the British and Irish Ice Sheet, *Proceedings of the Geologists' Asso*ciation, 126, 712-730

Bateman, M D, Evans, D J A, Roberts, D, H, Medialdea, A, Ely, J and Clark, C D 2018 The timing and consequences of the blockage of the Humber Gap by the last British-Irish Ice Sheet, *Boreas*, 47, 41-61

Bateman, M D, and Buckland, P C, 2001 Late Quaternary Record from Beyond the Icesheets, in M D Bateman *et al* (eds) *The Quaternary of East Yorkshire and North Lincolnshire Field Guide,* Quaternary Research Association, London, 13-20

Beckett, S C, 1975 *The Late Quaternary vegetation history of Holderness, Yorkshire*, unpubl PhD thesis, University of Hull

Beckett, S C, 1981 Pollen diagrams from Holderness, North Humberside, *Journal of Biogeography*, 8, 177-198

Berridge, N G, and Pattison, J, 1994 Geology of the country around Grimsby and Patrington, Memoir for 1:50,000 Geology sheets 90 and 91 and 81 and 82 (England and Wales*), Memoirs of the British Geological Survey*, HMSO, London

Bicket, A and Tizzard, L, 2015 A review of the submerged prehistory and palaeolandscapes of the British Isles, *Proceedings of the Geologists' Association*, 126 (6).

Bridgland, D R, and Thomas, G N, 1999 Kirmington, in D R Bridgland, B P Horton and J B Innes (eds), The Quaternary of North-East England Field Guide, *Quaternary Research Asso*ciation London, 180-84

Bridgland, D R, Howard, A, White, M, and White, T, 2014 *Quaternary of the Trent*, Oxbow

British Geological Survey (BGS), 2022 Geology of Britain viewer (classic) [Online] Available at: https://mapapps.bgs.ac.uk/geologyofbritain/home.html (accessed June 2022)

Buckland, P C, 1982 The coversands of North Lincolnshire and the Vale of York, in (eds) B H Adlam, C R Fenn and L Morris, *Papers in Earth Studies*, Geobooks, Norwich, 143-178

Buckland, P C, and Dolby, M J, 1973 Mesolithic and later material from Misterton Carr, Notts-an interim report, *Transactions of the Thornton Society of Nottinghamshire*, 17, 5-33

Buckland, P I, Bateman, M D, Bennike, O, Buckland, P C, Chase, B M, Frederick, C, Greenwood, M, Murton, J, Murton, D and Panagiotakopulu, E, 2019 Mid-Devensian climate and landscape

in England: new data from Finningly, South Yorkshire, Royal Society Research Article, accessed June 2022, published online https://royalsocietypublishing.org/doi/full/10.1098/rsos.190577
Burgess, A, and Daniel, P, 2018 Easington to Salt End: the archaeology of the Humber Gateway onshore cable route, *East Riding Archaeologist*, 17, 1-113

Burke, H F, Morgan, D J, Kessler, H and Cooper, A H, 2015 *A 3D geological model of the superficial deposits of the Holderness area*, British Geological Survey, Rep CR/09/122

Burke, H F, Ford, J R, Hughes, L, Thorpe, S and Lee, J R, 2017 *A 3D geological model of the superficial deposits in the Selby area*, British Geological Survey, Rep CR/17/112

Burchell, J P T, 1931 Palaeolithic implements from Kirmington, Lincolnshire, and their relation to the 100-foot raised beach of late Pleistocene times, *Antiquaries Journal*, 11, 262-72

Burchell, J P T, 1935 Some Pleistocene deposits at Kirmington and Crayford, *Geological Magazine*, 72, 327-31

Burgess, A and Daniel, P, 2018 Easington to Salt End – the Archaeology of the Humber Gateway Onshore Cable Route, in D H Evans (ed) *East Riding Archaeologist* 17, 1-113

Carrott, J, Hughes, P, Kenward, H and Large, F, 1997 *An evaluation of biological remains from excavation at Messingham, North Lincolnshire*, Reports from the Environmental Archaeology Unit, York, 97/48, 5

Catt, J A, 2007 The Pleistocene glaciations of eastern Yorkshire: a review, *Proceedings of the Yorkshire Geological Society*, 56, 177-207

Challis, K, 2002 *Component 3: Alluvium Depth and Character Modelling*, Trent Valley Geoarchaeology, York

Challis, K, Chris, C, Kincey, M, and Howard, A J, 2011 Assessing the preservation potential of temperate, lowland alluvial sediments using airborne LiDAR intensity, *Journal of Archaeological Science*, 38, 301-311

Chapman, H P and Gearey, B R, 2013 *Modelling archaeology and palaeoenvironments in wetlands: the hidden landscape archaeology of Hatfield and Thorne Moors, eastern England,* Oxbow Books, 1-205

Coles, B J, 1998 Doggerland: a speculative survey, *Proceedings of the Prehistoric Society*, 64, 45-81

Cooper, NJ, 2006 Cross-period research and the foundation of a research strategy, in The Archaeology of the East Midlands, 287-91, reproduced in *East Midlands research agenda: Overarching agenda themes* [Online] Available at: https://researchframeworks.org/emherf/research-agenda/overarching-agenda-themes/ (Accessed 14 July 2022)

Dinnin, M H, 1997a Introduction to the palaeoenvironmental survey, in Van de Noort, R and Ellis, S, (eds) *Wetland Heritage of the Humberhead Levels: an archaeological survey*, Humber Wetlands Project, University of Hull

Dinnin, M H, 1997b Holocene beetle assemblages from the Lower Trent floodplain at Bole Ings, Nottinghamshire, UK, in A C Ashworth, P C Buckland and J P Sadler (eds), Studies in Quaternary Entomology: an inordinate fondness for insects, *Quaternary Proceedings*, 5, 83-104

Dinnin, M H, and Brayshay, B, 1999 The contribution of a multiproxy approach in reconstructing floodplain development, in S B Marriott and J Alexander (eds)*, Floodplains: Interdisciplinary Approaches*, Geological Society of London Special Publication, 163, Bath, 179-95

Ellis, S, 1990 Soils, in S Ellis and D R Crowther (eds) *Humber perspectives: a region through the ages*, 29-42, Hull, Hull University Press

Evans, D H, 2016 Onshore cable route for the Westernmost Rough Offshore Windfarm (Tunstall to Salt End), *East Riding Archaeologist*, 15

Evans, D J A, Thomson, S A, and Clark, C D, 2001 The glacial history of East Yorkshire, in M D Bateman, P C Buckland, C D Frederick, and N J Whitehouse, (eds) 2001, The Quaternary of East Yorkshire and North Lincolnshire, Field Guide, *Quaternary Research Association*, 1-12

Eyles, N, McCabe, A M and Bowen, D Q, 1994 The stratigraphic and sedimentological significance of Late Devensian ice sheet surging in Holderness, Yorkshire, UK, *Quaternary Science Reviews*, 13, 727-759

Fairburn, W A, and Bateman, M 2016 A new multi-recessional model for Proglacial Lake Humber during the retreat of the last British-Irish Ice Sheet, *Boreas*, 45, 133-151

Farley, J, 2012 *At the edge of the empire: Iron Age and early Roman metalwork in the East Midlands*, unpubl PhD thesis, University of Leicester

Fleming, F and Royall, C, 2019, *The Inner Humber Estuary Rapid Coastal Zone Assessment: Aerial Investigation and Mapping Project*, Historic England Research Rep Series No 86

Fletcher, W and Van de Noort, R, 2007 The lake-dwellings in Holderness, East Yorkshire, revisited: a journey into antiquarian and contemporary wetland archaeology, in Scottish Wetlands Archaeology Programme (eds), *Archaeology from the Wetlands: Recent Perspective, Proceedings of the Eleventh WARP Conference*, Edinburgh 2005, WARP Occasional Paper 18, 313-21

Ford, J R, Kessler, H K, Price, S J, Hall, M and Cooper, A H, 2004 *Field guide to the glacial evolution of the Vale of York*, British Geological Survey, Rep IR/01/106

Frederick, C D, Buckland, P C, Bateman, M D and Owens, B, 2001 South Ferriby Cliff and Eastfield Farm, in M D Bateman, P C Buckland, C D Frederick, and N J Whitehouse, (eds) 2001, The Quaternary of East Yorkshire and North Lincolnshire, Field Guide, *Quaternary Research Association*, 25-34

Gale, S J and Hoare, P G, 2007 The glacial stratigraphy of lowland southern and eastern Britain: temperate stage deposits at Morston and Kirmington, *Proceedings of the Yorkshire Geological Society*, 56(1), 245-251

Gaunt, G D, 1974 A radiocarbon date relating to Lake Humber, *Proceedings of the Yorkshire Geologists' Association*, 40, 195-197

Gaunt, G D, 1975 The artificial nature of the River Don north of Thorne, *Yorkshire Archaeology Journal*, 47, 15-22

Gaunt, G D, 1981 Quaternary history of the southern part of the Vale of York, in J Neale and J Flenley (eds) *The Quaternary of Britain: Essays, reviews and original work on the Quaternary published in honour of Lewis Penny on his retirement*, 82-97, Pergamon Press

Gaunt, G D, 1987 The geology and landscape development of the region around Thorne Moors, *Thorne Moors Papers* 1, 6-30

Gaunt, G D, 1994 *Geology of the country around Goole, Doncaster and the Isle of Axholme. Memoir for one-inch sheets 79 and 88* (England and Wales), HMSO, London

Gaunt, G D, Buckland, P and Bateman, M, 2004 The geological background to the development and demise of a wetland – the Quaternary history of the Humberhead Levels*, Bulletin of the Yorkshire Naturalists' Union, Supplement Conference 2004 Proceedings*, 2006, **45**, 7-46

Gaunt, G D, Fletcher, T P, and Wood, C J, 1992 *Geology of the country around Kingston-upon-Hull and Brigg, Memoir for 1:50,000 Geology sheets 80 and 89* (England and Wales), HMSO, London

Gaunt, G D, and Tooley, M J, 1974 Evidence for Flandrian sea-level changes in the Humber Estuary and adjacent areas, *Bulletin of the Geological Survey of Great Britain*, **48**, 25-41

Gibbard, P L, and Hughes, P D, 2021 Terrestrial stratigraphic division in the Quaternary and its correlation, *Journal of the Geological Society*, **178**, 1-19

Gilbertson, D D, 1984, *Late Quaternary environments and man in Holderness*, British Archaeological reports (British Series), 134, Oxford

Glover, G, Flintoft, P, and Moore, R (eds), 2016 '*A mersshy contree called Holdernesse'. Excavations on the route of a National Grid pipeline in Holderness, East Yorkshire*, Oxford

Halkon, P, and Innes, J P, 2005 Settlement and economy in a changing prehistoric lowland landscape: an East Yorkshire example, *European Journal of Archaeology* **8(3)**, 225-259

Historic England, 2015 *Geoarchaeology. Using Earth Sciences to understand the archaeological record* [Online] Available at: https://historicengland.org.uk/images-books/publications/geoarchaeology-earth-sciences-to-understand-archaeological-record/. (Accessed 16 August 2022)

Historic England, 2020 *Deposit Modelling and archaeology: Guidance for mapping buried deposits* [Online] Available at: https://historicengland.org.uk/images-books/publications/deposit-modelling-and-archaeology/. (Accessed 16 August 2022).

Headland Archaeology, 2013 Keadby Wind Farm, North Lincolnshire, *Report on trial trench evaluation of upper peat deposits and coring programme*, unpubl rep, Headland Archaeology Ltd

Headland Archaeology 2018 Keadby II Combined Cycle Gas Turbine (CCGT) Power Station, North Lincolnshire, *Palaeoenvironmental Assessment Report*, unpubl rep, Headland Archaeology Ltd

Hunt, C O, Hall, A R, and Gilbertson, D D, 1984, The palaeobotany of the Late Devensian sequence at Skipsea Withow Mere, in D D Gilbertson(ed) *Late Quaternary environments and man in Holderness*, British Archaeological reports (British Series), 81-108, Oxford

Hosfield, R, Green, C, Fluck, H, and Batchelor, R, 2017 *Curating the Palaeolithic: Guidance* (Consultation Draft), University of Reading, Reading

Howard, A J, 2004 Geoarchaeological analysis, in Elliott 2004, Archaeological evaluation at Sturton le Steeple, Nottinghamshire, Nottingham, Trent and Peak Archaeological Unit, unpubl rep

Howard, A J, 2005 The contribution of Geoarchaeology to understanding the environmental history of the Trent Valley, UK, *Geoarchaeology*, 20, 93-107

Howard, A J, 2020 Updated period resource assessment: the palaeolithic period (updating J McNabb 2006), *East Midlands Historic Environment Research Framework*, [Online] Available at: https://researchframeworks.org/emherf/updated-period-resource-assessment-the-palaeolithic-period/ (Accessed 25 June 2022)

Howard, A J, Brown, A G, Carey, C, Challis, K, Cooper, L P, Kincey, M, and Toms, P, 2008 Archaeological resource modelling in temperate rivers: a case study from the Trent Valley, UK, *Antiquity*, 82, 1040-1054

Howard, A J, Carney, J, Greenwood, M, Keen, D, Mighall, T, O'Brien, C and Tetlow, E, 2011 The Holme Pierrepont sand and gravel and the timing of Middle and Late Devensian aggradation in the English Midlands, *Proceedings of the Geologists' Association*, 122, 419-431

Humber Field Archaeology (HFA), 2006 *Archaeological excavations on land at Immingham Combined Heat and Power plant, Killingholme, North Lincolnshire*, Unpubl rep

Jones, R L, and Gaunt, G D, 1976 A dated Late Devensian organic deposit at Cawood, near Selby, *The Naturalist*, 121-123

Kirby, J R, 1999 *Holocene floodplain vegetation dynamics and sea-level change in the lower Aire Valley, Yorkshire*, unpubl PhD thesis, University of Durham

Kirby, J R, 2001 Regional Late Quaternary marine and perimarine record, in M D Bateman, P C Buckland, C D Frederick, and N J Whitehouse, (eds) 2001, The Quaternary of East Yorkshire and North Lincolnshire, Field Guide, *Quaternary Research Association*, 25-34

Knight, D, and Howard, A J, 2004 *Trent Valley Landscapes*, Heritage: Kings Lynn

Le Quesne, C, 2015 Keadby II Power Station, *Historic Desk-based Assessment*, unpubl rep, Environmental Resources Management

Long, A J, Innes, J B, Kirby, J, Lloyd, J M, Rutherford, M M, Shennan, I, and Tooley, M J, 1998 Holocene sea-level change and coastal evolution in the Humber Estuary, eastern England: an assessment of rapid coastal change, *The Holocene,* 8, 229-247

Malone, S, and Williams, M (eds), 2010 *Rumours of Roman finds: recent work on Roman Lincolnshire*, Heckington,

McGrail, S, 1990 *Early boats of the Humber*, in S Ellis and D R Crowther (eds), Humber perspectives: a region through the ages, Hull University Press, Hull, 109-130

Metcalfe, S E, Ellis, S, Horton, B P, Innes, J B, McArthur, J, Mitlehner, A, Parkes, A, Pethick, J S, Rees, J, Ridgway, J, Rutherford, M M, Shennan, I, and Tooley, M J, 2000 The Holocene evolution of the Humber Estuary: reconstructing change in a dynamic environment, in *Holocene Land-Ocean Interaction and Environmental Change around the North Sea* (eds I Shennan and J Andrews), Geological Society London Special Publications 166, 97-118

Northern Archaeological Associates, 2000, *Humber Link Pipeline Project, Site 526, East Halton, Skitter*, unpubl doc

OA North, 2012 *Easington to Paull Natural Gas Pipeline, East Yorkshire: post-excavation assessment of archaeological fieldwork results*, unpubl doc

OA North 2016 *Feeder No. 9 River Humber Pipeline Replacement, Goxhill, Lincolnshire, Archaeological Evaluation,* unpubl rep

OA North 2017 *River Humber Gas Pipeline Replacement Project, Paull, East Yorkshire, Project Design for Archaeological Investigation*, unpubl doc

OA North, 2021 *River Humber Gas Pipeline Replacement Project, Paull, East Yorkshire: archaeological trial trenching, watching brief, and palaeoenvironmental coring report*, Unpubl rep

OA North 2022 *River Humber Gas Pipeline Replacement Project, Goxhill, North Lincolnshire, post-excavation assessment report*, unpubl doc

Penny, L, Coope, G R and Catt, J A, 1969 Age and insect fauna of the Dimlington Silts, East Yorkshire, *Nature*, *224*, 65-67

Pettitt, P, 2018 South Yorkshire Historic Environment Research Framework, accessed 6 June 2022, https://researchframework.org/syrf/palaeolithic/

Rackham, J, Giorgi, J, and Scaife, R, 2011 Palaeoenvironmental study of the sediments at 14/9, Paull Holme and 15/1, Cow Hill, Easington to Paull Natural Gas Pipeline, *The Environmental Archaeology Consultancy Report*, unpubl report

Research Frameworks, 2022 *The East Midlands Historic Environment Research Framework,* [Online] Available at: https://researchframeworks.org/emherf/ (Accessed 14 July 2022)

Savage, R, 2013 Salt End to Aldborough: the archaeology of a high voltage underground electricity cable route, *East Riding Archaeologist*, 14, 65-104

Shennan, I, Lambeck, K, Horton, B P, Innes, J, B, McArthur, J, Lloyd, J and Rutherford, M M, 2000a Holocene isostasy and relative sea-level changes on the east coast of England, in I Shennan and J E Andrews (eds) *Holocene Land-Ocean Interaction and environmental change around the North Sea,* Geological Society Special Publication, 166, 275-298

Shennan, I, Lambeck, K, Flather, R, Horton, B P, Innes, J, B, McArthur, J, Lloyd, J, Rutherford, M M, and Wingfield, R 2000b Modelling western North Sea palaeogeographies and tidal changes during the Holocene, in I Shennan and J E Andrews (eds) *Holocene Land-Ocean Interaction and environmental change around the North Sea,* Geological Society Special Publication, 166, 299-319

SSE Thermal 2021 Land at and in the vicinity of the Keadby Power Station site, Trentside, Keadby, North Lincolnshire, Environmental Statement vol 11 – Appendix 15A, Cultural Heritage Desk Based Assessment, Aecom Rep, published online, accessed June 2022, https://www.ssethermal.com/media/pkajudjx/k3-document-6-3-29-es-appendix-15a-cultural-heritage-desk-based-assessment.pdf

Straw, A, 2018 Geomorphology of the Kirmington interglacial deposits and the Immingham Channel, north Lincolnshire, *Mercian Geologist* 19 (3), 133-140

Straw, A, 2019 A case for MIS 4 Glaciation of eastern England, *Mercian Geologist*, 19(4), 207-215

Thomson, S A, and Evans, D J A, 2001, Gembling, in Bateman, M D, Buckland, P C, Frederick, C D and Whitehouse, N J, (eds) 2001, The Quaternary of East Yorkshire and North Lincolnshire, Field Guide, *Quaternary Research Association*, 73-82

Timpany, S, 2012 *Palaeoenvironmental report on the results of the gouge auger sediment survey, Keadby Wind Farm, North Lincolnshire*, Headland Archaeology Ltd., report for SSE Renewables

Trent and Peak Archaeology 2021 Keadby 3 Low Carbon Gas Power Station, Lincolnshire, Land at and in the vicinity of the Keadby Power Station site, Trentside, Keadby, North Lincolnshire, Environmental Statement vol 11 – Appendix 15B, Geoarchaeological Hand Auger Survey Fieldwork Report, Trent and Peak Archaeology Rep 47/2021

Turner, R C, and Scaife, R G (eds) 1995 *Bog bodies: new discoveries and new perspectives*, London, British Museum Press

Tweddle, J C, 2000 A *high resolution palynological study of the Holocene vegetational development of central Holderness, eastern Yorkshire, with particular emphasis on the detection of prehistoric human activity*, unpubl PhD thesis, University of Sheffield

Tweddle, J C, 2001 Regional Vegetation History, in M D Bateman *et al* (eds) *The Quaternary of East Yorkshire and North Lincolnshire Field Guide,* Quaternary Research Association, London, 35-46

Van de Noort, R, and Ellis, S, 1995 *Wetland Heritage of Holderness: an archaeological survey*, Humber Wetlands Project, University of Hull

Van de Noort, R and Ellis, S, 1997 *Wetland Heritage of the Humberhead Levels: an archaeological survey*, Humber Wetlands Project, University of Hull

Van de Noort, R and Ellis, S, 1998 *Wetland Heritage of the Ancholme and Lower River Trent Valleys: an archaeological survey*, Humber Wetlands Project, University of Hull

Van de Noort, R and Ellis, S, 1999 *Wetland Heritage of the Vale of York: an archaeological survey*, Humber Wetlands Project, University of Hull

Walker, M J C, *2005 Quaternary Dating Methods*, Wiley, Chichester

Walker, M J C, Cooper, G R, and Lowe, J J, 1993 The Devensian (Weichselian) Lateglacial palaeoenvironmental record from Gransmoor, East Yorkshire, England, *Quaternary Science Reviews*, 12, 659-680

Watts, W, 1959 Pollen spectra from the Interglacial deposits at Kirmington, Lincolnshire, *Proceedings of the Yorkshire Geologists' Association*, 32, 145-152

West Yorkshire Archaeology Advisory Service (WYAAS) 2016 *Revised Report on the Enhancement of the West Yorkshire Historic Environment Record for the Palaeolithic and Mesolithic Periods*, Historic England Project 6619

White, M J, 1999 Comment on the Kirmington Artefacts, in D R Bridgland, B P Horton and J B Innes (eds), The Quaternary of North-East England Field Guide, *Quaternary Research Association*, London, 185

Whittaker, S, 2001 Display: Pleistocene bones and shells from the Kelsey Hill Gravels, in *Abstracts from the Pleistocene world*, meeting 13th October, 2001, Humberside Geologist online, http://www.hullgeolsoc.co.uk/hgabs141.htm

York Archaeological Trust, 2022 *The Keadby 3 Carbon Capture Power Station Project: Interim report on archaeological investigation and recording*, Rep No YA/2022/063

Zant, J, and Gregory, R, forthcoming *Feeder 9 Natural Gas Pipeline, Paull, East Yorkshire, and Goxhill, North Lincolnshire*

Zant, J, and Howard-Davis, C, in prep *Easington to Paull natural gas pipeline*

APPENDIX A BOREHOLE DATA

Holderness

Borehole Reference Number	Depth (m) (total)	Deposit
TA12NE37 - Paull	13.9	Made ground, alluvium, peat, alluvium, glacial
TA12NE39 - Paull	8.7	Made ground, peat, alluvium, glacial
TA12NE48 - Paull	7.9	Made ground, alluvium, glacial
TA12NE51 - Paull	9	Made ground, alluvium, glacial
OA North (Paull boreholes)	15	Alluvium, peat, alluvium, peat, glacial

Summary list of historical borehole data available near Paull, Holderness.

Humber Estuary

Borehole Reference Number	Depth (m) (total)	Deposit
TA12SE11	46.79	Alluvium, bedrock
TA12SE12	46.33	Alluvium, bedrock
TA12SE13	52.43	Alluvium, bedrock
TA12NE33/B	52.73	Alluvium, bedrock
TA12NE33/C	56.69	Alluvium, bedrock
TA12SW82/A	46.33	Alluvium, bedrock
TA12SW82/B	52.43	Alluvium, peat, alluvium, bedrock
OA North (Goxhill boreholes)	12	Alluvium, peat, alluvium

Summary list of historical borehole data available for the Humber crossing of the HLCP.

Trent and Ancholme valleys

Borehole Reference Number	Depth (m) (total)	Deposit
SE80NE21	12.19	Topsoil, alluvium, peat, alluvium, bedrock
SE80NE22	10.67	Topsoil, alluvium, bedrock
SE80NE23	10.06	Topsoil, alluvium with peat, bedrock
SE80NE24	9.75	Topsoil, alluvium, bedrock
SE80NE82	11.2	Topsoil, peaty alluvium, alluvium, bedrock
SE80NE83	11.8	Alluvium, bedrock
SE80NE218	21.35	Topsoil, bedrock
SE80NE219	8	Topsoil, bedrock
SE80NW27	16	Topsoil, alluvium, peat, alluvium, bedrock
SE80NW34	23.16	Topsoil, alluvium, peat, alluvium, bedrock
SE80NW35	24.99	Topsoil, alluvium, bedrock
SE80NW39	12.19	Made ground, peat, alluvium, bedrock
SE80NW44	10.06	Topsoil, alluvium, peat, alluvium
SE80NW46	12.19	Topsoil, alluvium with peat, peat, alluvium, bedrock
SE80NW58	21.95	Alluvium with peat, alluvium, bedrock
SE90NW462	2.40	Topsoil, alluvium, peat, alluvium

Borehole Reference Number	Depth (m) (total)	Deposit
SE90NW464	2.25	Topsoil, alluvium, peat, alluvium
SE90NW473	2	Topsoil, alluvium
SE90NW474	2.25	Topsoil, alluvium, peat, alluvium
SE90NW476	0.75	Topsoil, bedrock
TA11SW112	6.1	Topsoil, alluvium, bedrock
TA11SW114	10.1	Made Ground, alluvium, bedrock
TA10NW6/B	30.48	Topsoil, alluvium, bedrock
TA00NW30	30.48	Alluvium, bedrock

Summary list of historical borehole data available for the Trent and Ancholme areas.

Humberhead Levels/Vale of York

Borehole Reference Number	Depth (m) (total)	Deposit
SE62NE203	5	Topsoil, alluvium
SE62NE204	5	Topsoil, alluvium
SE62NE205	5	Topsoil, alluvium
SE62NE206	3	Topsoil, alluvium
SE62NE207	3	Topsoil, alluvium
SE62NE208	3	Topsoil, alluvium
SE62NE209	3	Topsoil, alluvium
SE62NE210	3	Topsoil, alluvium
SE62NE211	3	Topsoil, alluvium
SE62NE212	3	Topsoil, alluvium
SE62NE213	5	Topsoil, alluvium
SE62NE214	5	Topsoil, alluvium
SE62NE216	2	Topsoil, alluvium
SE62NE228	3.75	Topsoil, alluvium
SE62NE229	2.9	Topsoil, alluvium
SE62NE123	23.39	Topsoil, alluvium, bedrock
SE62NE124	35.05	Made ground, alluvium, bedrock
SE62NE128	25.3	Topsoil, alluvium, bedrock
SE62NE129	25.91	Alluvium, bedrock
SE62NE130	24	Topsoil, alluvium, peat, alluvium, bedrock
SE62NE139	24.08	Topsoil, alluvium, bedrock
SE62NE142	24.38	Topsoil, alluvium, bedrock
SE72SW6/A	7.92	Topsoil, alluvium, peat, alluvium, bedrock

Summary list of historical borehole data available for the area of Humberhead/Vale of York portion of the HLCP. Note insufficient data from shallow interventions.

APPENDIX B SITE SUMMARY DETAILS

Site name:	Humber Low Carbon Pipeline
Grid Reference	---
Type:	Desk-based Geoarchaeology Assessment
Area of Site	120 km
Location of archive:	The archive is currently held at OA, Mill 3, Moor Lane Mills, Moor Lane, Lancaster, LA1 1QD.

Summary of Results: The HLCP is a Nationally Significant Infrastructure Project (NSIP)as set out in the *Planning Act* 2008, comprising the construction of dual pipelines to transport carbon dioxide (to facilitate carbon capture, usage and storage (CCUS)) and hydrogen, together with associated above ground installations (AGIs). The Project stretches for *c* 120km from Easington in eastern Holderness, across the Humber Estuary, parts of the Lincolnshire Wolds, the Ancholme valley, Lincoln Edge, the lower Trent Valley, the Humberhead Levels and the lower Vale of York (Drax, North Yorkshire).

The broader area, within which several river valleys are located, is known for its rich floodplain archaeology, with evidence of fish traps, log boats, rafts, historical mills and bridges, all recovered from postglacial sand and gravel deposits, sealed beneath thick fine-grained alluvium. Low-lying broad river valleys, which provide access to riverine resources, have previously produced evidence of both ritual and settlement activity.

The geoarchaeological assessment has shown that there is scope across the area for potential preservation of pre-Devensian and Devensian (Palaeolithic) deposits as well as post-glacial and Holocene (Mesolithic to Post-Medieval) deposits. Previous historical borehole data are available, but sparse, across the site and are of some value, for example, in the lower Trent area. Other borehole data are of little value, as the data lack specific criteria such as altitude records and do not discriminate superficial deposits where identified. The better-quality data could contribute to development of a deposit model for the area; however, further data should be obtained from project specific ground interventions, and consideration given to positioning interventions in areas likely to yield geoarchaeological information.

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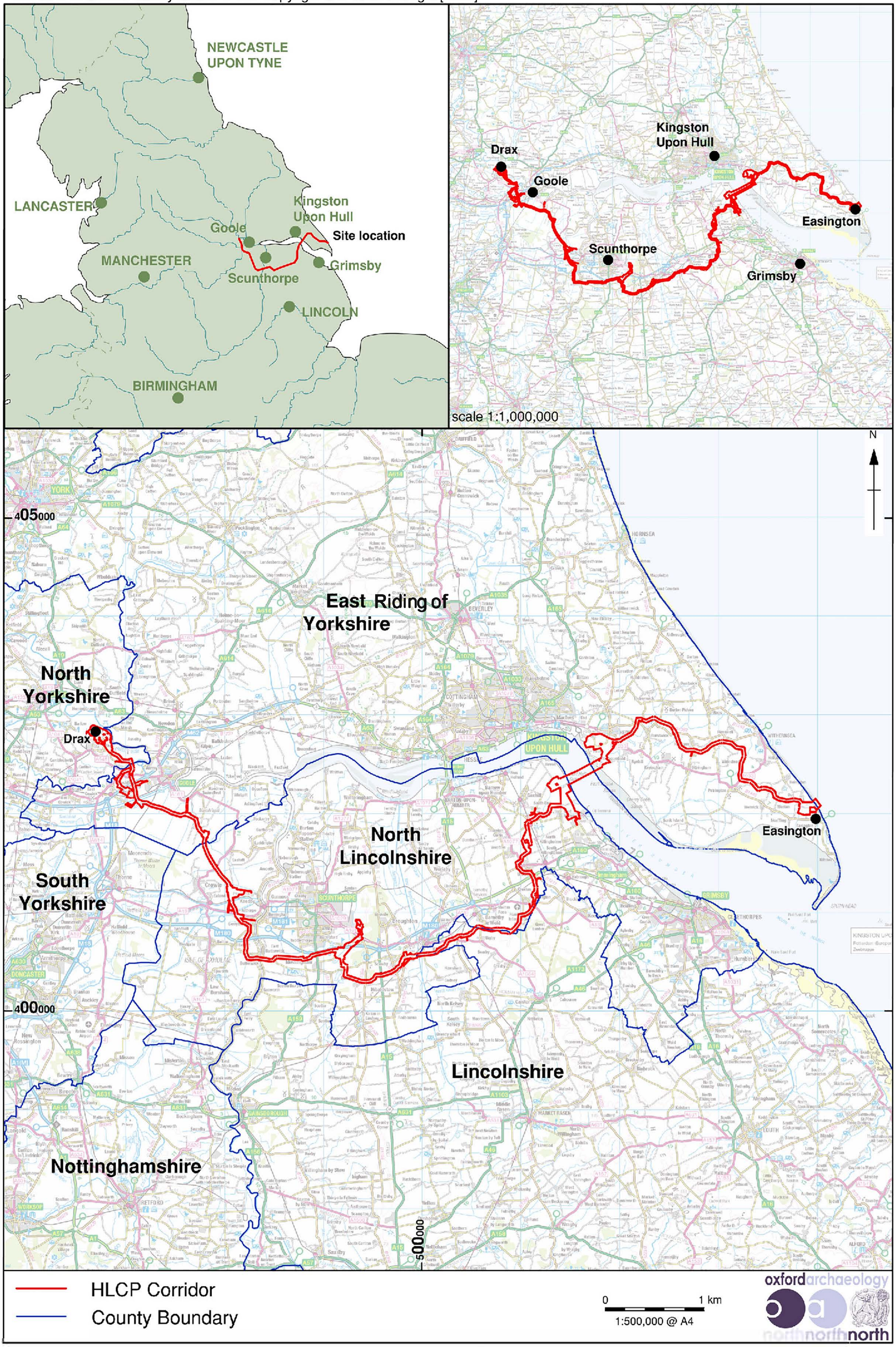

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Figure 1: Site location

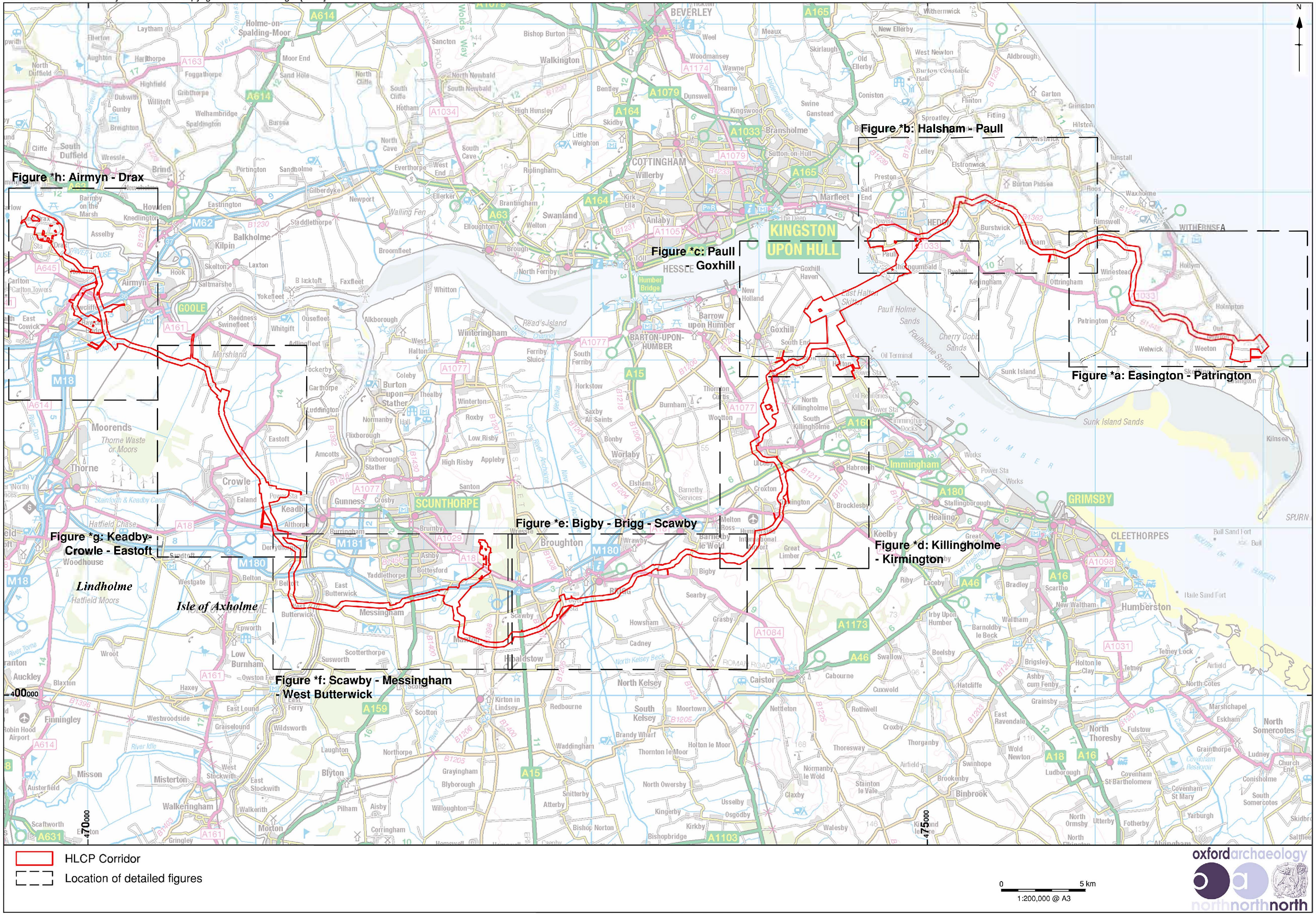

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Figure 2: Location of detailed figures

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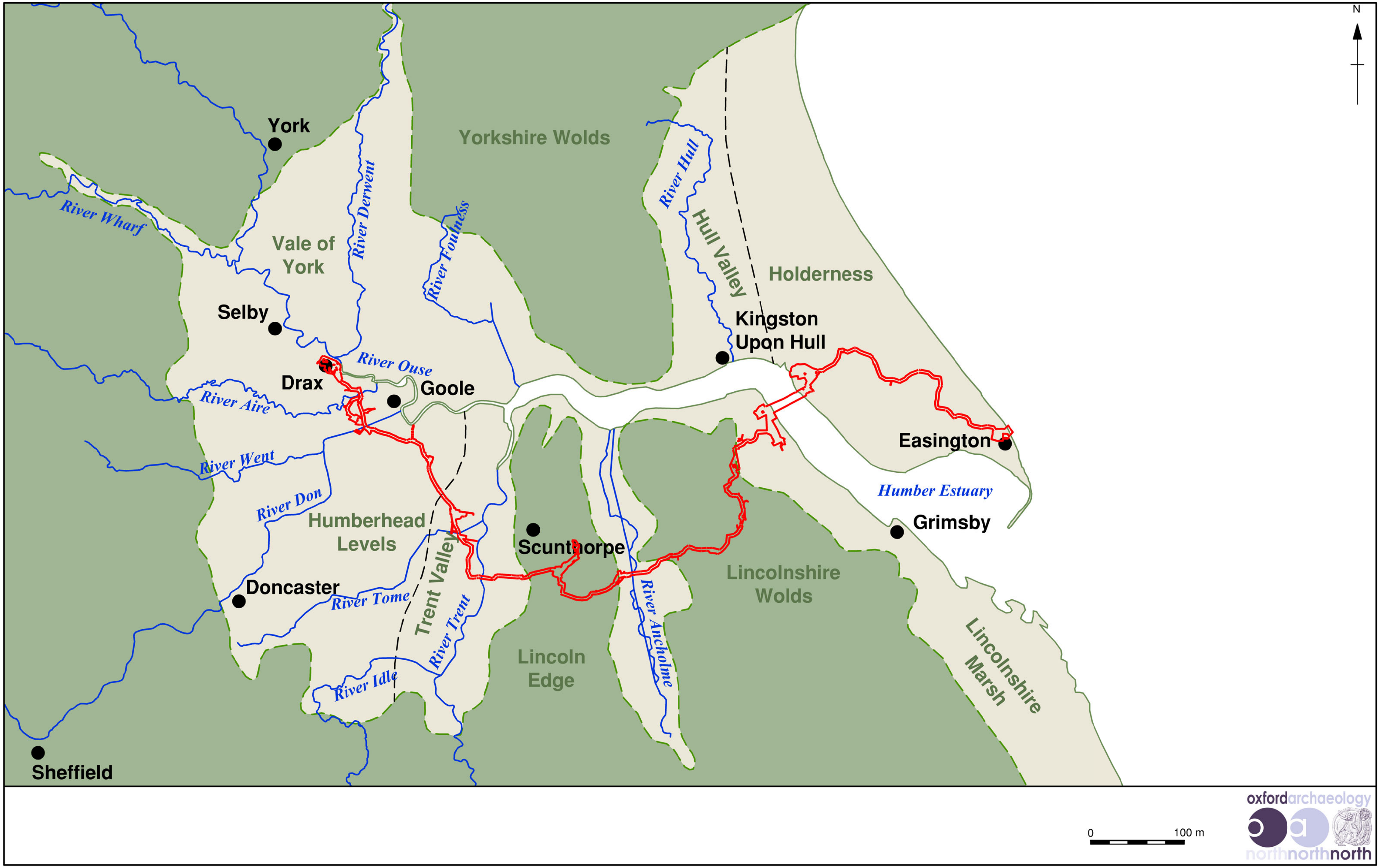

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Figure 3: Topographical regions traversed by and surrounding HLCP

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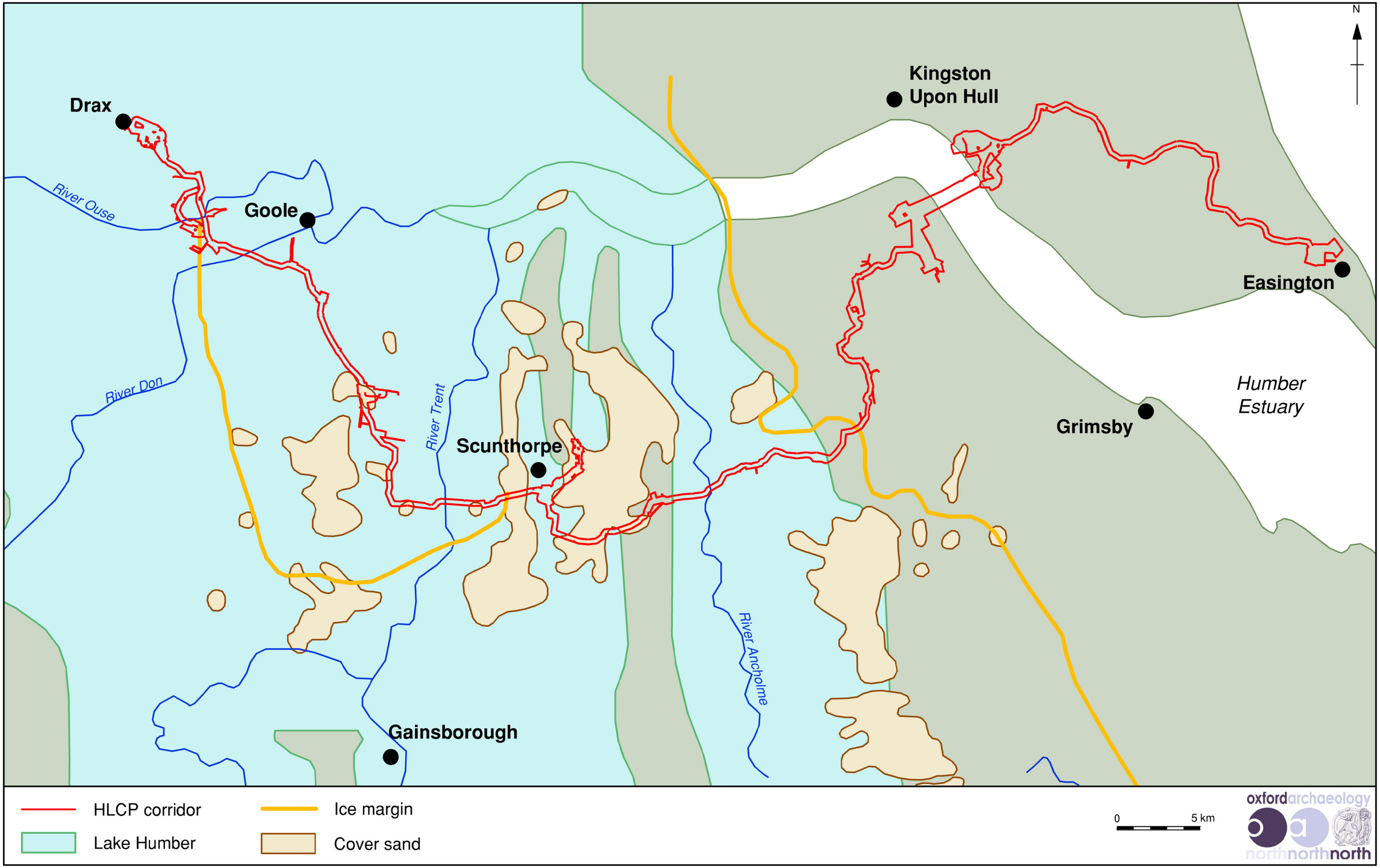

Figure 4: Extent of Proglacial Lake Humber and Devensian ice margins (re-drawn afer Buckland et al 2019; Bateman *et al* 2015)

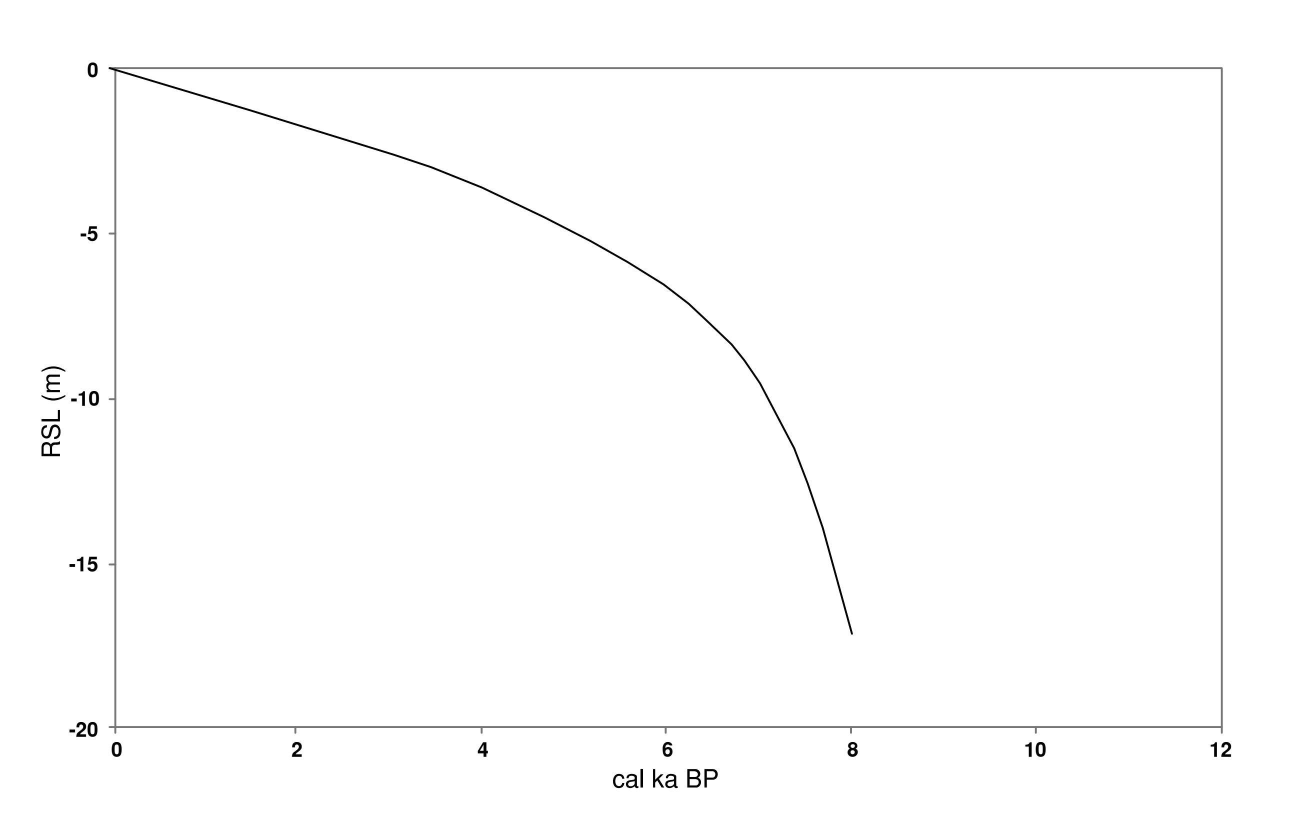

Figure 5: Humber Estuary relative sea-level curve, based on index points (re-drawn after Shennan *et al* 2000a). Index point errors are not shown but are available in the original publication.

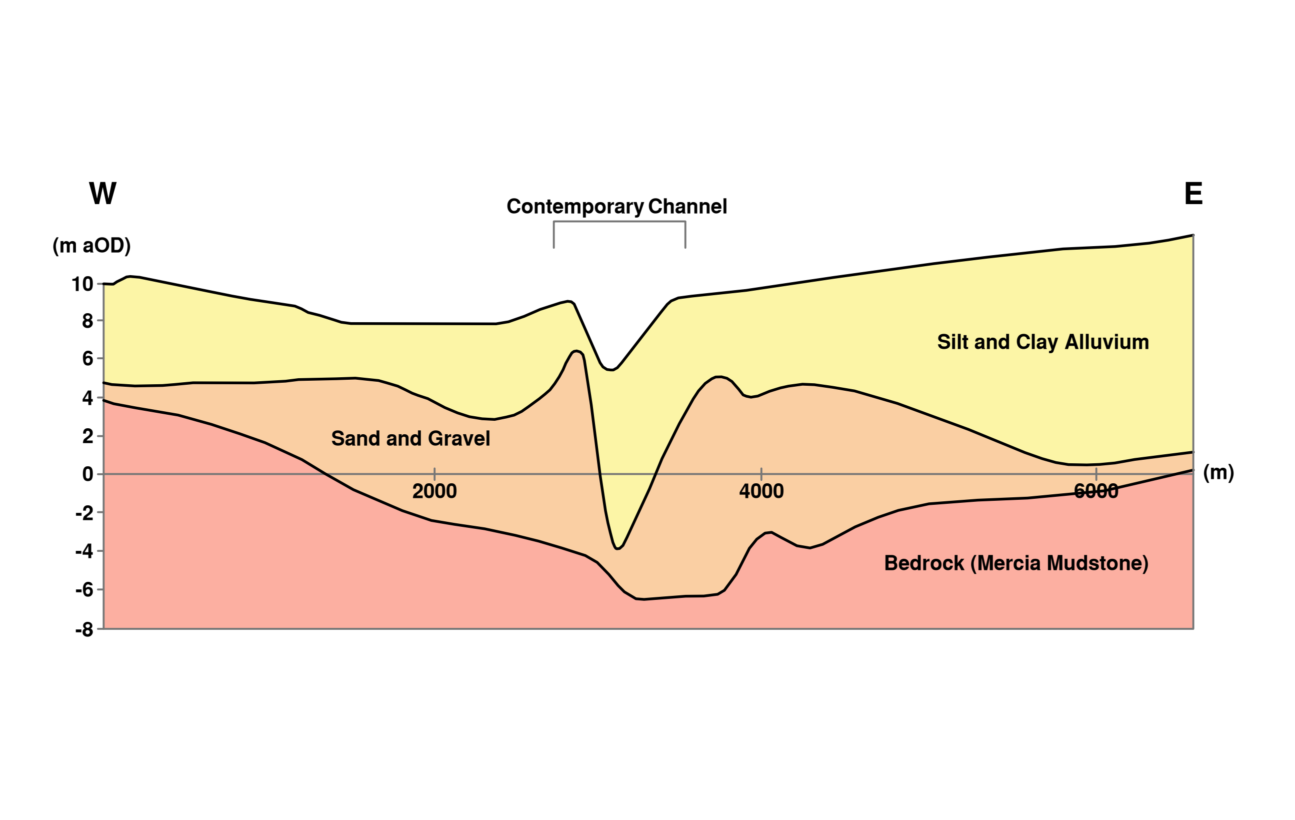

Figure 6: Profile through the alluvial deposits of the Lower Trent Valley, modelled by the sub-surface digital elevation model (DEM), re-drawn after Challis (2000)

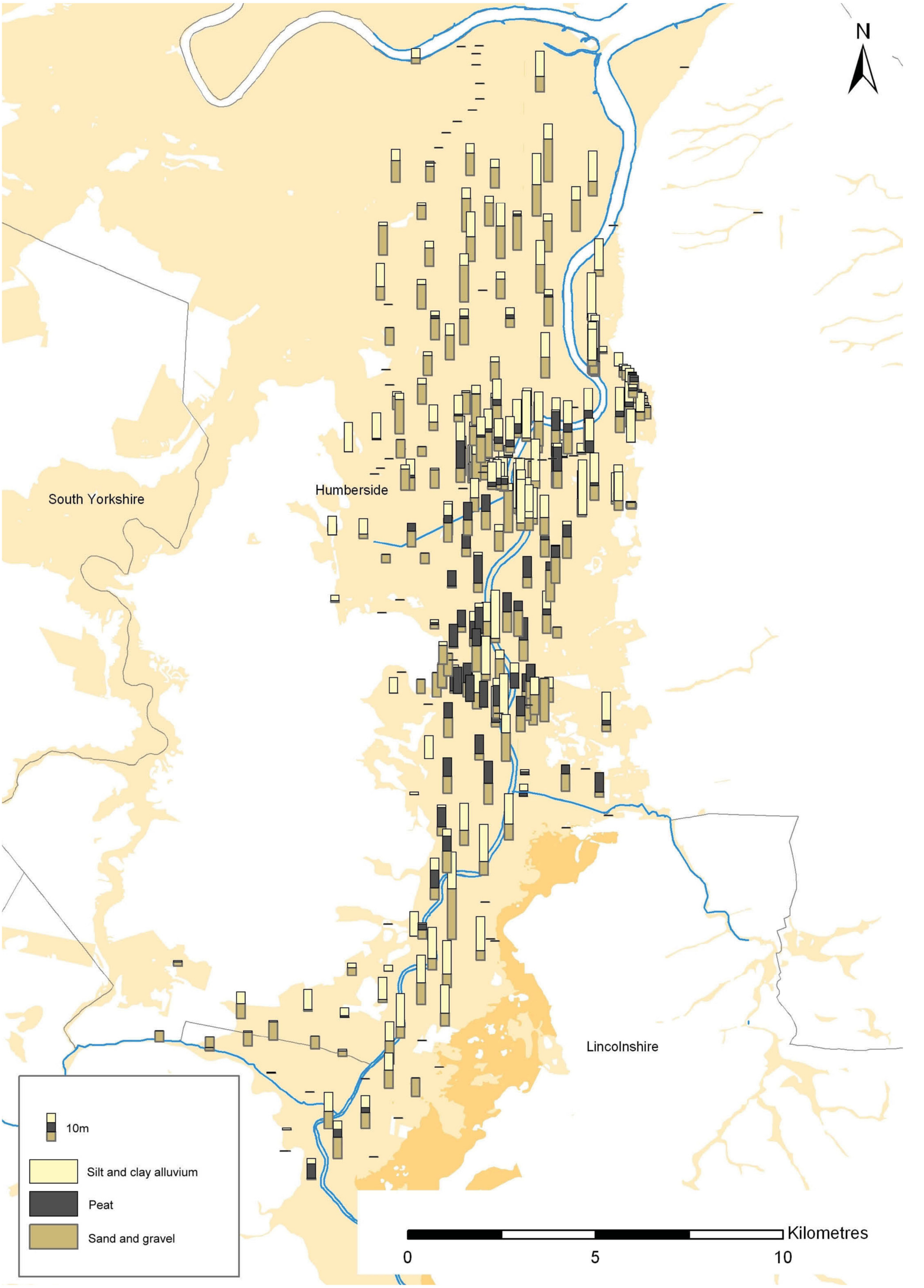

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Figure 7: Borehole records across the River Trent (Challis 2000)

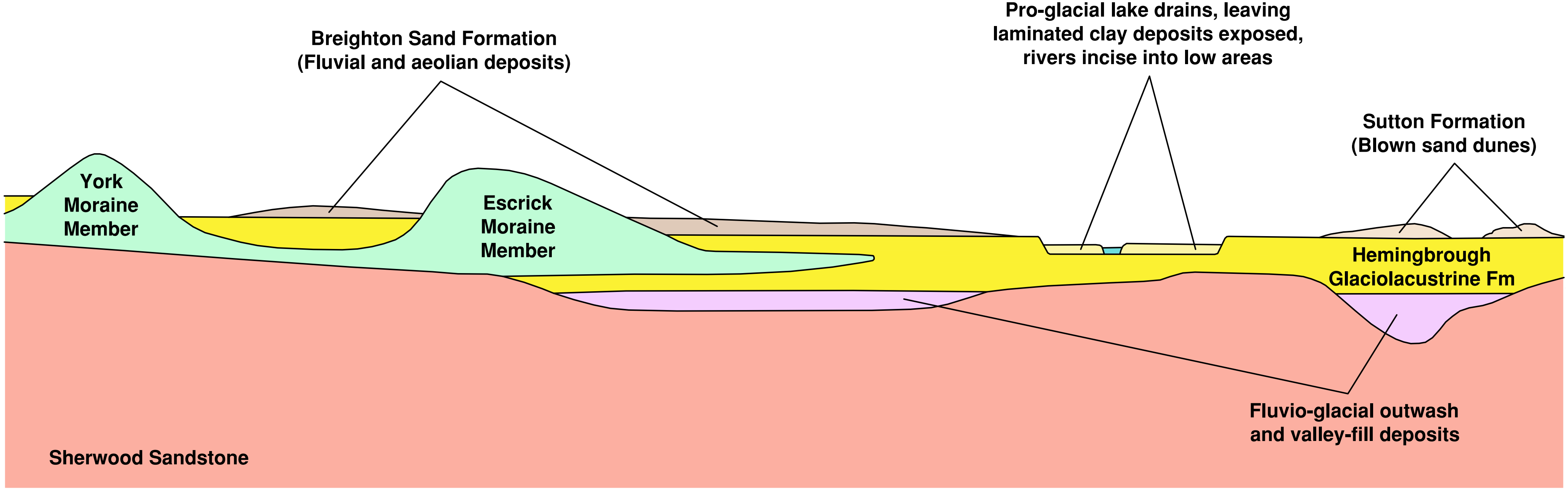
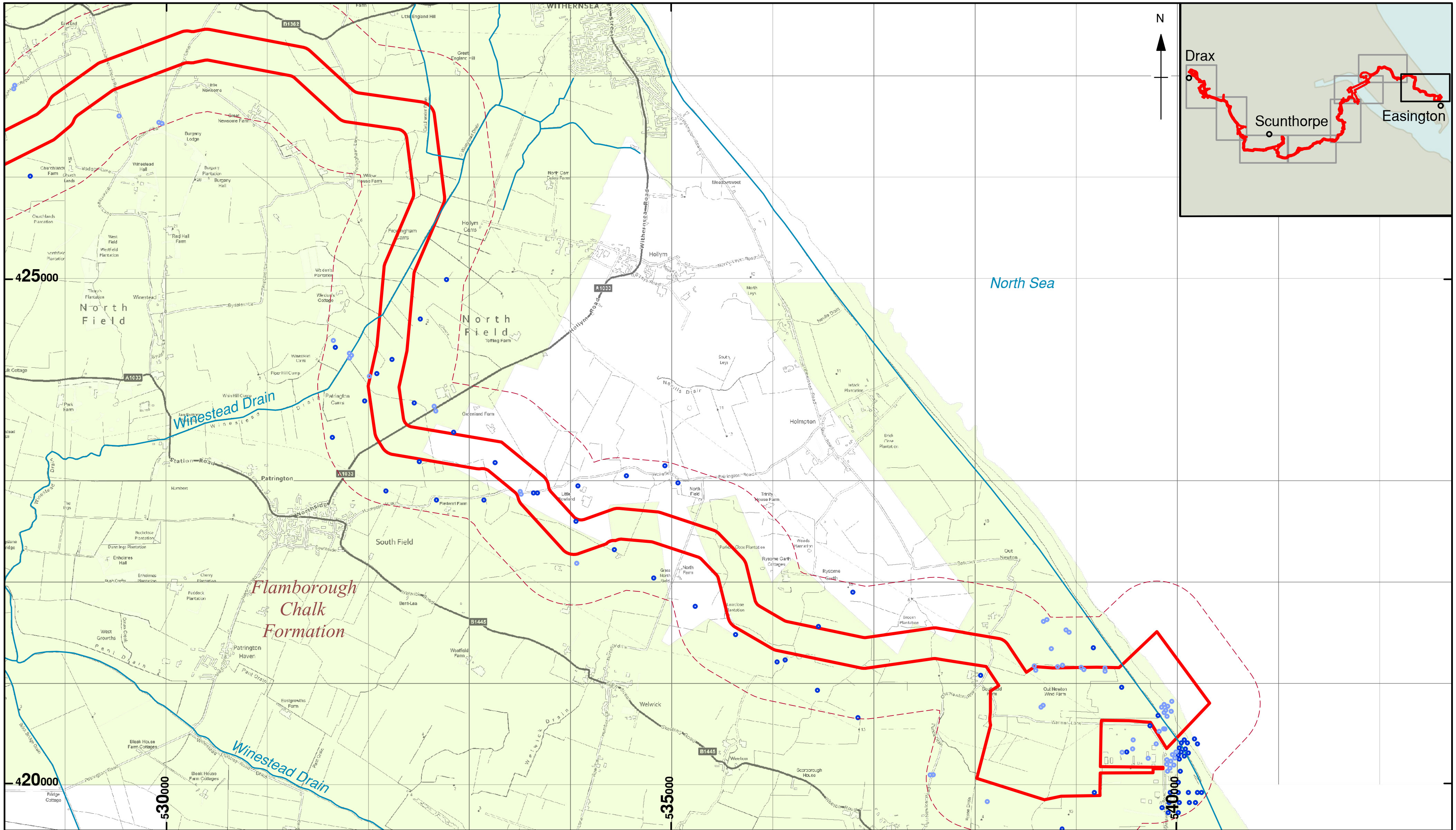


Figure 8: Glacial evolution of the Vale of York, re-drawn after Ford *et al* (2004).



HLCP Corridor
500m Buffer
BGS Borehole (publicly available)
BGS Borehole (confidential)

0 1 km
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Figure 9a: Eastern Holderness, Easington - Patrington, Solid geology and BGS borehole locations

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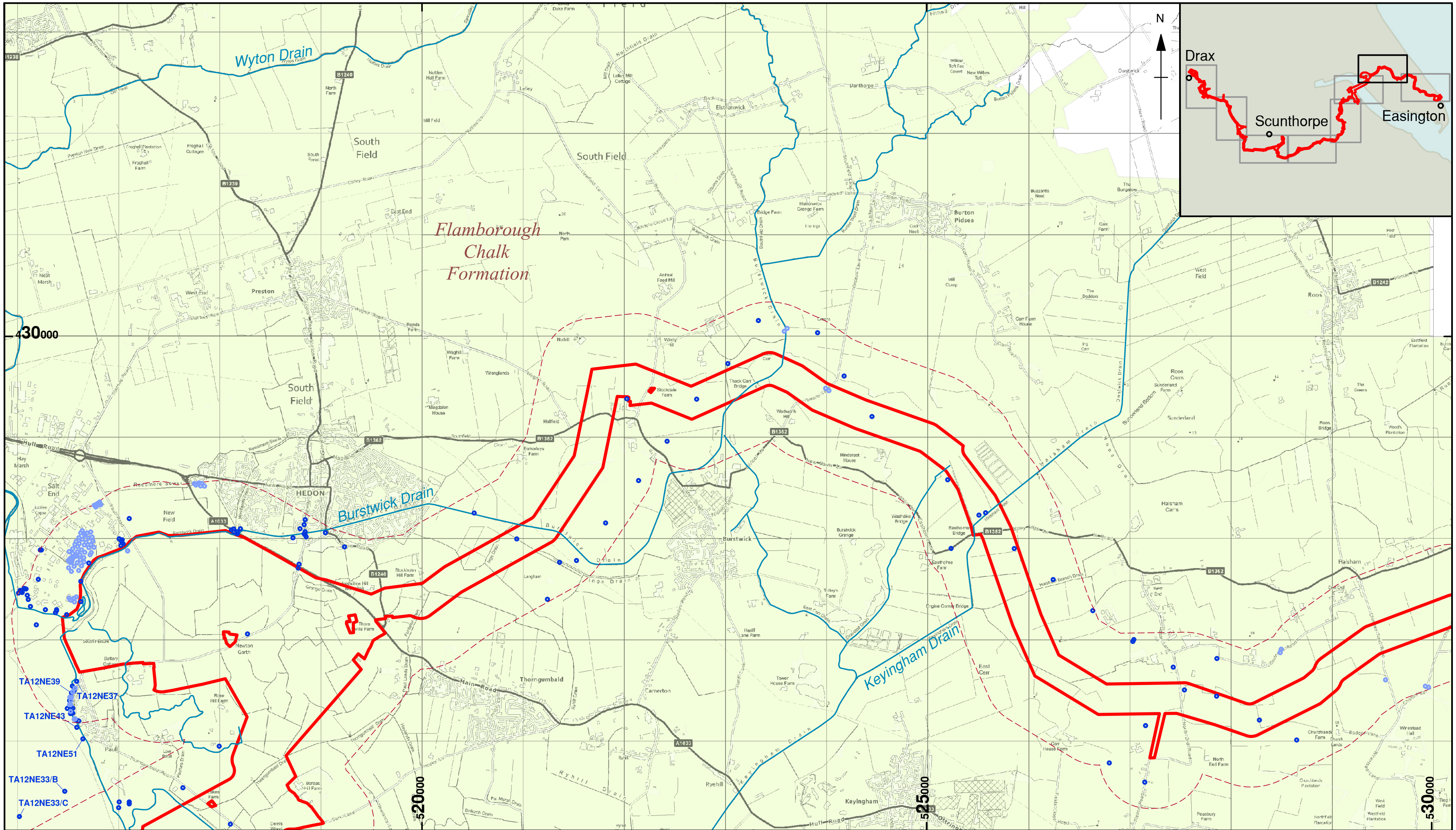

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Figure 9b: Western Holderness; Halsham - Paull, Solid geology and BGS borehole locations

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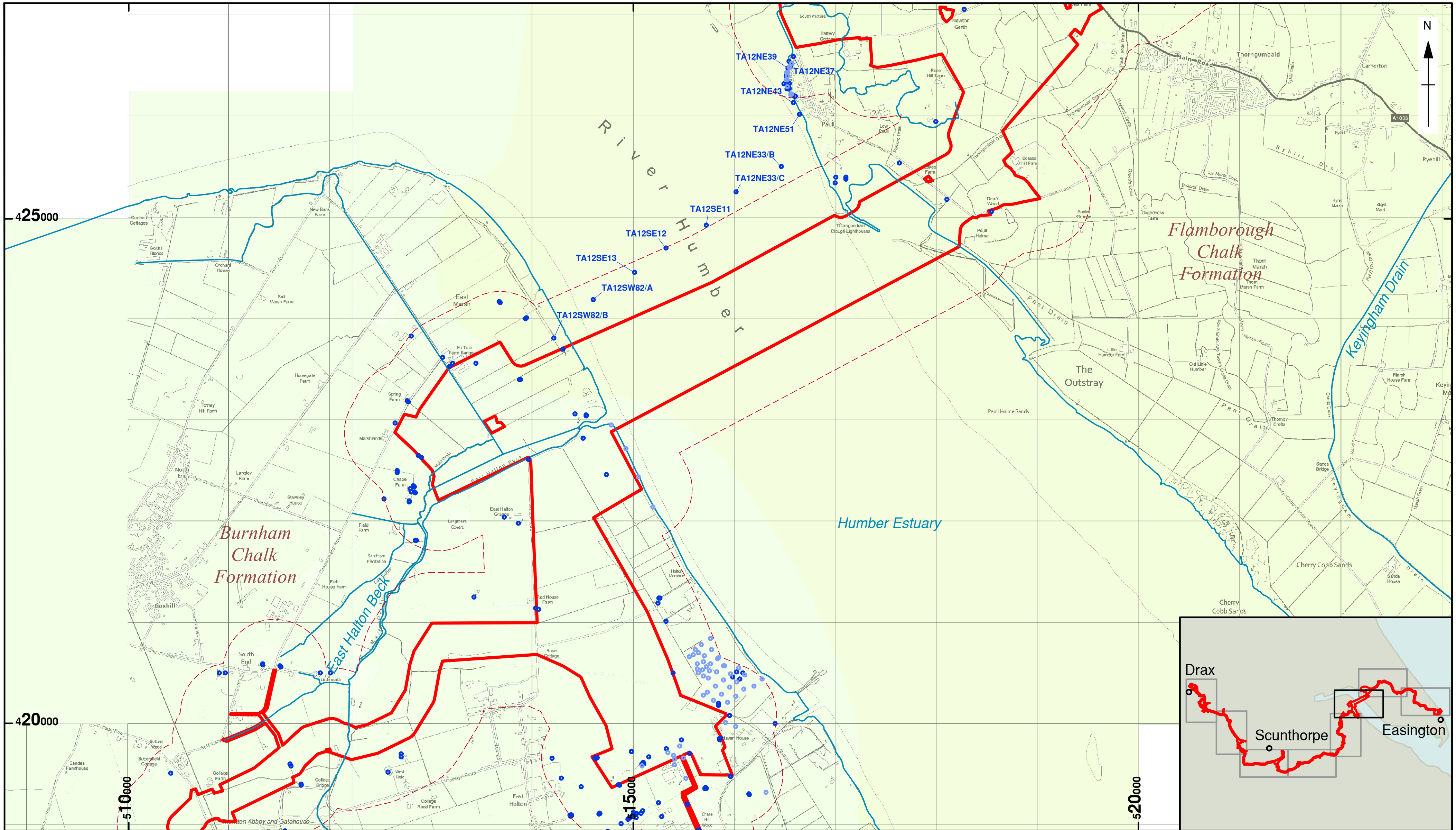

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Figure 9c: Humber Estuary; Paull - Goxhill, Solid geology and BGS borehole locations

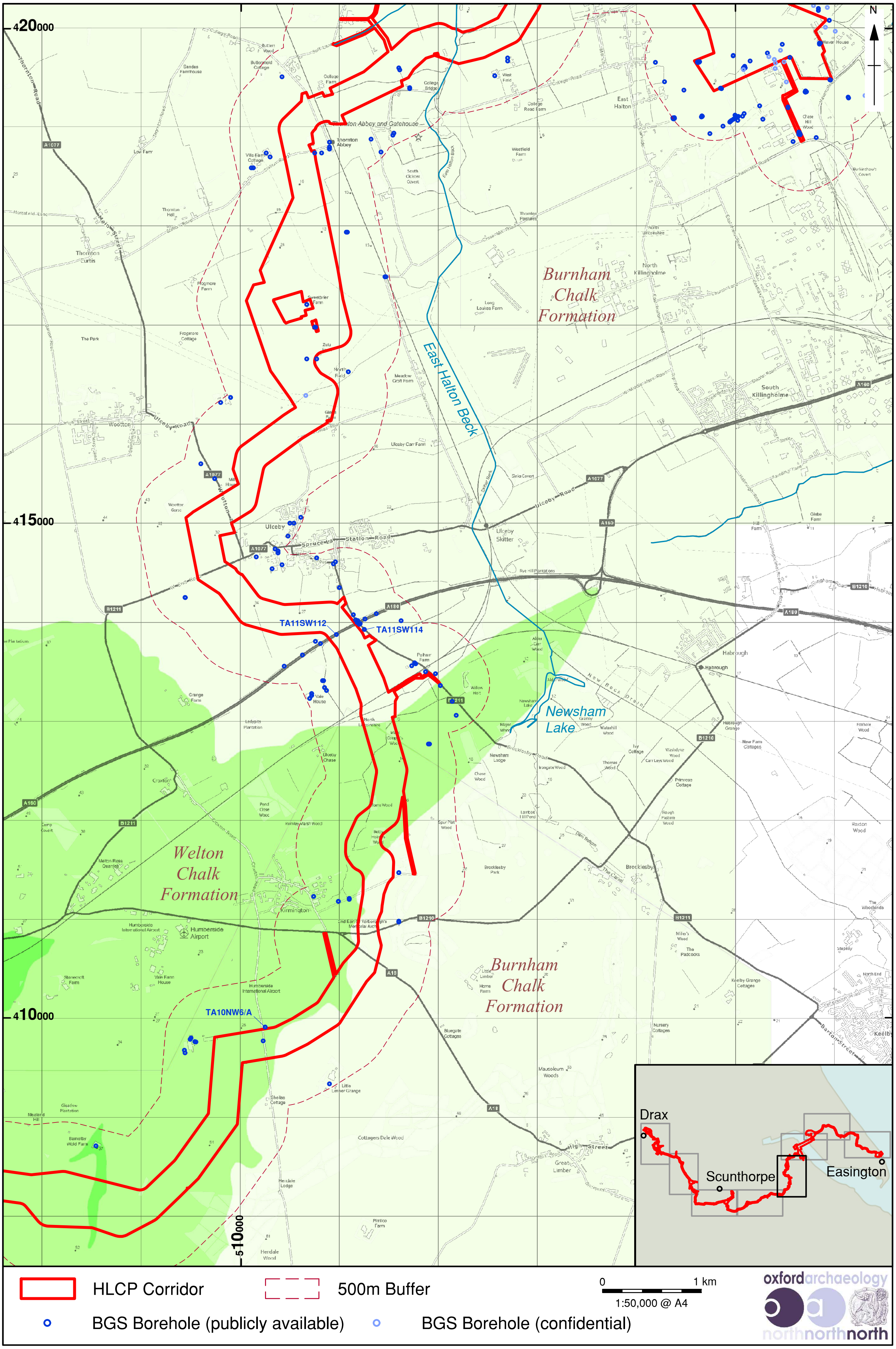

Figure 9d: Lincolnshire Wolds (part); Killingholme - Kirmington, Solid geology and BGS borehole locations

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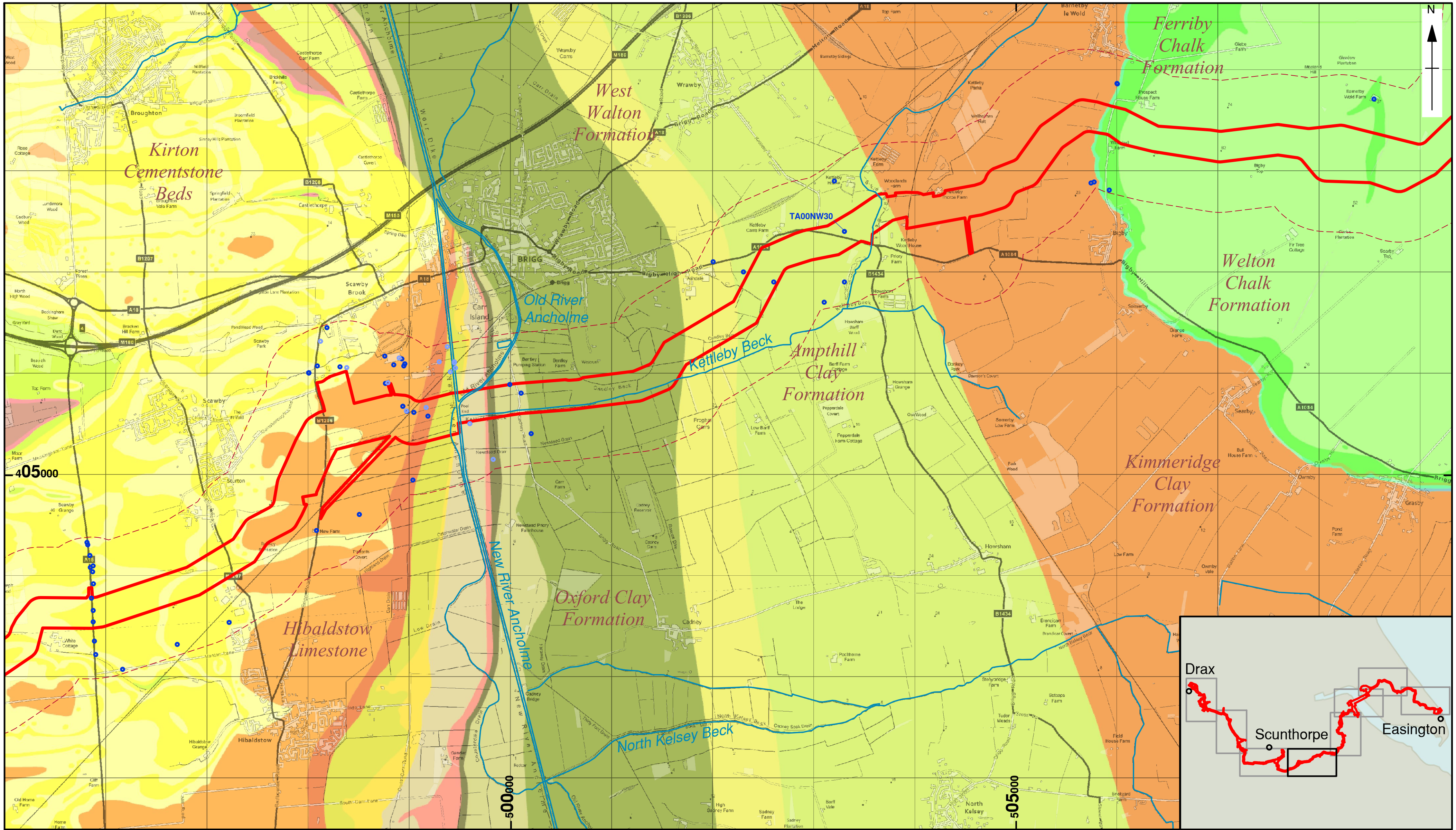

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BGS Borehole (confidential)

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Figure 9e: Lincolnshire Wolds (part) / Ancholme Valley; Bigby-Brigg-Scawby, Solid geology and BGS borehole locations

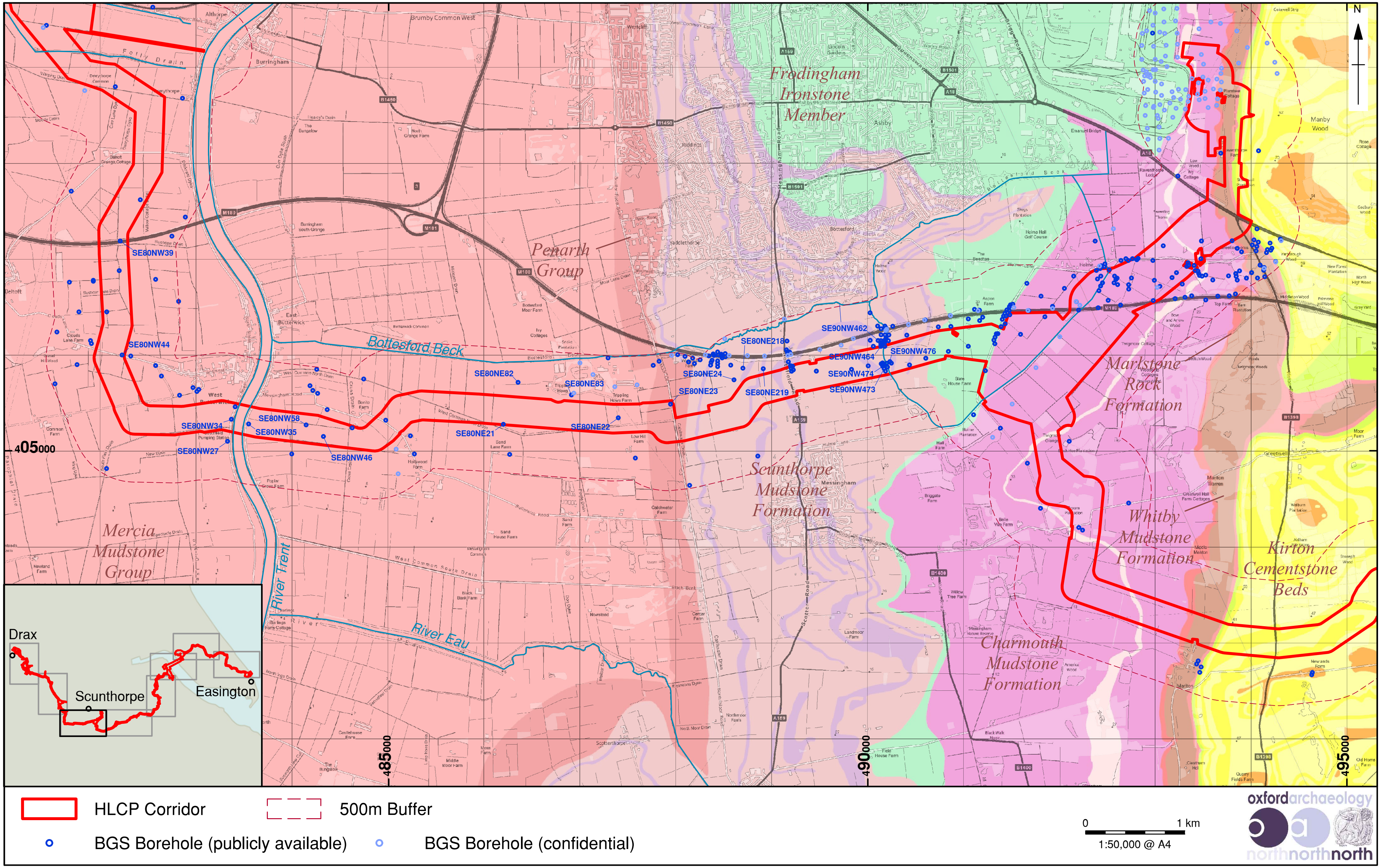

Figure 9f: Trent Valley; Scawby -Messingham-West Butterwick, Solid geology and BGS borehole locations

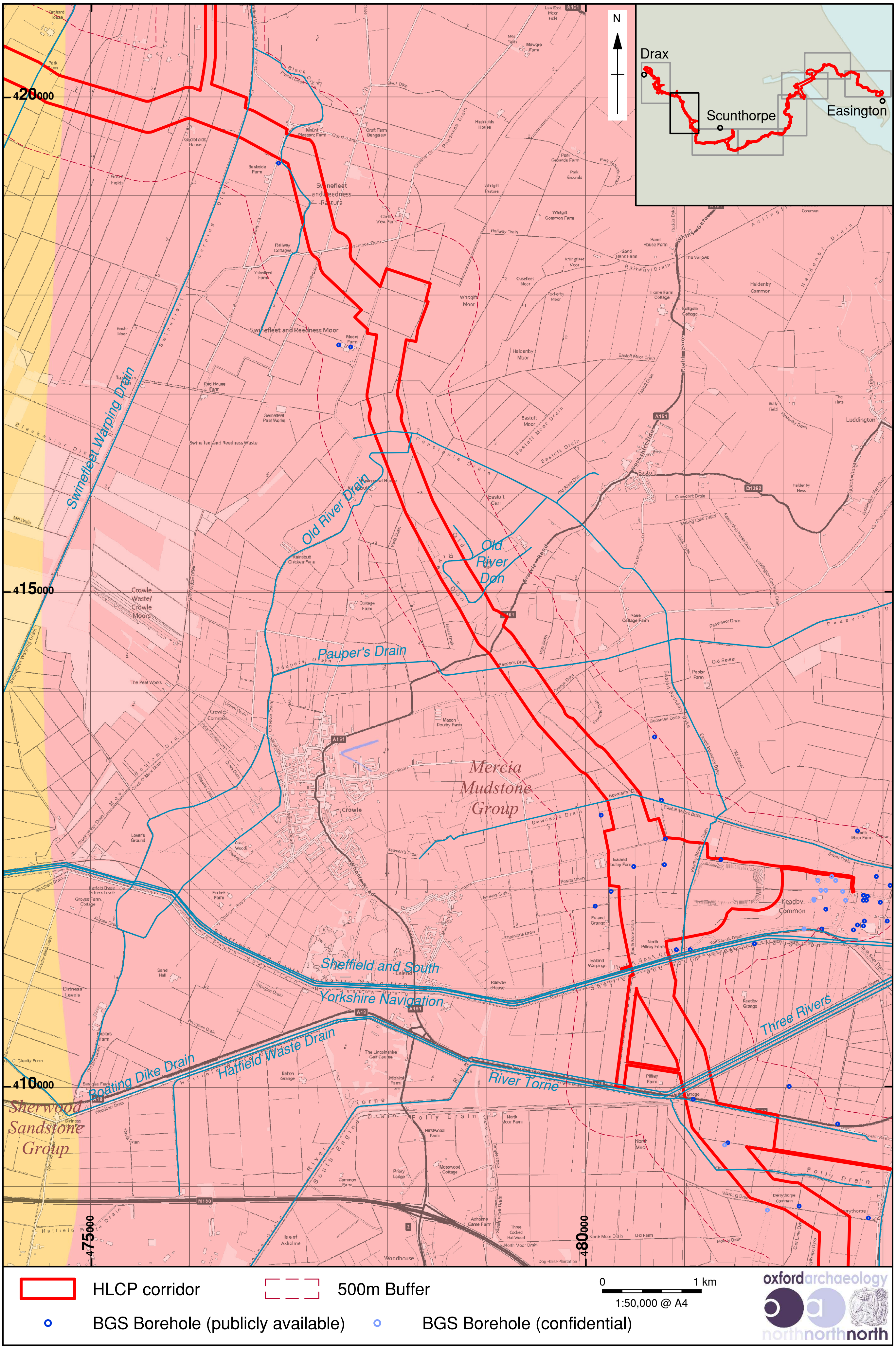

Figure 9g: Trent Valley/Humberhead Levels; Keadby-Crowle-Eastoft, Solid geology and BGS borehole locations

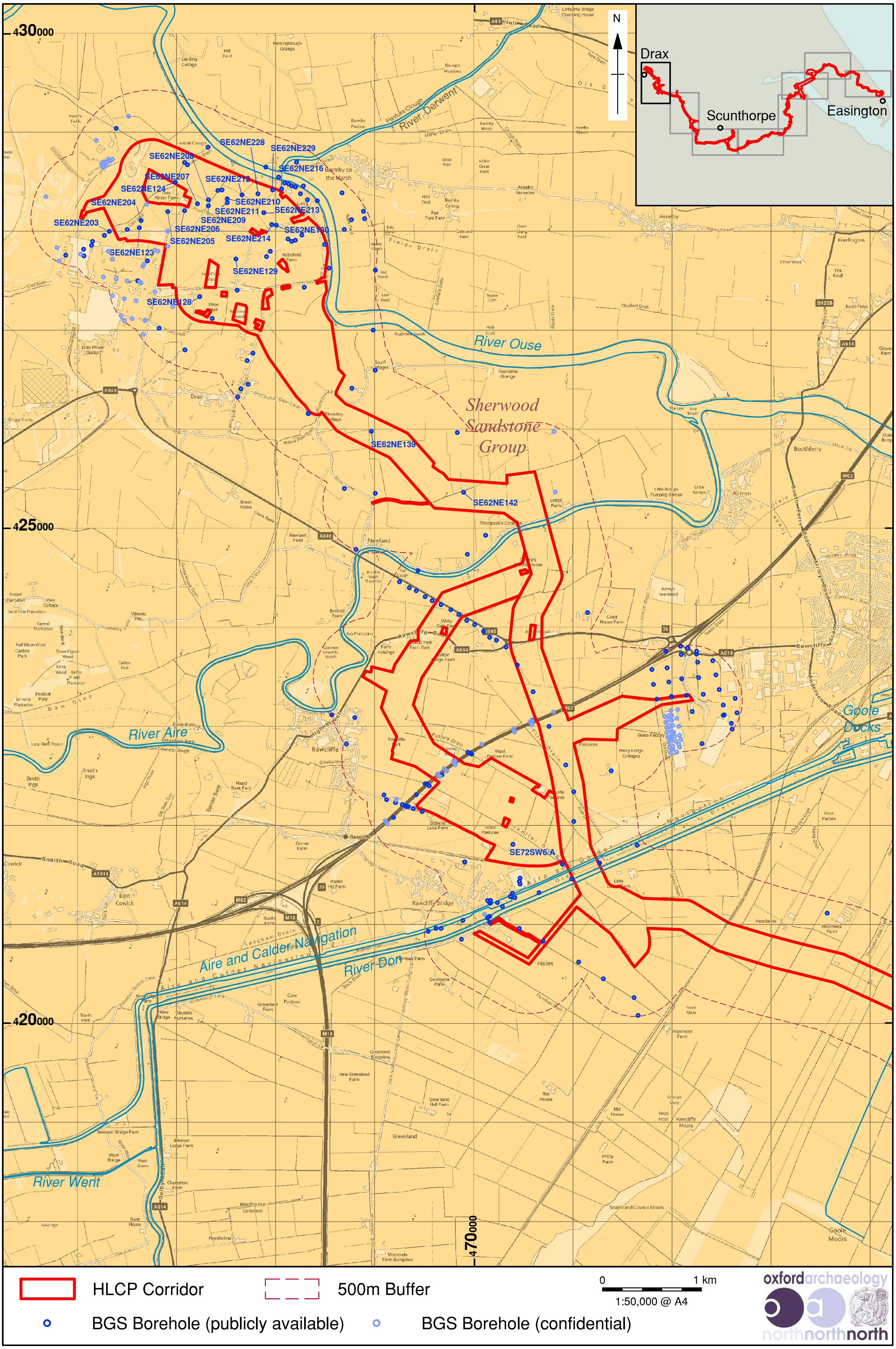

Figure 9h: Humberhead Levels/Vale of York; Airmyn-Drax, Solid geology and BGS borehole locations

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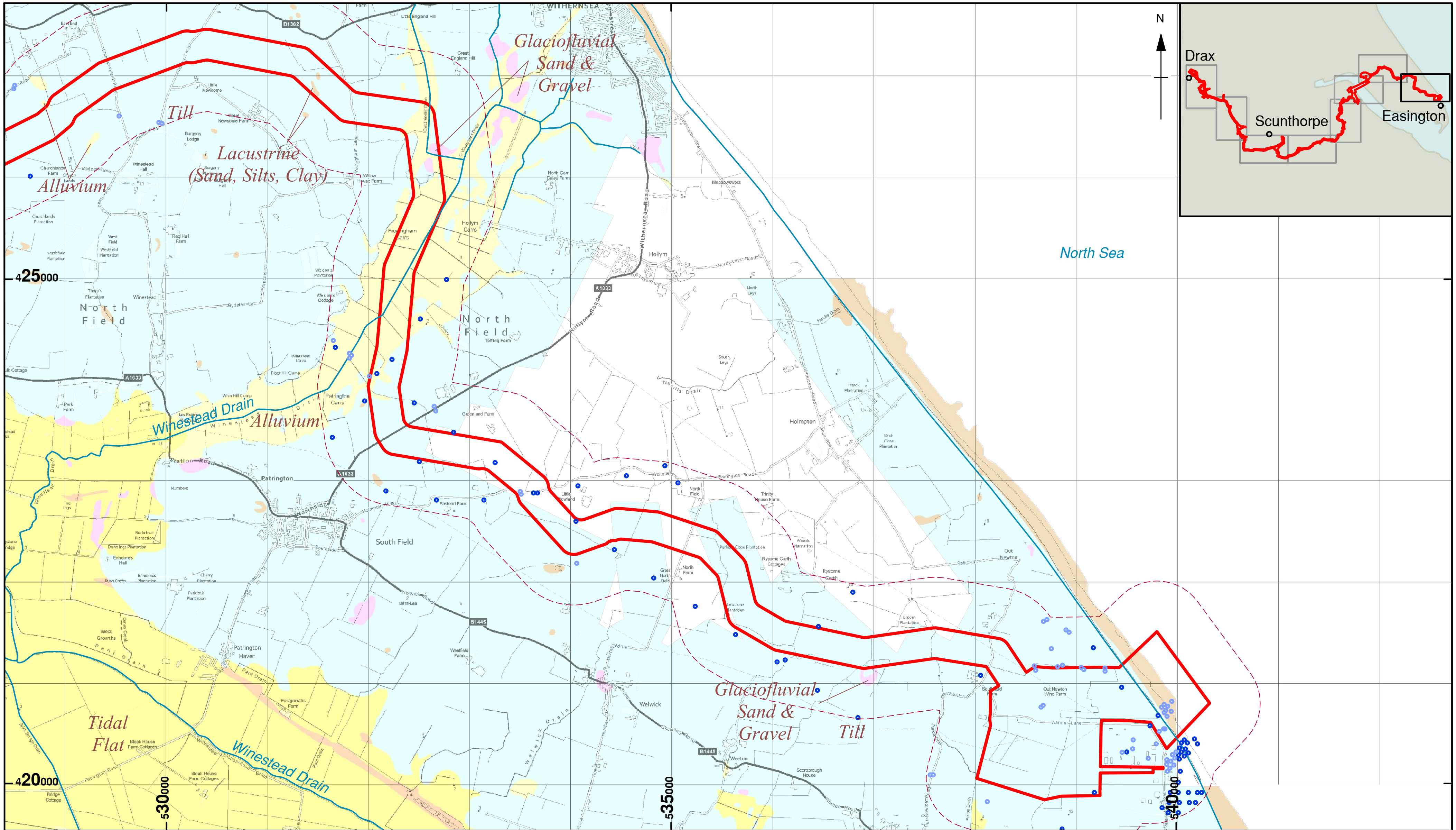

HLCP Corridor
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BGS Borehole (publicly available)
BGS Borehole (confidential)

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Figure 10a: Eastern Holderness; Easington - Patrington, Superficial geology and BGS borehole locations

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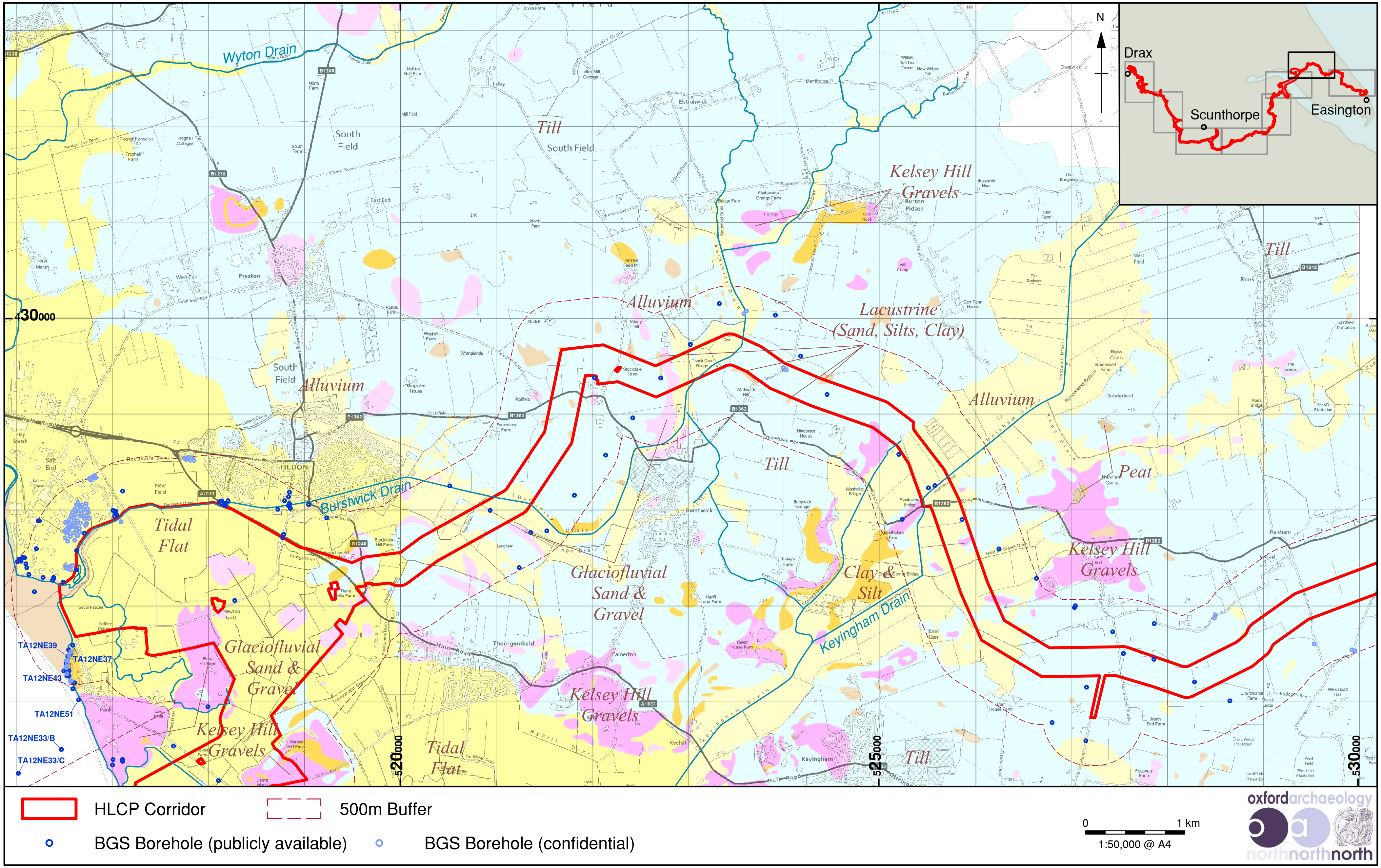

Figure 10b: Western Holderness; Halsham - Paull, Superficial geology and BGS borehole locations

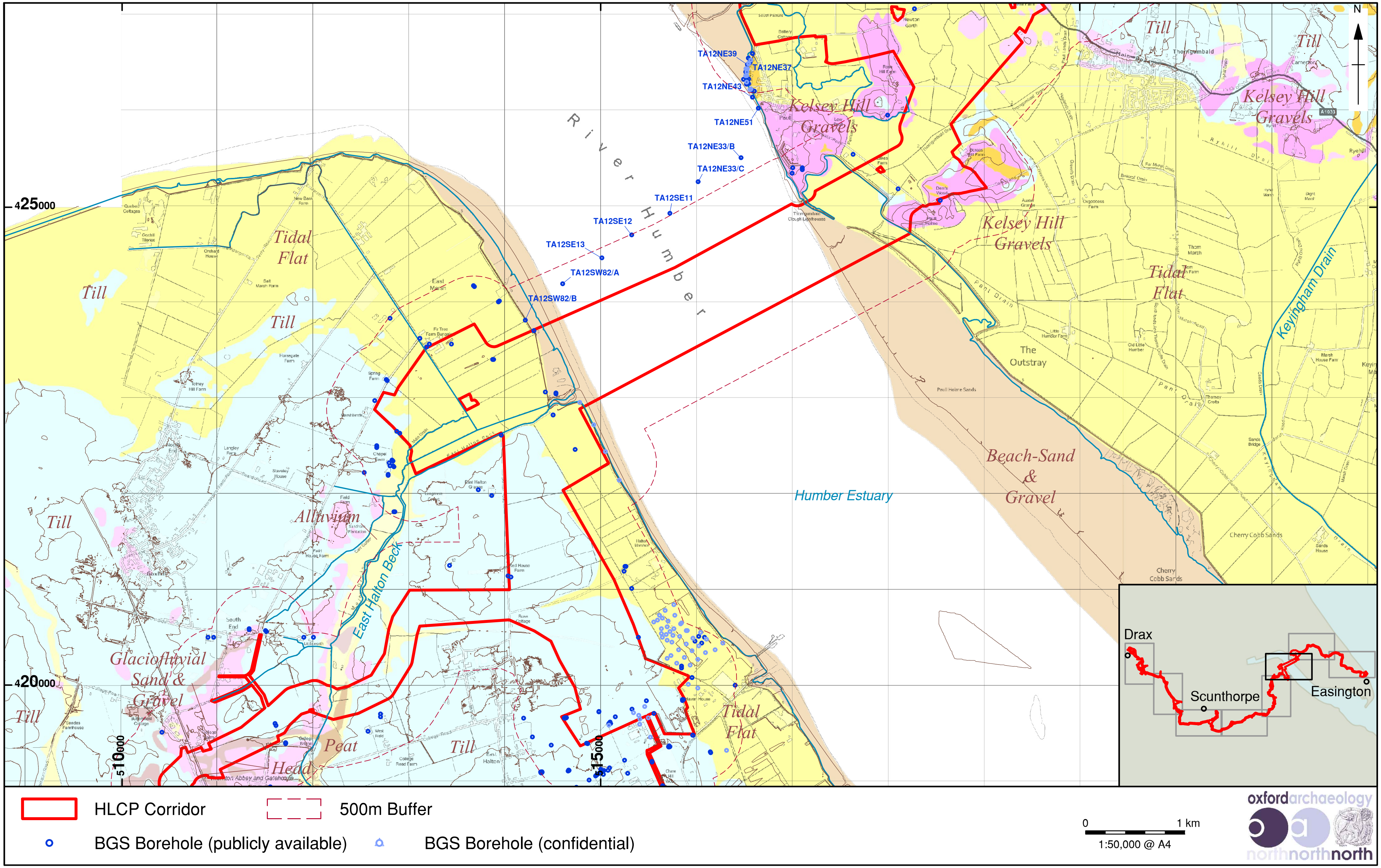

Figure 10c: Humber Estuary; Paull - Goxhill, Superficial geology and BGS borehole locations

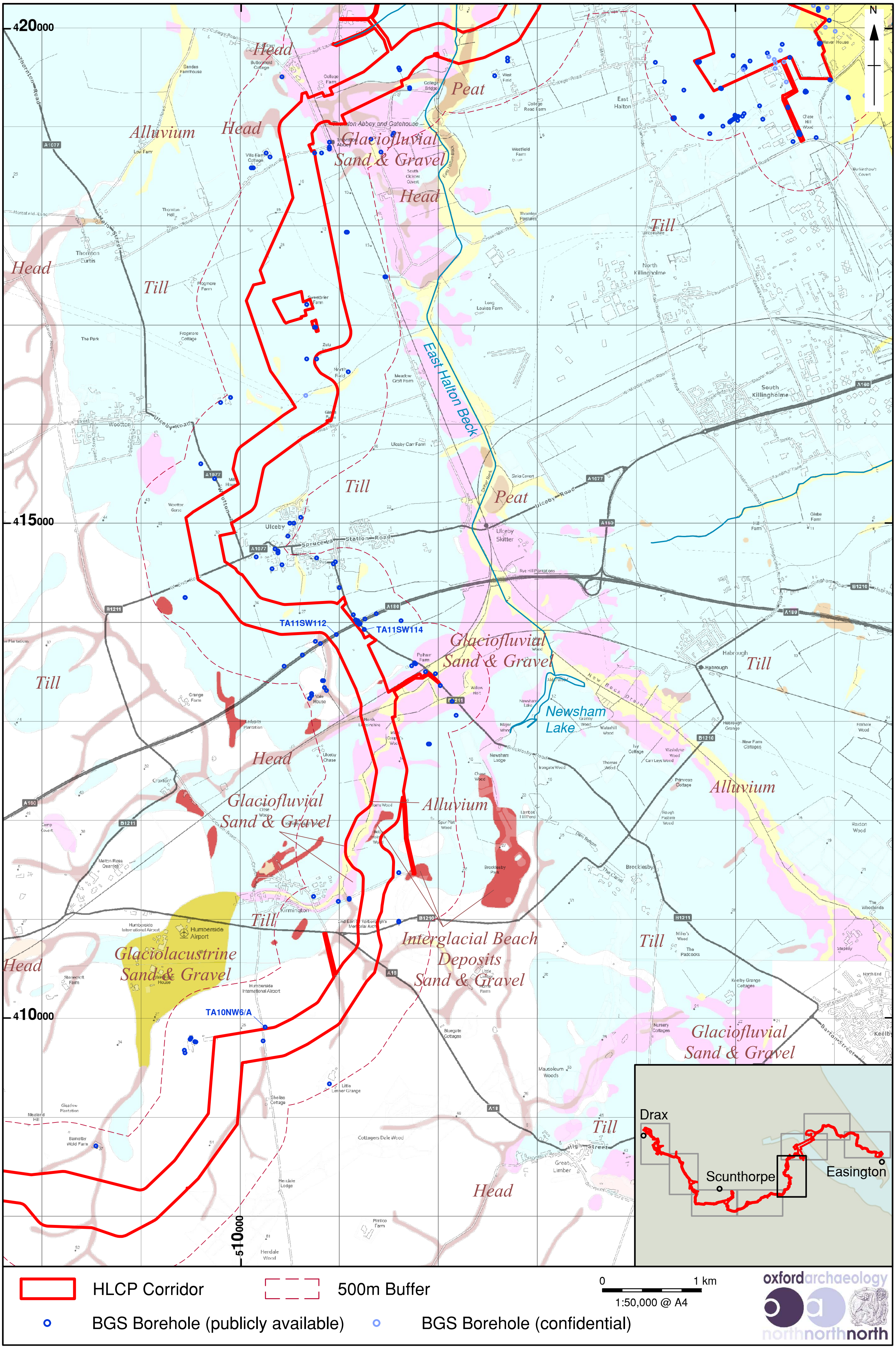

Figure 10d: Lincolnshire Wolds (part); Killingholme - Kirmington, Superficial geology and BGS borehole locations

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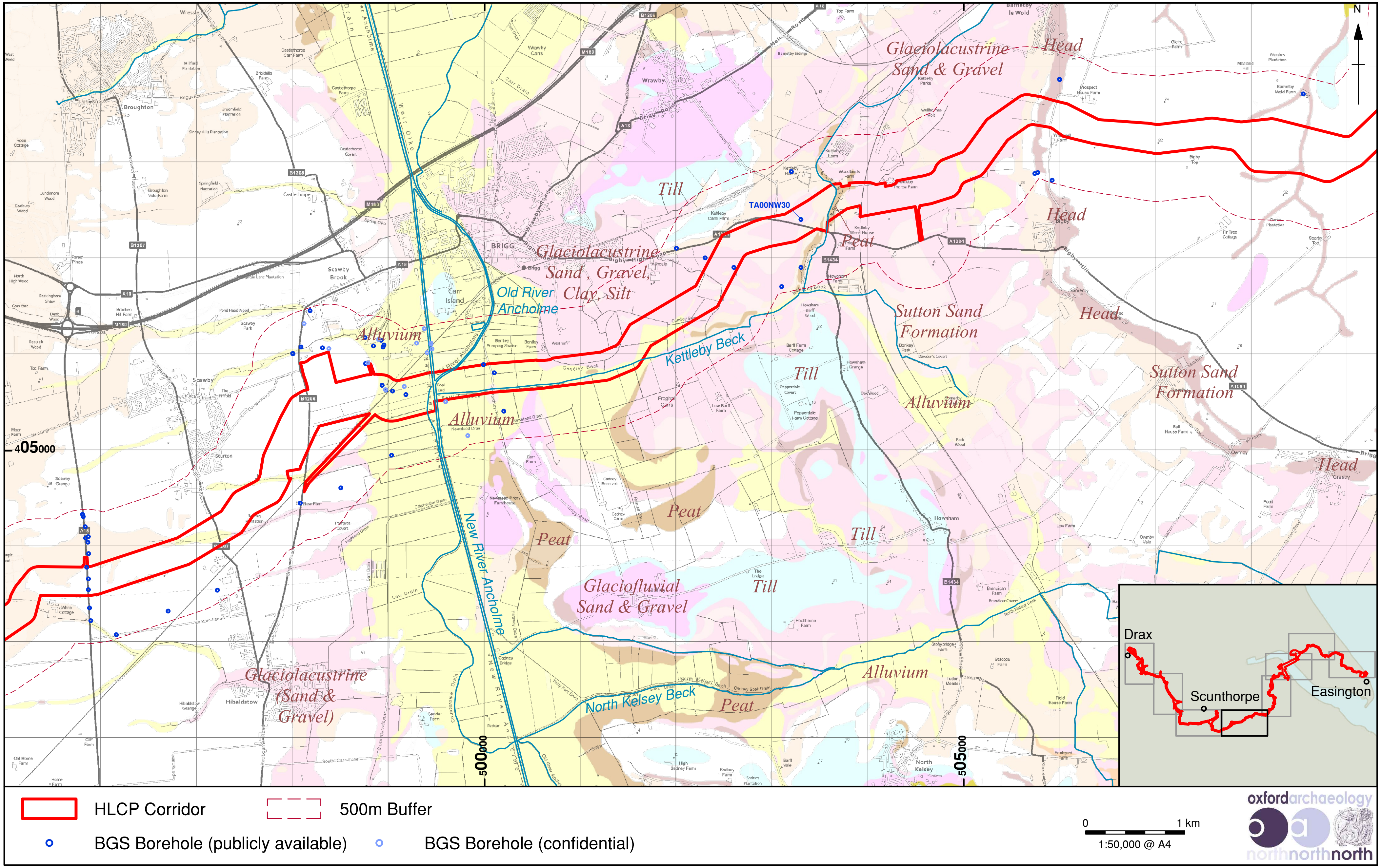

Figure 10e: Lincolnshire Wolds (part) / Ancholme Valley; Bigby-Brigg-Scawby, Superficial geology and BGS borehole locations

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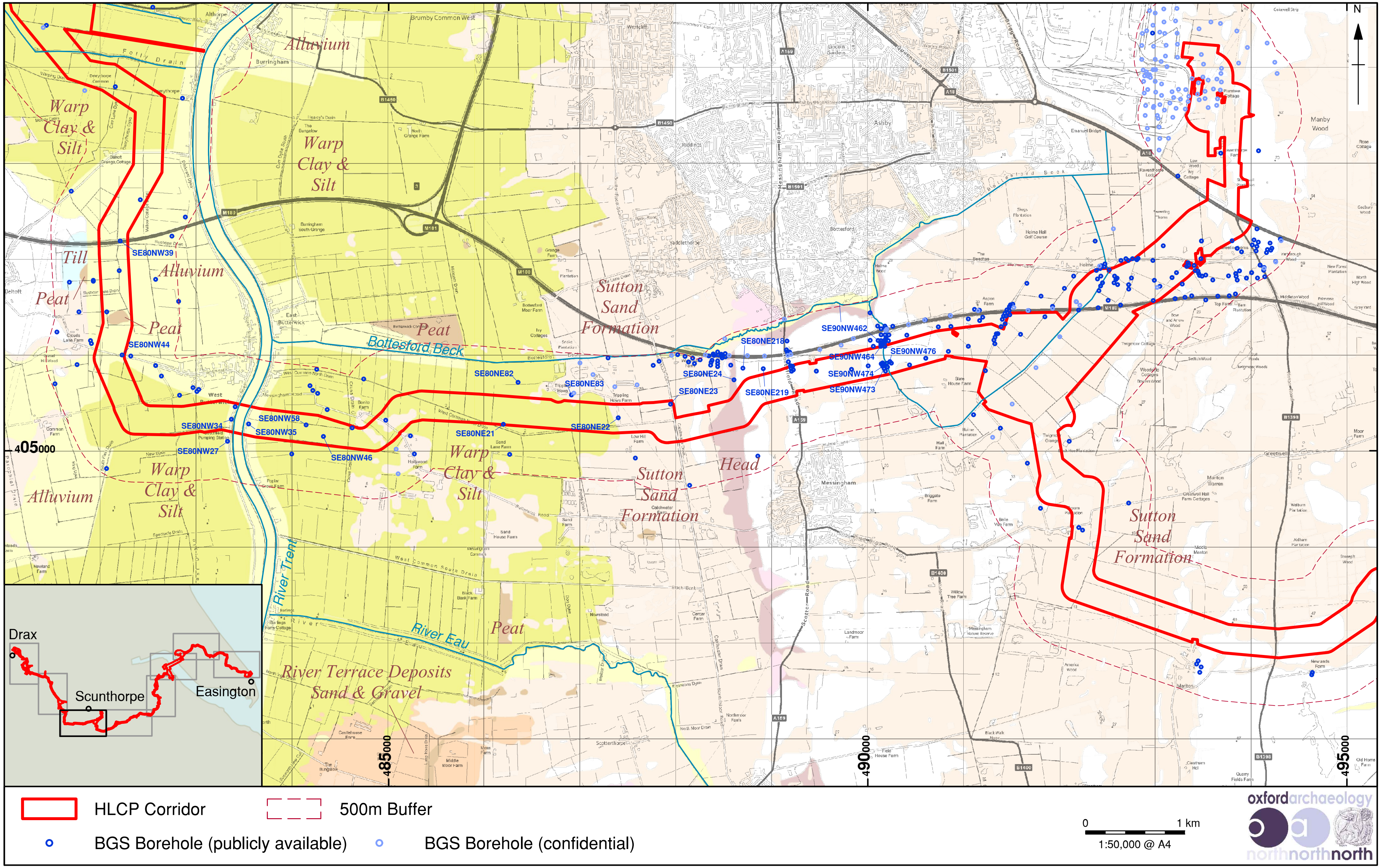


Figure 10f: Trent Valley; Scawby -Messingham-West Butterwick, Superficial geology and BGS borehole locations

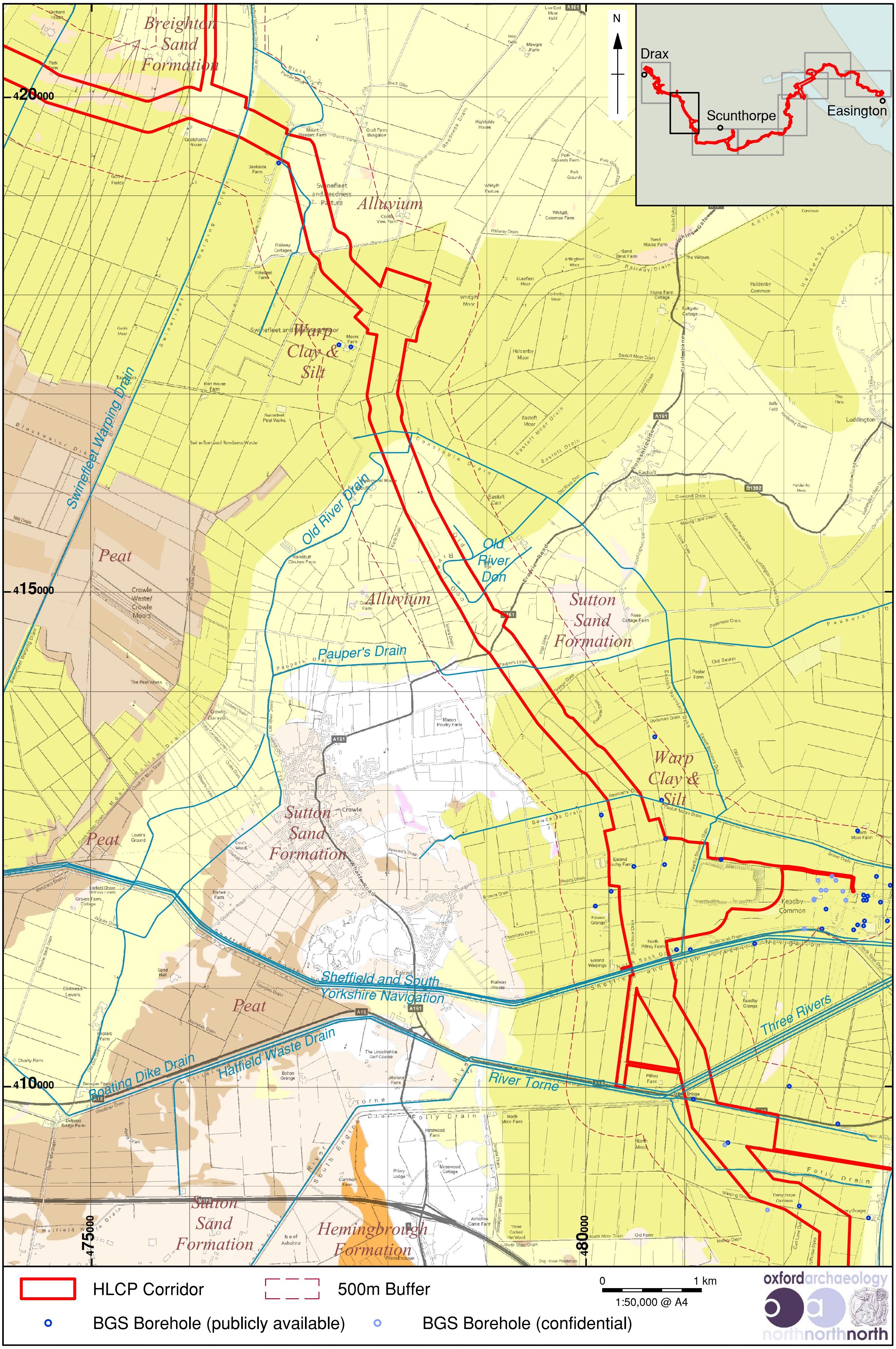
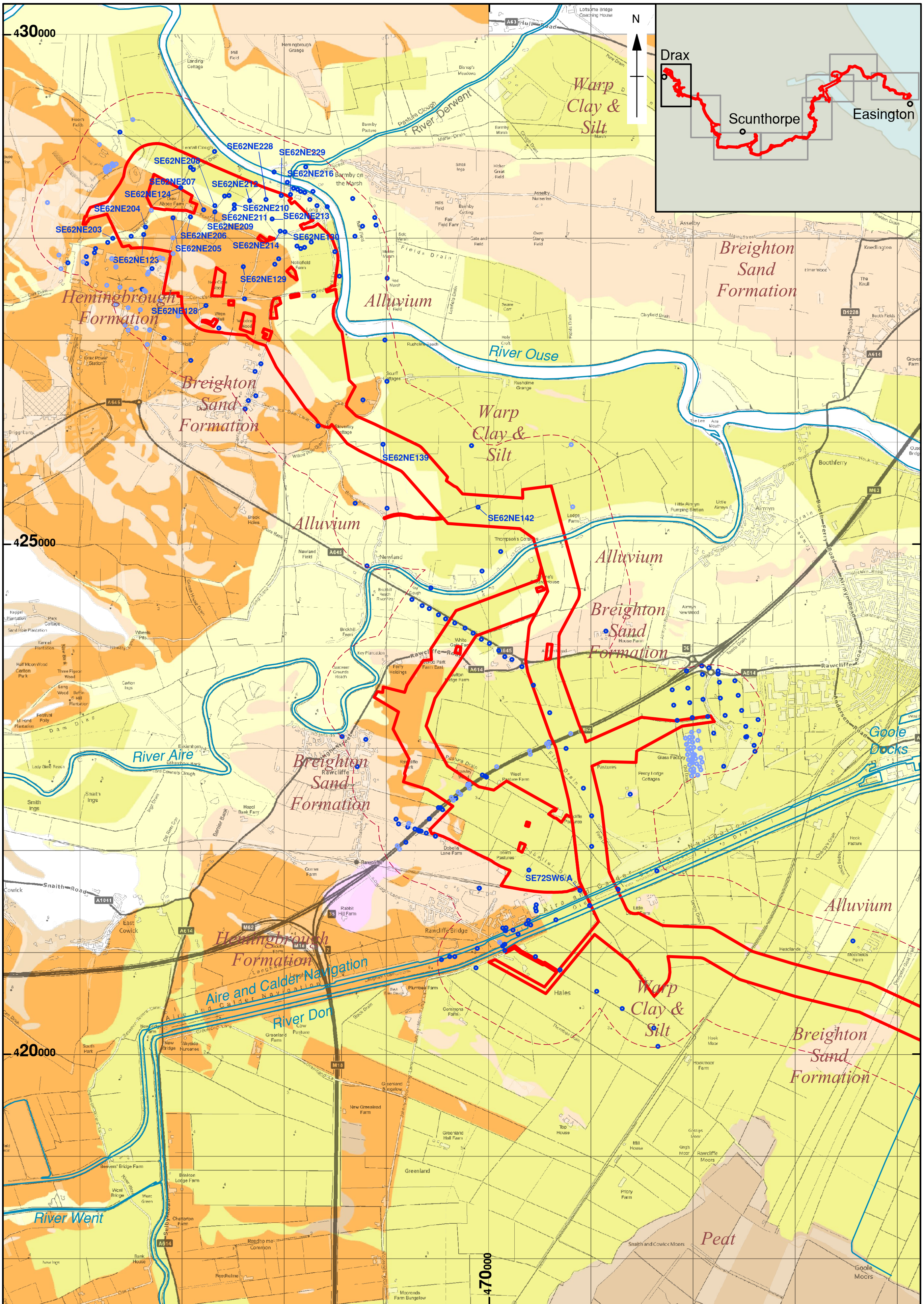


Figure 10g: Trent Valley/Humberhead Levels; Keadby-Crowle-Eastoft, Superficial geology and BGS borehole locations



HLCP Corridor

500m Buffer

BGS Borehole (publicly available)

BGS Borehole (confidential)

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Figure 10h: Humberhead Levels/Vale of York; Airmyn-Drax, Superficial geology and BGS borehole locations

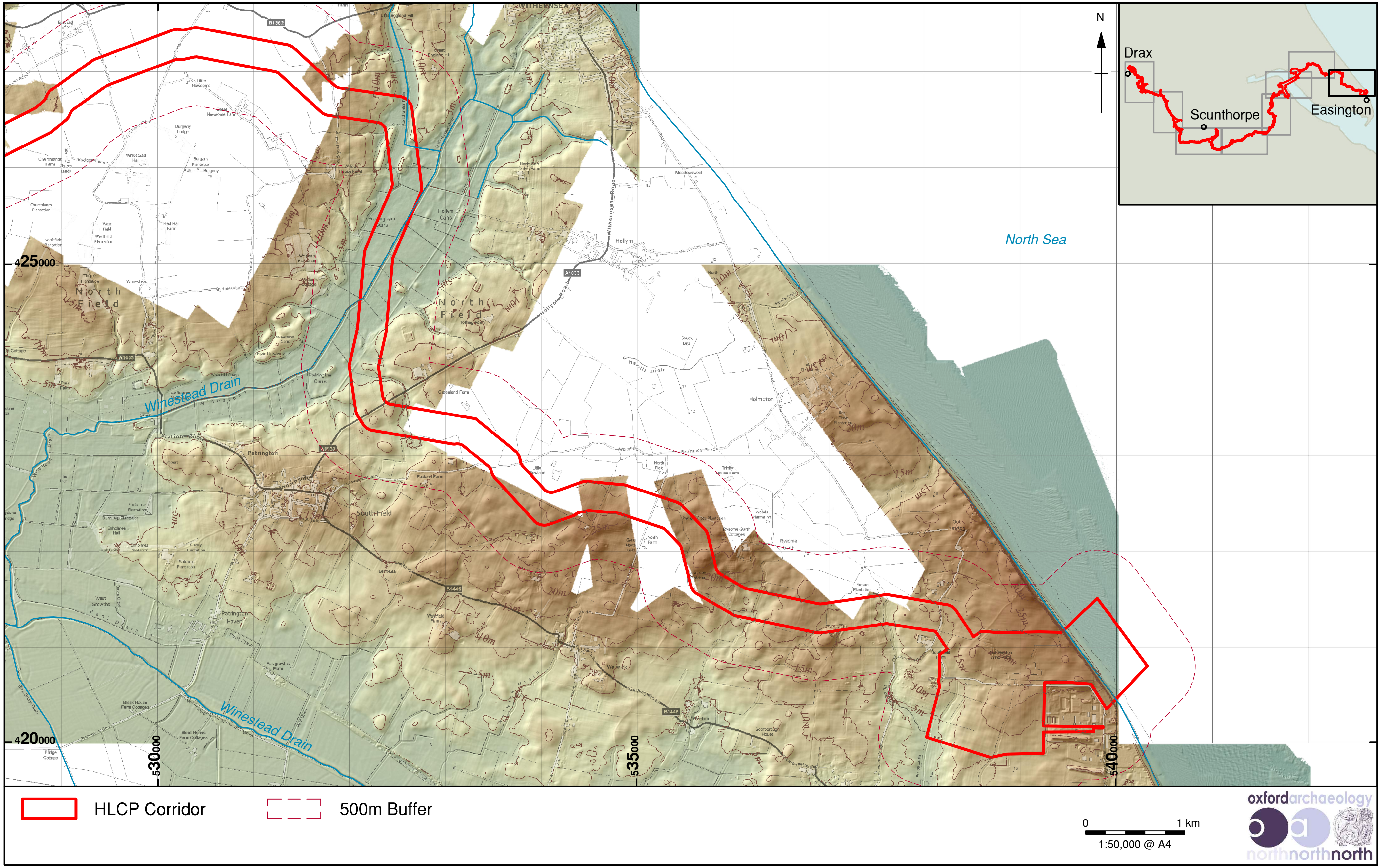

Figure 11a: Eastern Holderness; Easington - Patrington, LiDAR Digital Terrain Model (Ground Elevation)

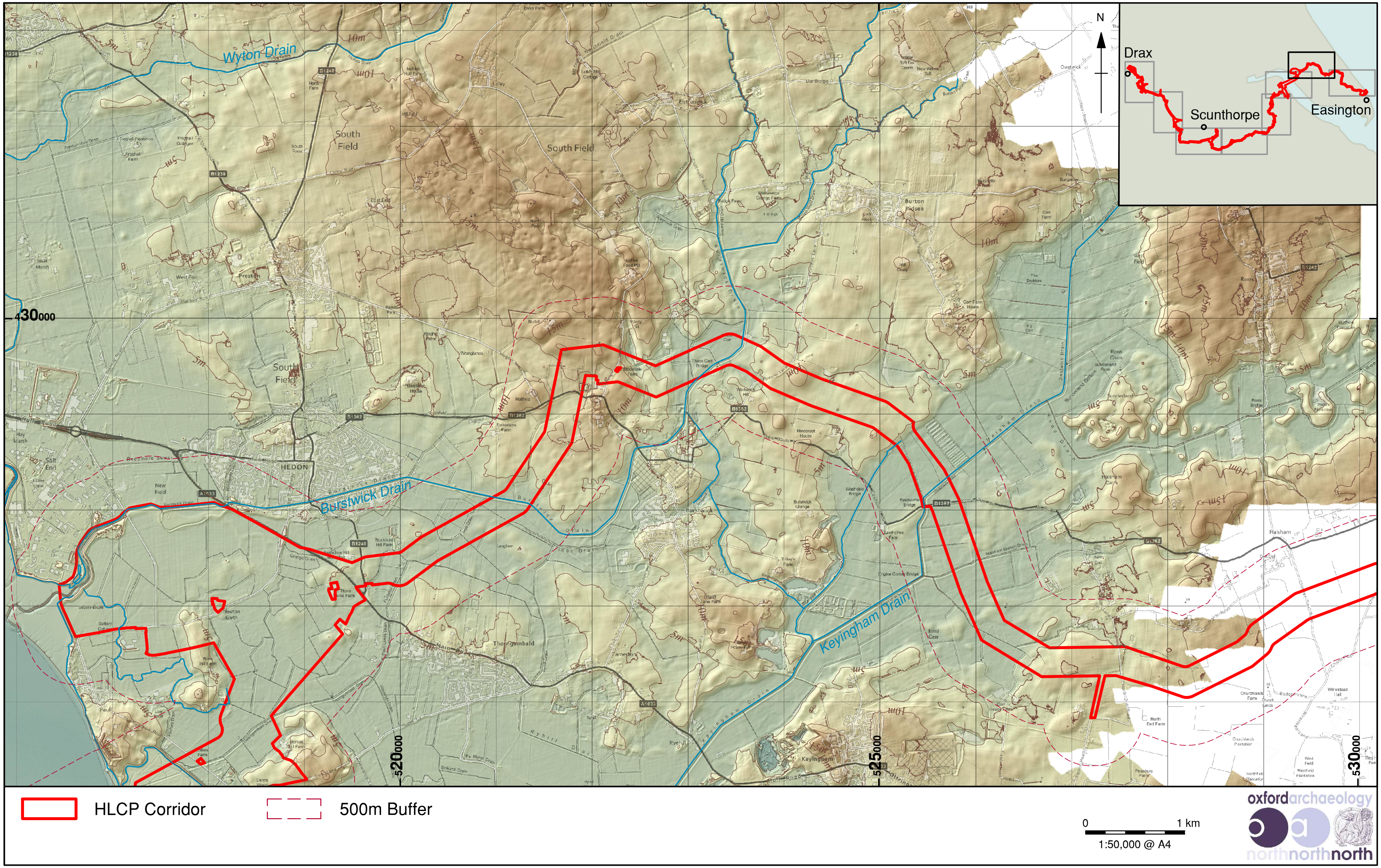

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Figure 11b: Western Holderness; Halsham - Paull, LiDAR Digital Terrain Model (Ground Elevation)

HLCP Corridor
500m Buffer
Possible palaeochannel

0 1 km
1:50,000 @ A4

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Figure 11c: Humber Estuary; Paull - Goxhill, LiDAR Digital Terrain Model (Ground Elevation)

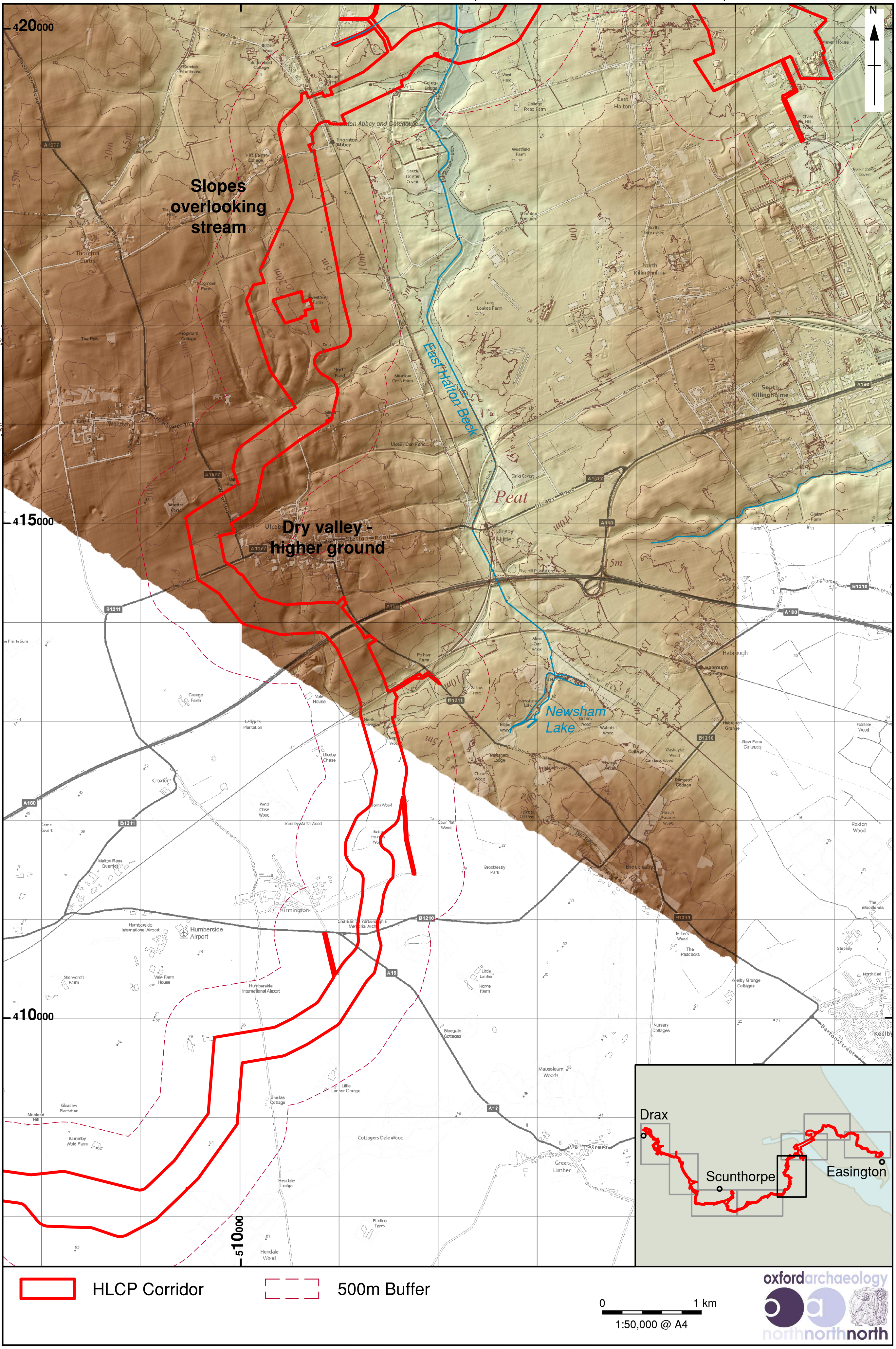


Figure 11d: Lincolnshire Wolds (part); Killingholme - Kirmington, LiDAR Digital Terrain Model (Ground Elevation)

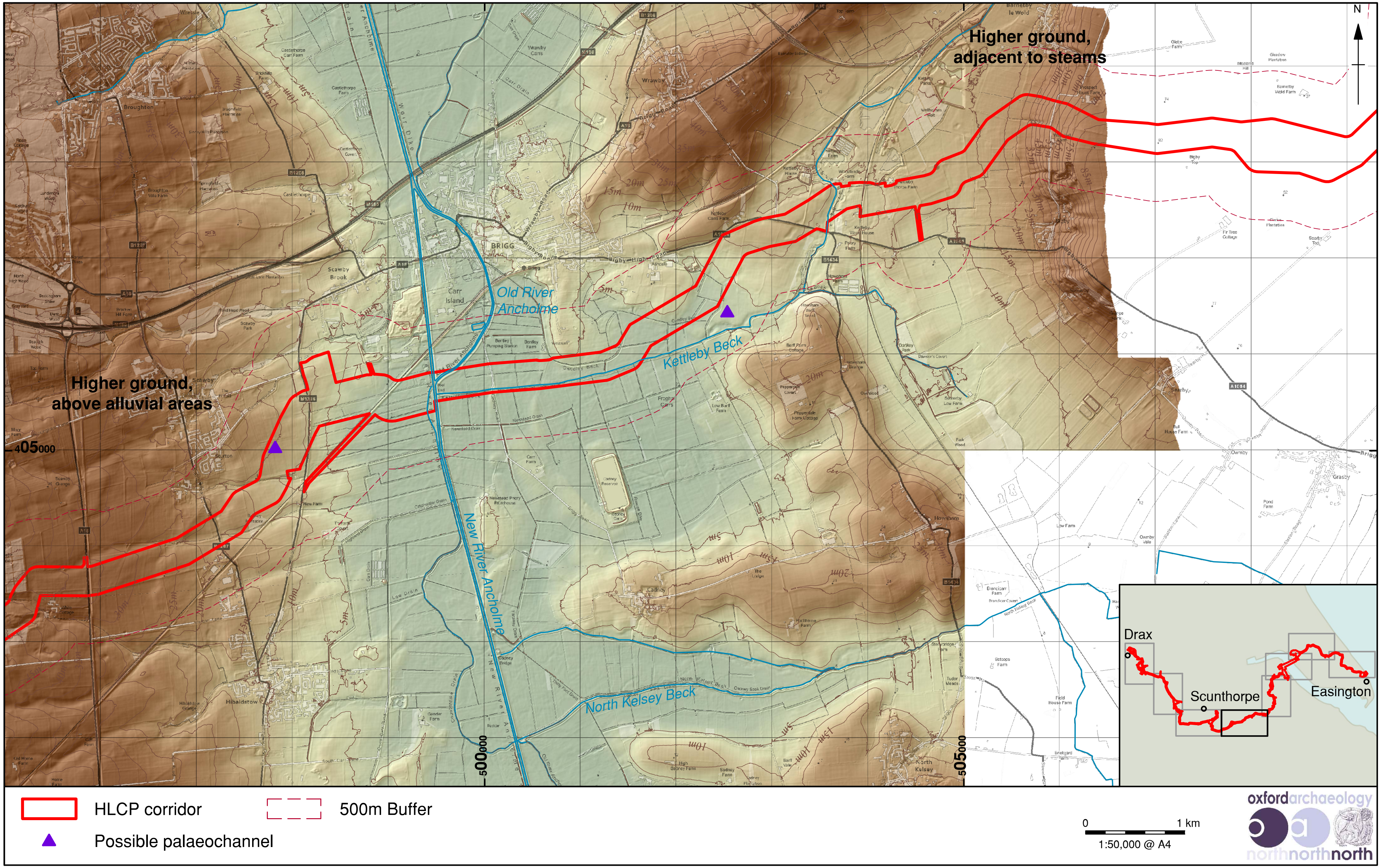
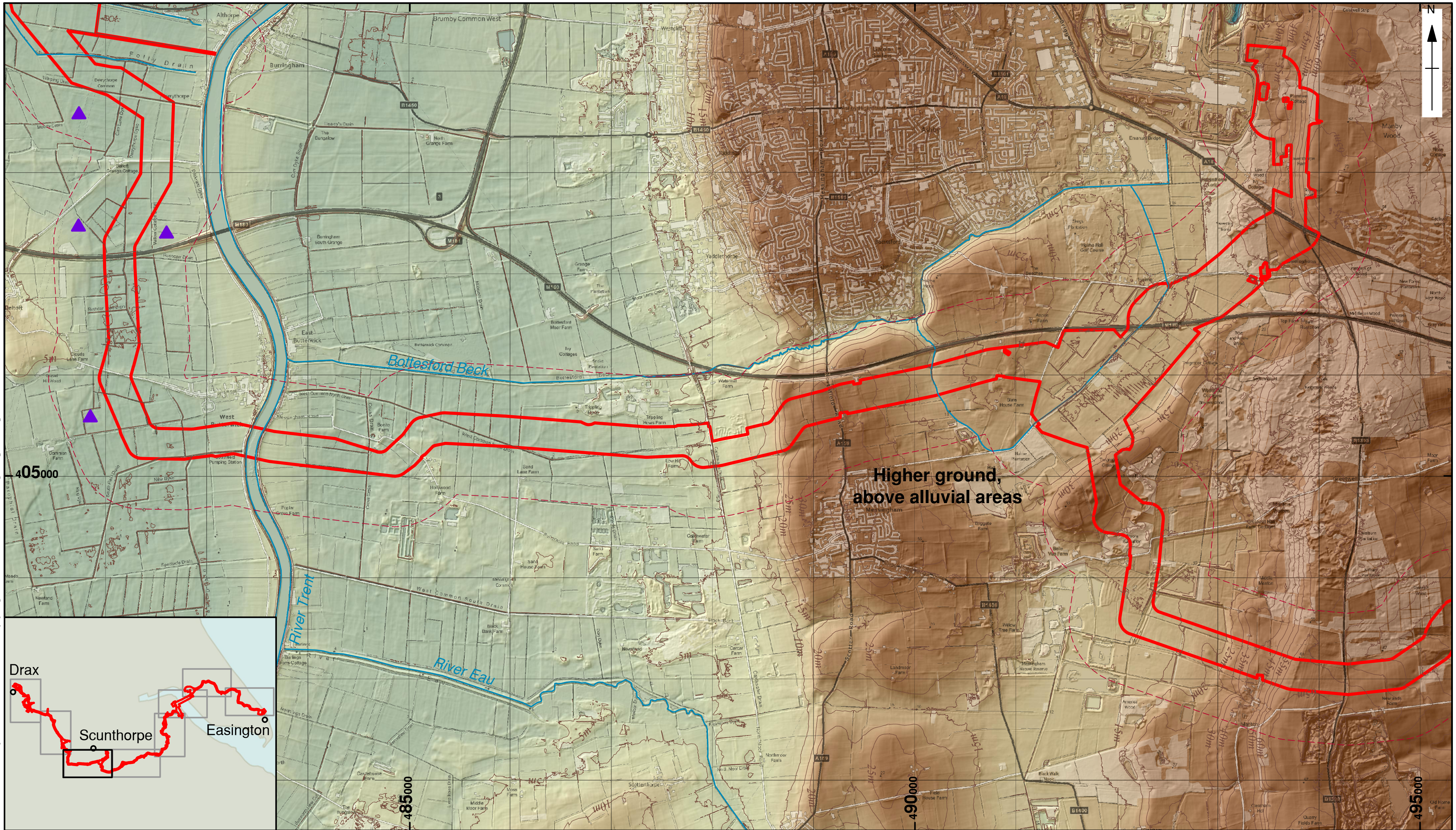


Figure 11e: Lincolnshire Wolds (part) / Ancholme Valley; Bigby-Brigg-Scawby, LiDAR Digital Terrain Model (Ground Elevation)



HLCP Corridor
500m Buffer
Possible palaeochannel

0 1 km
1:50,000 @ A4

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Figure 11f: Scawby - Messingham-West Butterwick, LiDAR Digital Terrain Model (Ground Elevation)

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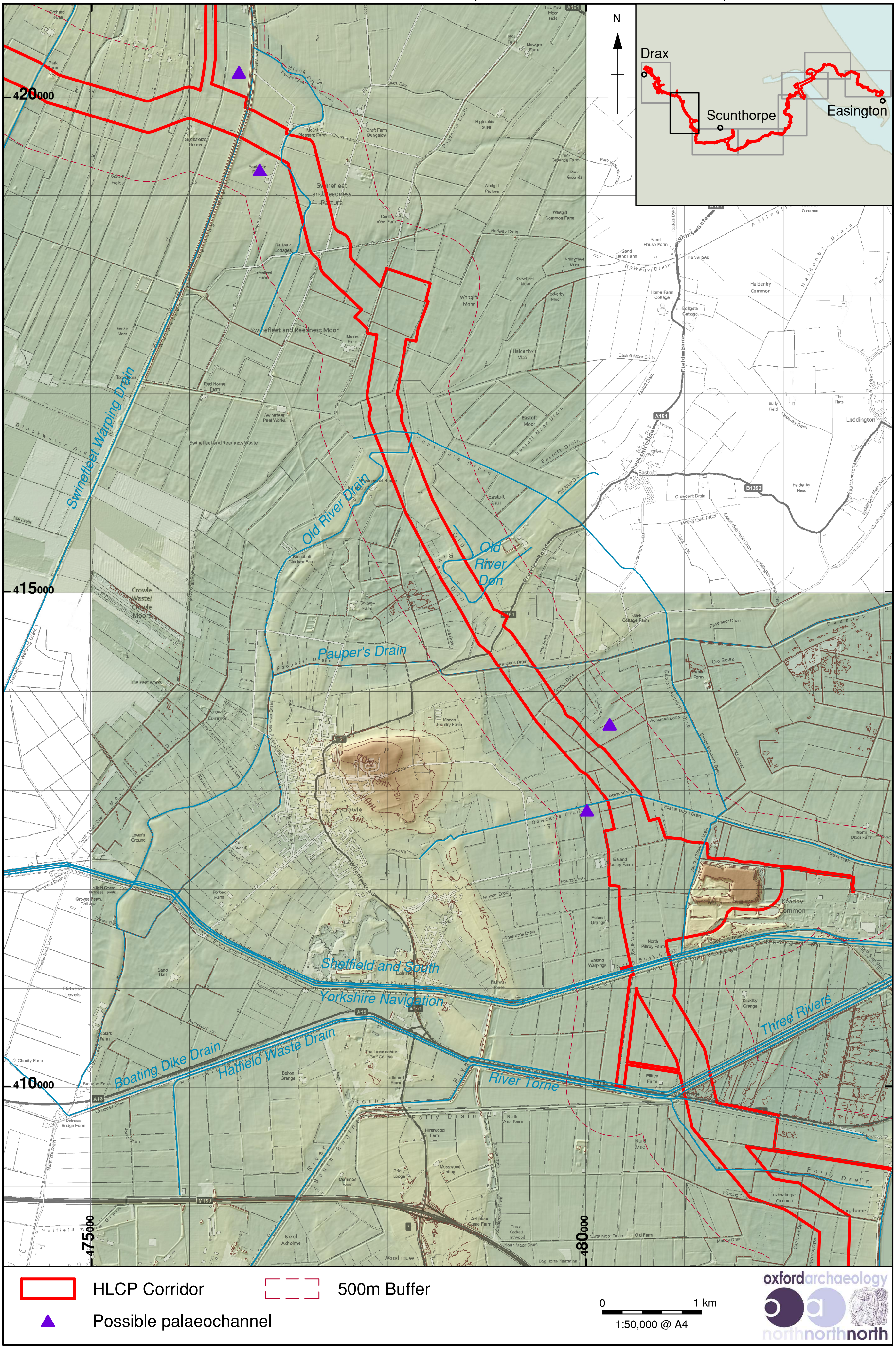

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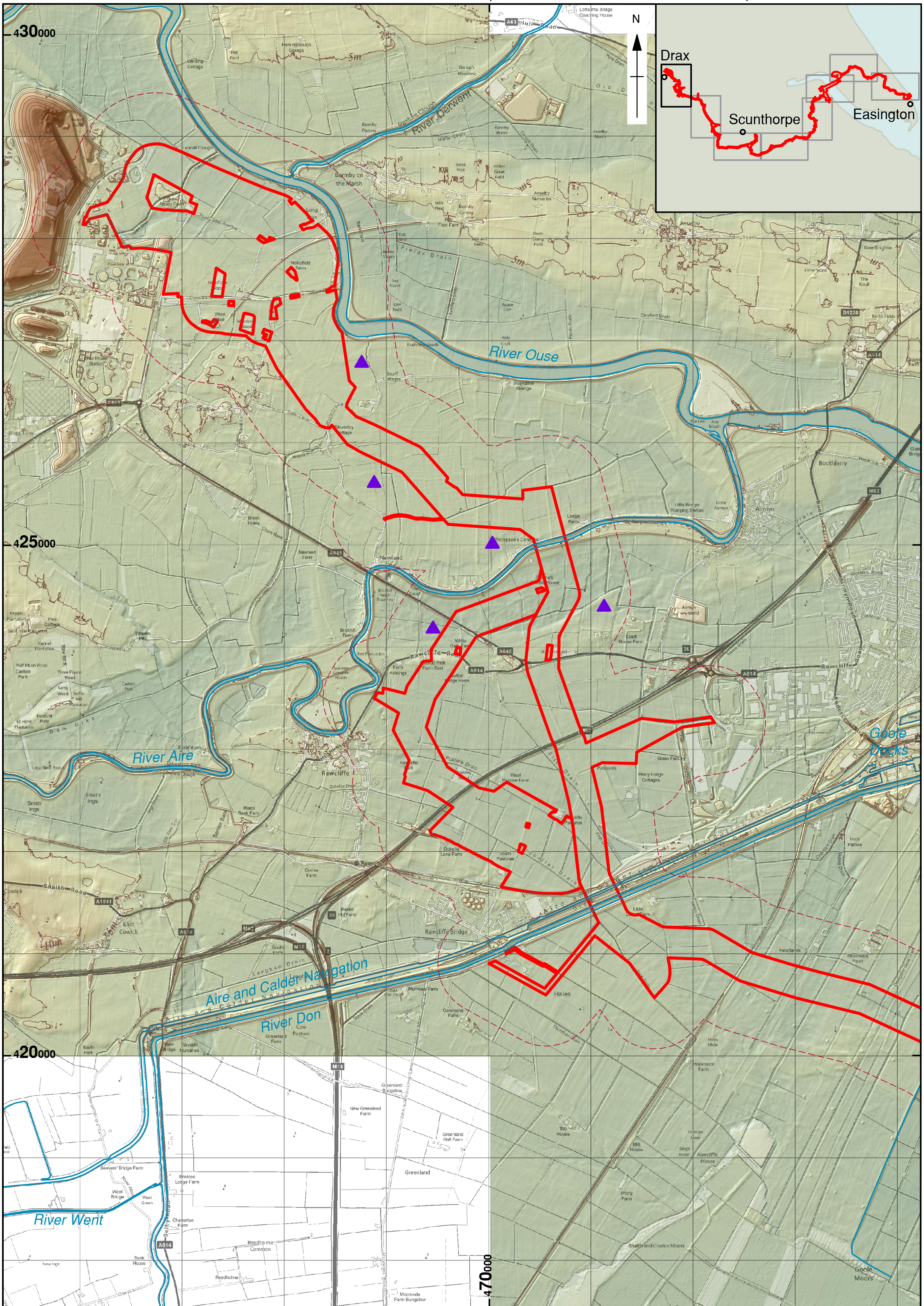
Figure 11g: Trent Valley/Humberhead Levels; Keadby-Crowle-Eastoft, LiDAR Digital Terrain Model (Ground Elevation)



HLCP Corridor
500m Buffer
Possible palaeochannel

0 1 km
1:50,000 @ A4

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Figure 11h: Humberhead Levels/Vale of York; Airmyn-Drax, LiDAR Digital Terrain Model (Ground Elevation)