

Scientific and technical report to accompany the Rib-Ash- Stort 3D geological map & model

National Programme

Internal Report CR/26/016



BRITISH GEOLOGICAL SURVEY

NATIONAL PROGRAMME

COMMISSIONED REPORT CR/26/016

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Map

Map Sheet 204, 1:50 000
scale, Biggleswade
Map Sheet 205, 1:50 000
scale, Saffron Walden
Map Sheet 221, 1:50 000
scale, Hitchin
Map Sheet 222, 1:50 000
scale, Great Dunmow
Map Sheet 239, 1:50 000
scale, Hertford
Map Sheet 240, 1:50 000
scale, Epping

Front cover

The Collier's End pebble bed
(Lambeth Group) near
Standon.

Bibliographical reference

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British Geological Survey offices

**Nicker Hill, Keyworth,
Nottingham NG12 5GG**

Tel 0115 936 3100

BGS Central Enquiries Desk

Tel 0115 936 3143

email enquiries@bgs.ac.uk

BGS Sales

Tel 0115 936 3241

email sales@bgs.ac.uk

**The Lyell Centre, Research Avenue South,
Edinburgh EH14 4AP**

Tel 0131 667 1000

email scotsales@bgs.ac.uk

**Natural History Museum, Cromwell Road,
London SW7 5BD**

Tel 020 7589 4090

Tel 020 7942 5344/45

email bgs-london@bgs.ac.uk

**Cardiff University, Main Building, Park Place,
Cardiff CF10 3AT**

Tel 029 2167 4280

**Geological Survey of Northern Ireland, Department of
Enterprise, Trade & Investment, Dundonald House,
Upper Newtownards Road, Ballymiscaw,
Belfast, BT4 3SB**

Tel 01232 666595

www.bgs.ac.uk/gsni/

**Natural Environment Research Council, Polaris House,
North Star Avenue, Swindon SN2 1EU**

Tel 01793 411500

Fax 01793 411501

www.nerc.ac.uk

**UK Research and Innovation, Polaris House,
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www.ukri.org

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Shop online at www.geologyshop.com

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Dr Michael Kehinde, MBE C. Geol, FGS
Technical Specialist (Groundwater Resources)
Environment Agency
Groundwater and Hydrology
Hertfordshire and North London Area

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Summary

This report describes the geology of part of the Rib, Ash and Stort river catchments in the Chilterns. The mapped area extends from Odsey in the northwest, Saffron Walden in the northeast, south through Buntingford and Bishops Stortford to Hertford, Ware and Harlow in the south. The mapping covers the Upper Cretaceous Chalk Group and the overlying Paleogene Lambeth Group and London Clay formations, together with Quaternary superficial deposits including the Clay-with-Flints Formation, river terrace gravels and extensive Anglian glacial deposits. Artificial Ground was not mapped. The geological map was created on behalf of the Environment Agency to improve conceptual geological understanding of the Rib, Ash and Stort catchment areas and the role of the buried valleys and chalk stratigraphy on the aquifer.

1 Introduction

This report documents the results of a project to create a geological map and 3D geological framework model (henceforth referred to as 'the model') of the Rib, Ash and Stort river catchments in the Chiltern Hills. The geological mapping and 3D model were prepared for the Environment Agency (EA) in response to their requirement for an improved understanding of the 3D geological structure of the Chalk of the Rib, Ash and Stort river catchments in the Chiltern Hills. The main aim of the project was to create a 3D geological model of the Rib, Ash and Stort river catchments between Odsey and Saffron Walden in the north and the Hertford-Harlow area in the south (as shown in Figure 1).

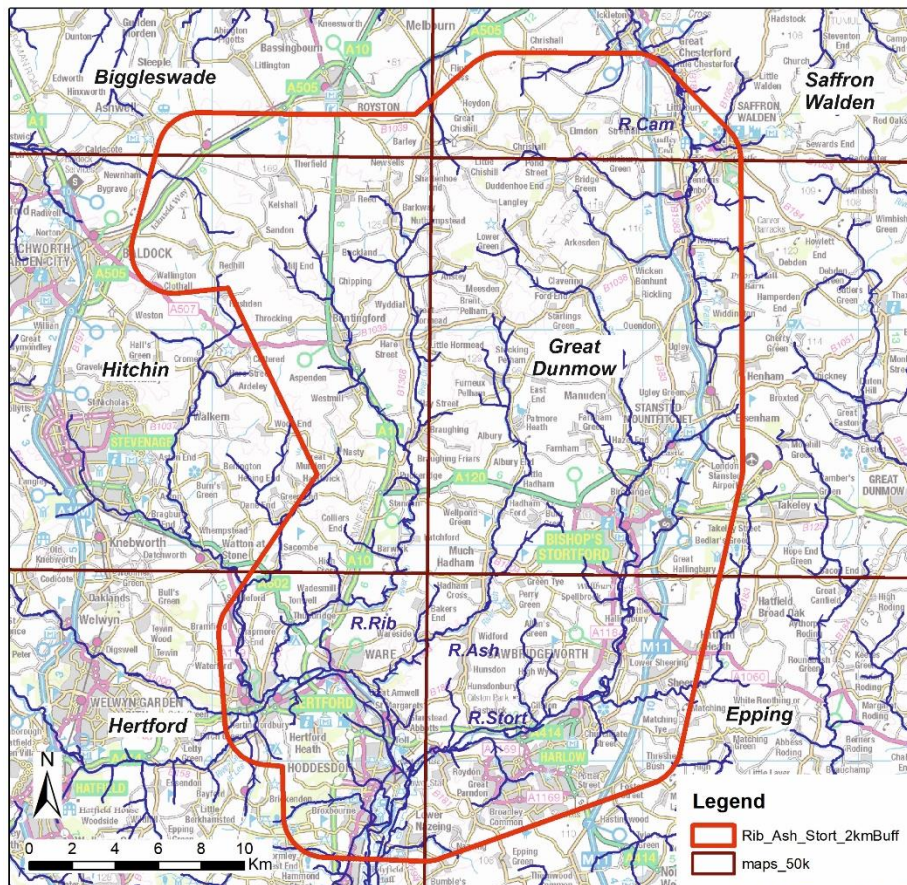


Figure 1. The Rib-Ash-Stort catchment model area and BGS 1:50K map sheet boundaries. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

This study involved four key stages:

Stage 1 - initial data review

Stage 2 – borehole assessment, interpretation and coding

Stage 3 - fieldwork & ground truthing; and

Stage 4 – creation of the 3D geological model

Stage 1 involved an office-based review of existing geological data of the study area. Data examined included BGS datasets (boreholes, old field slips, palaeontological data), but also external literature and third-party data. This provided an initial conceptual model of the geology that was tested by fieldwork in Stage 3. Stage 2 involved the acquisition and interpretation of any relevant borehole data within the area of interest, including geophysical data. Those boreholes not previously interpreted were coded into the BGS Borehole Geology database.

Stage 3 involved updating the existing geological linework through fieldwork, mostly focused on the Chalk outcrop where the data was known to be inadequate, but also assessing any new data for other parts of the catchment. This was done through targeted geological mapping at 1:10,000 scale using the modern Chalk stratigraphy. For the bedrock geology, the emphasis was on subdividing the Chalk Group into its constituent formations and delimiting the Paleogene Lambeth Group and London Clay Formation. The former 'Middle Chalk' is now divided into the Holywell Nodular Chalk and New Pit Chalk formations, whilst the 'Upper Chalk' has been divided into the Lewes Nodular Chalk and Seaford Chalk formations. Several key marker beds in the Lewes Nodular Chalk have also been mapped. These are the 'Chalk Rock', the Kensworth Member and the 'Top Rock'. The delineation of the new Chalk formations and members helps to identify the geological structure. In addition, the extent of the Paleogene outcrop has been revised and improved, particularly beneath the superficial deposits.

The focus for the superficial geology was to improve the mapping of the Anglian glacial deposits, in particular the complex succession of glacial and glaciofluvial deposits and the geometry of the buried valleys. A second aim was to update the ancestral Thames terraces and add the extensive solifluction deposits. This data fed into the geological modelling phase (Stage 4). The geological data acquired in phases 1-3 were used in BGS Groundhog Desktop 3D modelling software to create a network of interlocking geological cross sections that were interpolated to create a full 3D geological model.

1.1 GEOLOGY

The geology of the study area is dominated by Cretaceous and Paleogene strata, together with unconsolidated superficial deposits of Quaternary age. The Chiltern Hills escarpment forms the most prominent topographical feature within the study area and is composed of the Upper Cretaceous Chalk Group. The Chalk Group strata generally dip gently south-eastwards at less than 1°. The overlying Paleogene strata occur southeast of a line between Braughing, Manuden and Ugley. Younger Quaternary alluvial, river terrace, glacial and glaciofluvial deposits progressively cover the Chalk Group to the south and east. In the northern half of the catchment, the Neogene to Pleistocene Clay-with-Flints Formation and extensive glacial deposits, principally the Lowestoft Till Member, cover the interfluvies in the headwaters of the Ash, Rib, Cam and Stort rivers. Further to the southeast, the palaeo-Thames Westland Green terrace gravels extend across the middle of the catchment between Collier's End and Widdington.

Gravel deposits cover much of the southern part of the project area, comprising a mix of palaeo-Thames terrace deposits and glaciofluvial outwash sediments, locally interbedded with glacial lake sediments and the Anglian aged Lowestoft Till Member. These gravel deposits have been extensively worked around Hertford and Ware.

Several buried valley systems, formed during the Anglian glaciation and infilled with glaciofluvial and glacial till deposits, extend across the project area. The largest follows the Upper Cam valley and extends down the Stort valley to Harlow. A second buried valley follows the River Rib valley, although in the southern part of the catchment, the fluvioglacial gravels are preserved as isolated terrace fragments. A smaller channel, mainly preserved as terrace fragments occurs in the Ash valley. Isolated fragments of fluvioglacial gravel cutting through the Chalk escarpment to the north may represent truncated fragments of this buried valley network.

Younger solifluction deposits cover many of the slopes and the bottom of the dry valleys across the catchment, with alluvium and post-Anglian river terrace gravels in the larger valleys.

The revised geological interpretation of the Rib, Ash and Stort catchments is based on existing baseline data together with new data gathered from field mapping, remote sensing and borehole data acquisition and interpretation.

2 Baseline Data

The new geological map and 3D geological model outlined in this report are based on the analysis of a number of datasets held by the British Geological Survey (BGS). They include both digital and analogue data, some with considerable spatial and temporal variability in quality. Datasets examined include borehole logs (both lithological and geophysical), geological maps (BGS Geology 1:10 000 and 1:50 000 scale data), original field slips, reports, topographical maps, digital terrain models, published papers and external reports. The model does not incorporate or review existing hydrogeological data such as groundwater levels, water quality, tracer or pump test results.

2.1 EXISTING GEOLOGICAL LINEWORK

Six 1:50 000-scale geological maps, published by BGS, cover the project area. These were published at different times and the geological interpretation varies.

The northwestern extremity of the project area is located on Sheet 204 (Biggleswade). This sheet was revised and resurveyed at 1:10 560 scale in 1930 to 1934. The area south of Northing 40 was resurveyed at 1:10 000 scale in 1986 to 1992 and published in 2001. A brief explanation of the geological map was published in 2004 (Moorlock et al., 2004).

The west of the catchment lies on Sheet 221 (Hitchin). This is a relatively modern sheet, last surveyed at 1:10 000 scale in 1982-1985 and 1987-1992 and published in 1995 (British Geological Survey, 1995). The memoir for the Hitchin sheet was published in 1996 (Hopson et al., 1996). Geological notes and local details for some 1:10 000 scale map sheets are documented in Aldiss (1991; 1992a, 1992b). The east of the catchment area lies on the western half of Sheet 222 (Great Dunmow). This sheet was surveyed at 1:10 000 and 1:10 560 scale between 1975 and 1985 and published in 1990.

The southwestern part of the catchment is on Sheet 239 (Hertford). This based on 1:10 560 scale surveys dating from 1911-14 and 1921. It was reconstituted for the one-inch scale without geological revision and reprinted on the 1st Series 1:50 000 base in 1978 (British Geological Survey, 1978). The memoir was published in 1924 (Sherlock and Pocock, 1924). The southeast corner of the project area lies on Sheet 240 (Epping). This was surveyed at one-inch scale and published in 1868-1884. It was surveyed at 1:10 560 scale in 1969-70 and 1975-77 and published in 1981. The memoir was published in 1987 (Millward et al., 1987).

The existing published 1:10,000 scale geology is shown in Figure 2. Figure 3 and Figure 4 show the existing published 1:50,000 scale geology. The Hitchin, Great Dunmow, Epping and Hertford published maps do not incorporate the new Chalk Group lithostratigraphy. The Chalk Group linework on the Hertford sheet dates from the original pre-1920s survey data, whilst the Hitchin, Great Dunmow and Epping sheets are based on more recent mapping. On all these sheets, the published paper map uses the old stratigraphical nomenclature. The digital map (Figure 3) has been updated to reflect the new stratigraphical terminology where possible using undivided formation names. The Biggleswade and Saffron Walden map sheets have subdivided the Chalk on the basis of the new Chalk stratigraphy, but this was done largely as a desktop revision. Subsequent work in the Beane and Upper Cam catchments demonstrates that these sheets also need revising. In particular the base of the Lewes Nodular Chalk was taken at the Chalk Rock but actually lies some distance below. In addition, the Top Rock, which is not shown on the published maps, can be mapped across the region.

The superficial deposits on the Hertford sheet predate the realisation that the early pre-Anglian River Thames once flowed through the Vale of St Albans and underestimates the complexity of the Anglian glacial deposits (Catt, 1978). The new mapping undertaken for this project has identified a sequence of river terrace deposits that relate to the early Thames, as well as post-Anglian terraces of the River Lea and its tributaries. At least three individual ice advances during the Anglian glaciation, interspersed with glacial meltwater gravels and glaciolacustrine deposits have been identified in the adjacent Beane catchment, and which continue eastwards onto the Great Dunmow and Epping sheets. On the Hitchin sheet, the superficial deposits are generally well mapped, but significant improvements were made in the depiction of the

Westland Green terrace gravels, which had often been mapped as glaciofluvial deposits, the buried valley fills, and the extent of the periglacial deposits.

Fieldwork on the Great Dunmow and Epping sheets shows that, whilst the Westland Green terrace gravels were mapped (but grouped with the Kesgrave Catchment Subgroup), they have often been grouped with more recent periglacial mass-movement deposits. In some cases, sand and pebble beds in the Lambeth Group, notably the Collier's End Pebble Bed, have been mistaken for Kesgrave Catchment Subgroup deposits.

Modern 1:10 000 scale digital linework was used where available. The available 1:10 000 scale bedrock and superficial data were restricted to the Hitchin, Great Dunmow and Saffron Walden 1:50 000 scale map sheet areas (Figure 2). For the rest of the model area, the only available pre-existing linework was from 1:10 560 scale county series surveys. The geological data on all of the 1:50 000 scale sheets were deemed inadequate for 3D modelling purposes, given that they did not show the new Chalk Group lithostratigraphical subdivisions, or many of the superficial deposits known to exist in the model area.

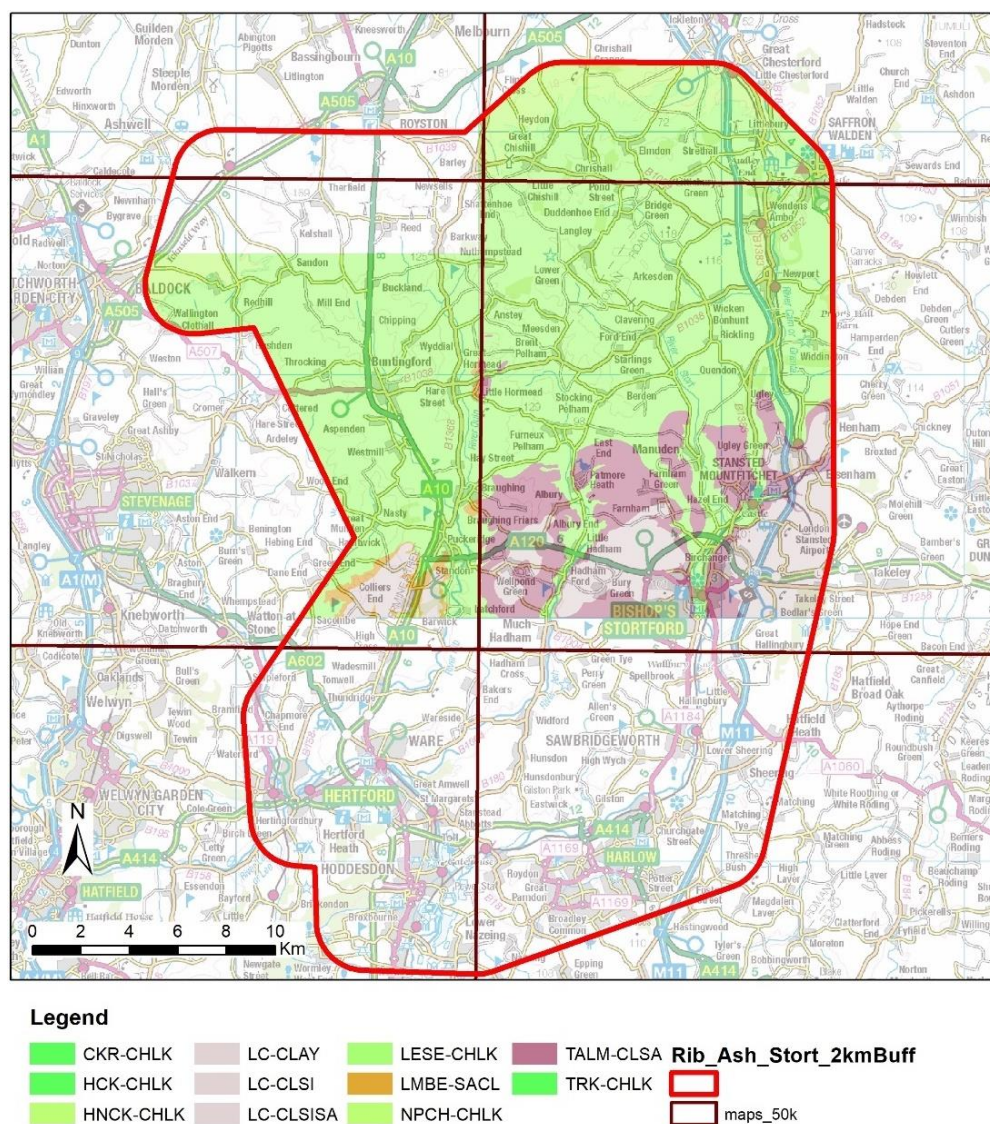
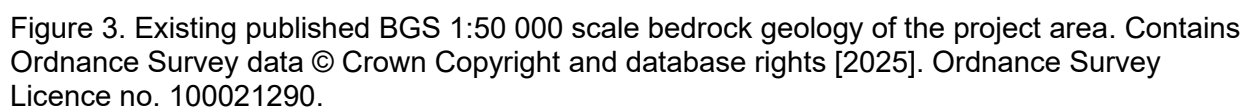
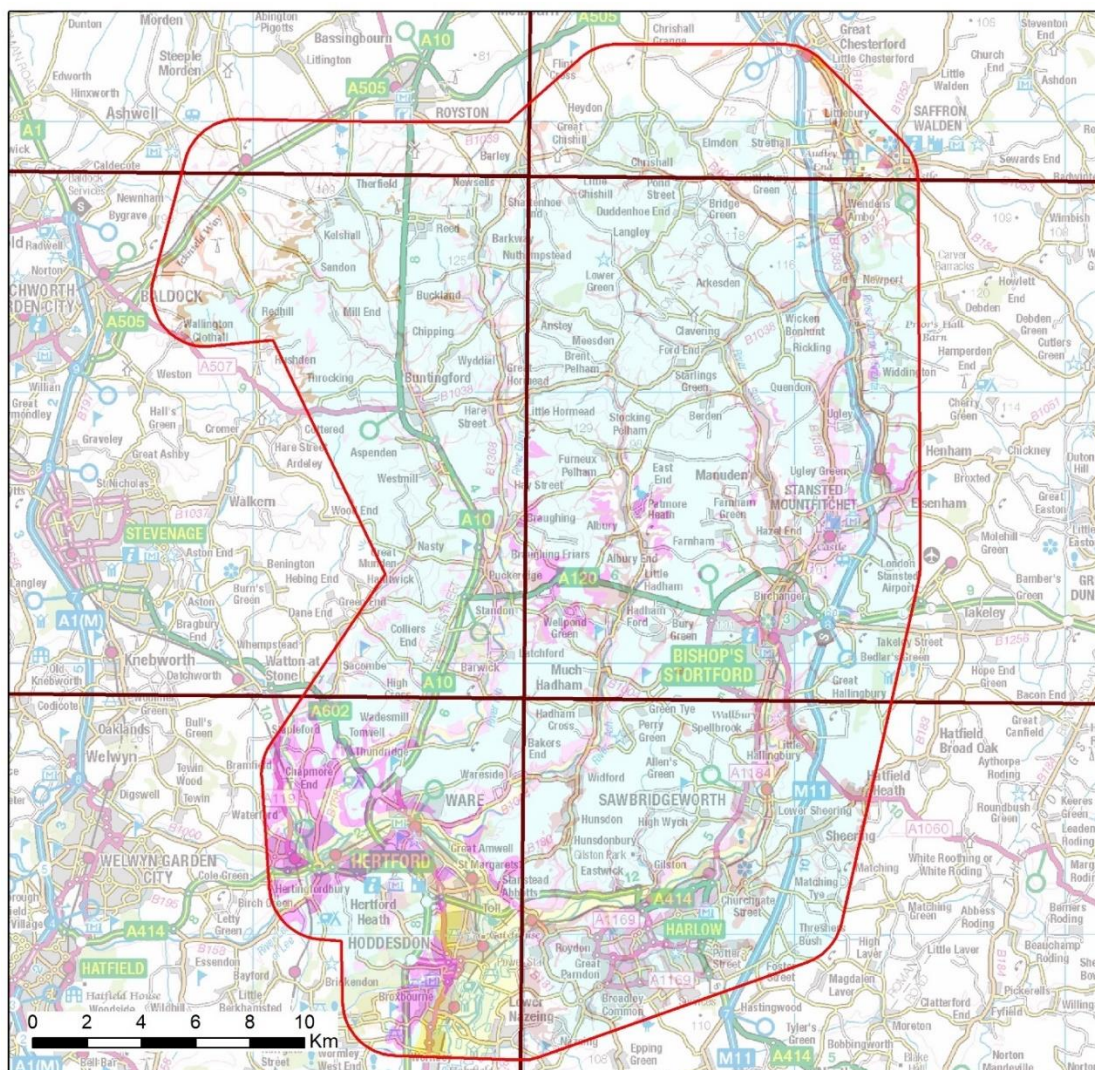


Figure 2. Existing published BGS 1:10 000 scale bedrock geology of the project area. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.





Legend

Rib_Ash_Stort_2kmBuff		LOFT-DMRC	IGLD-XCZ	RTD2-XSV
		LOFT-DMTN	KGCA-XSV	RTD3-XSV
	maps_50k	LOFT-XCZ	ALF-XCZSV	RTDU-XSV
LEX_RCS_I		LOFT-XSV	ALF-XSZ	SUPD-XSV
	ALV-XCZSV	11102249_DHGR-XSV	HEAD-XCZSV	SUPD-SED
	ESI-XCZ	GFDMP-XSV	HEAD-XVSZC	CWF-XCZSV
	KPGR-XSV	GLLMP-XCZ	PEAT-P	
	TPGR-XSV	TILMP-DMTN	RTD1-XSV	



Figure 4. Existing published BGS 1:50 000 scale superficial geology of the project area. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

2.2 GEOLOGICAL MAPPING

Geological surveying was carried out in 2022 and 2023 by A R Farrant, J R Lee and H Burke. The existing 1:50 000 scale linework was checked in the field and revised based on both existing field information and new data obtained from field observations, logging of quarry sections, borehole data, remote sensing datasets and palaeontological specimens.

2.3 BOREHOLE DATA.

Borehole records examined included logs held at both Keyworth and Wallingford. BGS holds approximately 4900 borehole records within the Rib-Ash-Stort catchment and buffer zone of 2 km (Figure 5).

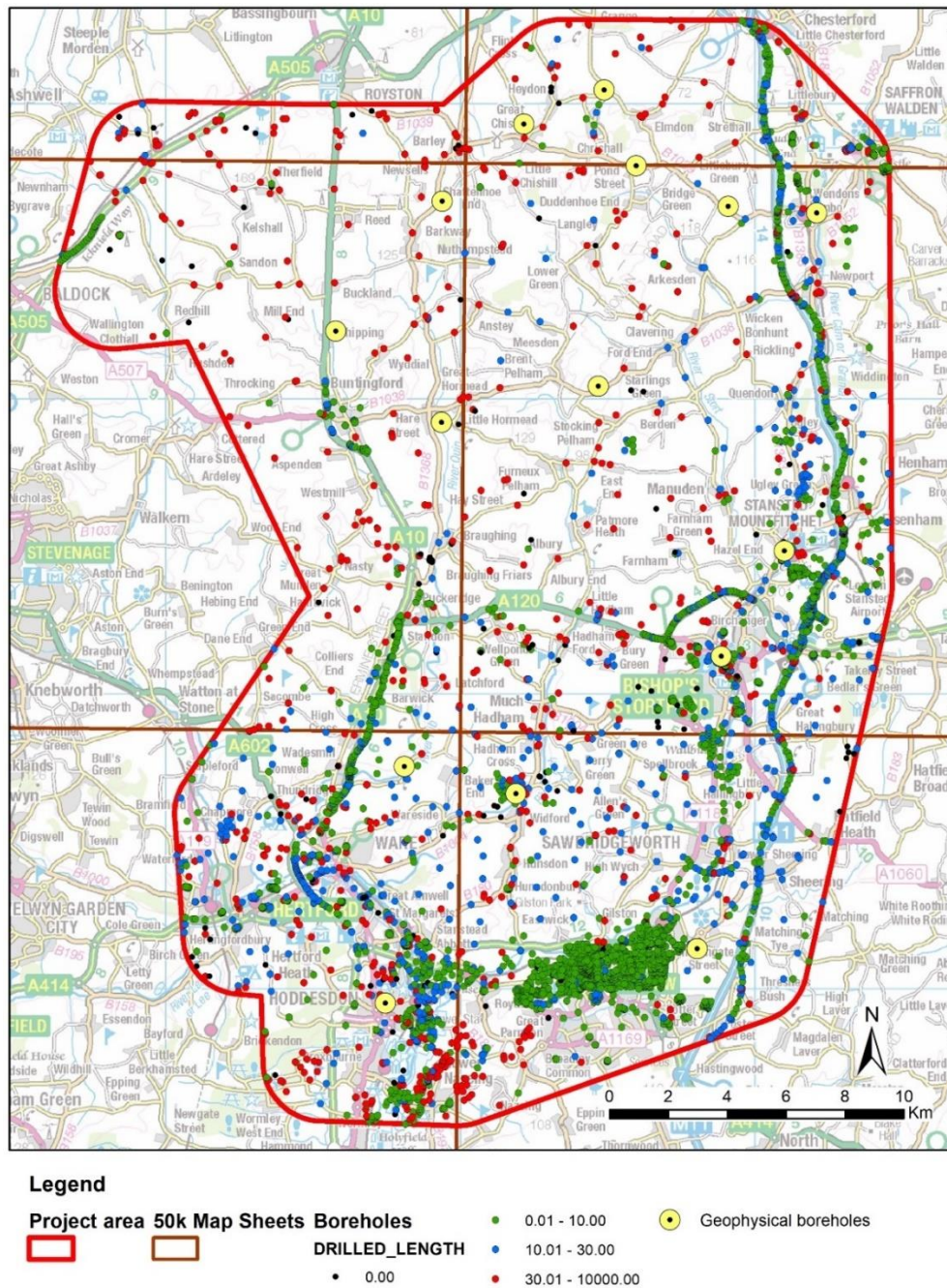


Figure 5. Lithological boreholes in the BGS SOBI database and geophysical boreholes. Contains Ordnance Survey data © Crown Copyright and database rights [2022]. Ordnance Survey Licence no. 100021290.

Not all of these were used in the mapping or modelling, as many are too shallow, of insufficient quality or do not contain data suitable for coding. Many of the Chalk boreholes are old water wells and do not contain enough information to determine the lithostratigraphy. Many borehole logs simply state 'chalk', although some identify particular stratigraphical horizons or units such as the Chalk Rock, which can be correlated with the standard Chalk Group lithostratigraphy, but the quality of the logs, many of which date back to the 19th Century, is often suspect. Some of the boreholes, particularly in excavations along major roads or in gravel quarries no longer fit the DTM. Others are shallow site investigation boreholes or trial pits, particularly along the major roads and motorways and were not deep enough to constrain the model.

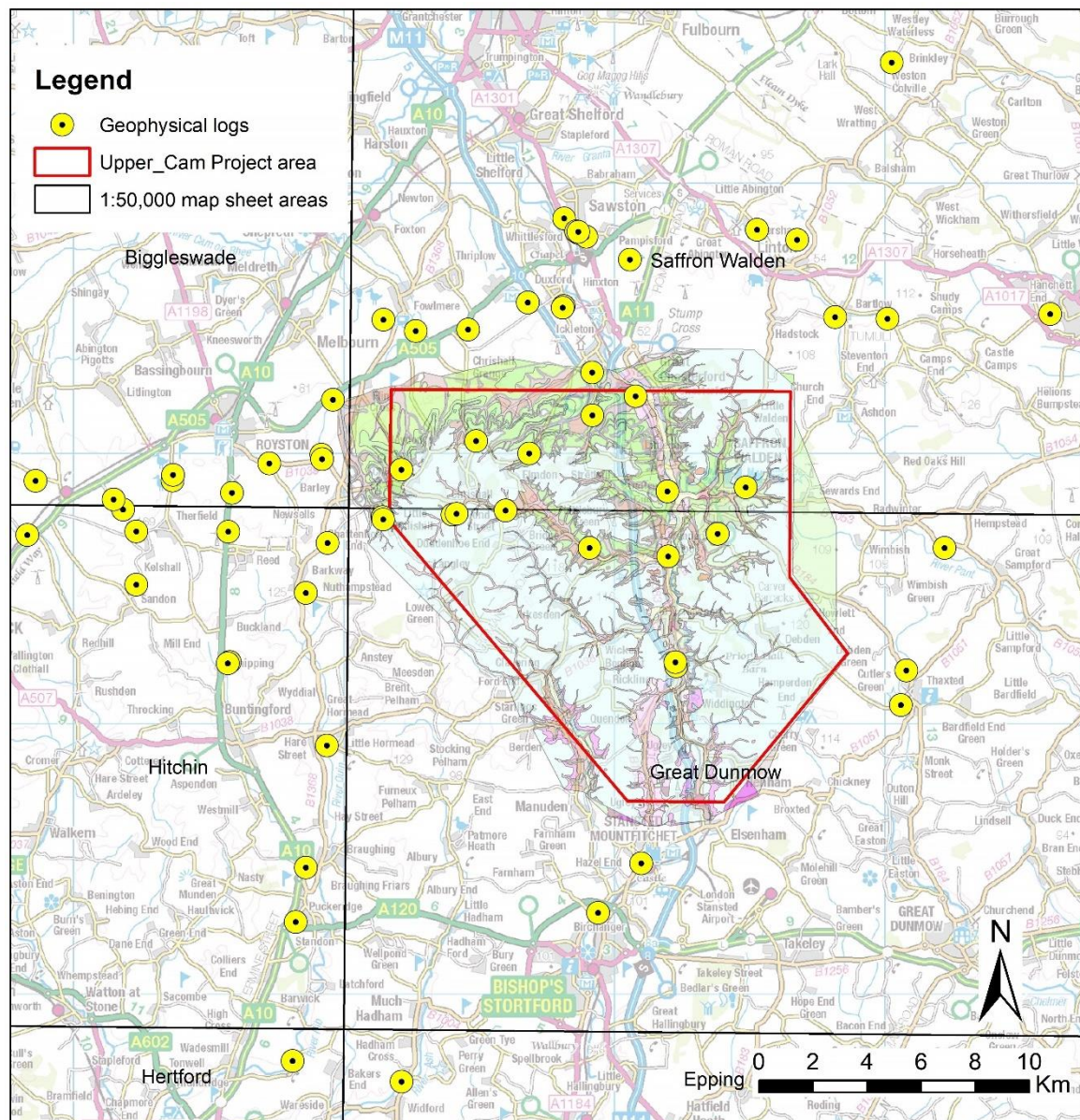


Figure 7. Geophysical Borehole location map showing locations of boreholes used in the Upper Cam catchment study. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

The Plenus Marls typically form a very sharp and easily identified low resistivity marker at the base of the Holywell Nodular Chalk, and the Chalk Rock/Top Rock form sharp peaks near the base of the Lewes Nodular Chalk. Between these large-scale regional markers there are particular intervals with distinctive log response patterns that allow fine-scale correlation and provide insight into how thickness patterns change laterally within Chalk formations. Confidence in borehole geophysical log correlations is based on data from cored and geophysically logged boreholes, where stratigraphical data can be related to geophysical log responses. For the Rib-Ash-Stort catchment work, ground-truth for the interpretations is provided by the Thundridge Borehole (Figure 8), the stratigraphy of which was published by Wood (1986).

Despite this, it is not always possible to be confident of geophysical log interpretations, partly because of variability in how the logs were acquired, and occasionally because the logged intervals of boreholes are too short and the inflections too ambiguous to confidently match with the signatures of adjacent boreholes. This aspect affects some short intervals of geophysical log (mainly within the New Pit and Lewes Nodular Chalk formations) reviewed as part of this study. For interpretation of the base of the Zig Zag Chalk Formation, typically coincident with the Totternhoe Stone in the Upper Cam catchment, interpretation of geophysical logs is guided by the cored and succession in the Thriplow Borehole just north of the project area (Woods, 1997) and the Stowlangtoft Borehole, near Bury St Edmunds, Suffolk (Figure 7 of Bristow, 1990).

Interpretation of the base of the Seaford Chalk Formation is guided by general stratigraphical knowledge of this unit, particularly its relatively high clay content in the lower part, and the likely responses of geophysical logs to this feature.

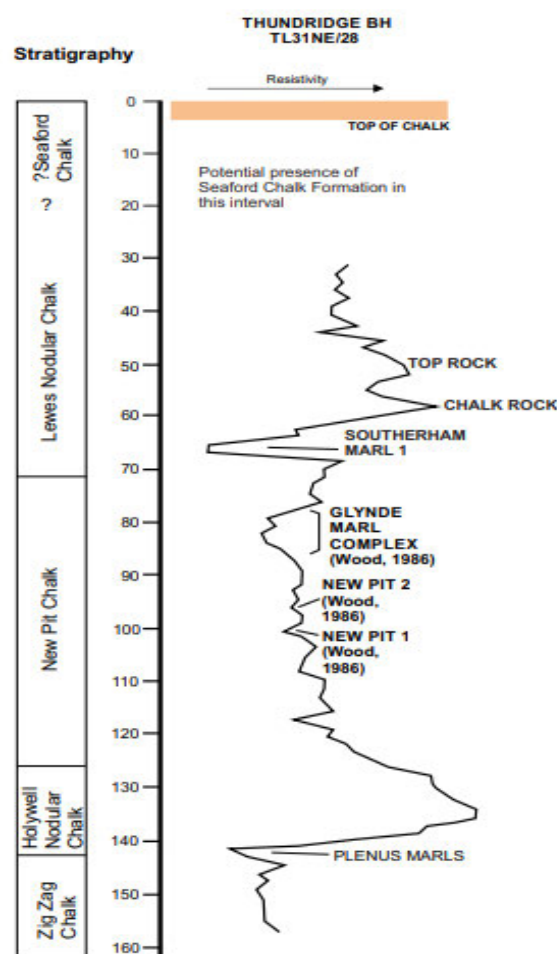


Figure 8. Borehole resistivity log of the Thundridge Borehole with stratigraphical interpretation. Based on Wood (1986) Figure 21.

The marker beds identified in this part of the Chilterns differ somewhat from those widely described in the Chalk of southern England. This partly reflects the particular character of the Chalk of East Anglia, which is identified as part of a distinct region of chalk sedimentation (the 'Transitional Province' of Mortimore, 1983). Marker beds identified on geophysical logs forming part of this work are briefly summarised below:

Cambridge Greensand: Unit of glauconitic sand rich in phosphatic nodules at the base of the Chalk Group and laterally equivalent to the Glauconitic Marl.

Totternhoe Stone: Unit of indurated, silty/sandy chalk at the base of the Zig Zag Chalk Formation, with erosive base that may locally cut deeply into the underlying West Melbury Marly Chalk Formation.

Jukes-Browne Bed 7: Comprises a marl-rich interval (typically with common oysters) overlain by a unit of hard, massive-bedded chalk.

Plenus Marls: Clay-rich interval, with interbedded limestones at the base of the Holywell Nodular Chalk Formation.

Marker-Marl 1 (M1): Informal marker bed identified in interpretations herein inferred to be a marl based on its geophysical log response.

Marker-Marl 2 (M2): As above. This marl seam is identified as New Pit Marl 1 by Wood (1986).

Pilgrim's Walk Marl (Glynde Marls) and associated marl seam(s) (herein: Pilgrims Walk Marl Complex): On geophysical logs often appears as a distinct pattern of low resistivity inflections

(the 'distinctive quadruple signature' of Mortimore & Wood (1986) or may be resolved into a wider low resistivity component with lower resistivity spikes at the base and top. Two marls have previously been identified with these inflections, the Pilgrim's Walk Marl underlain by a marl referred to as the 'Lower Marl'. Evidence from inter-regional correlations suggests that these two marls equate with the Glynde Marls of Mortimore (1986). These are a group of at least four marl seams occurring near the top of the New Pit Chalk Formation in southern England.

Mount Ephraim Marl (Southerham Marl 1): Strongly developed single marl seam that evidence from inter-regional correlations (Mortimore & Wood, 1986) suggests is laterally equivalent to Southerham Marl 1 of Mortimore (1986). This is a strongly developed marl seam typically a few metres above the base of the Lewes Nodular Chalk Formation in southern England.

Chalk Rock: An interval of highly cemented chalk in the middle part of the Lewes Nodular Chalk Formation. The Chalk Rock includes one or more hardgrounds and represents a period of restricted chalk deposition in the regions where it is developed. In southern England, where sedimentation was more continuous, equivalent strata are thicker and correspond with bands of hard nodular chalk.

Top Rock: An interval of hard cemented chalk in the middle part of the Lewes Nodular Chalk Formation up to 10 m above the Chalk Rock. Represents multiple hardgrounds and is a well-developed feature in East Anglia.

Initial borehole correlations are shown in Figure 9 and Figure 10.

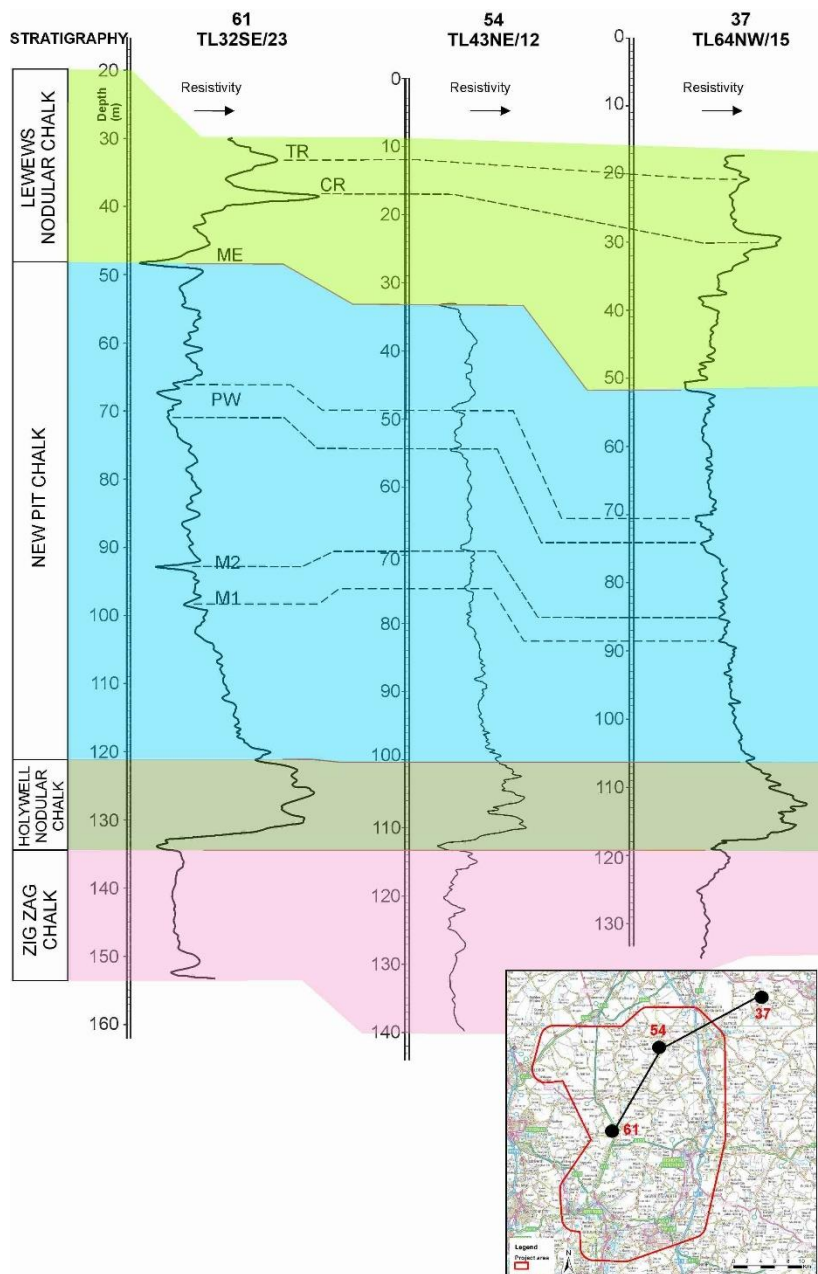


Figure 9. Key borehole correlation across the northern part of the project area. Inset map contains Ordnance Survey data © Crown Copyright and database rights [2022]. Ordnance Survey Licence no. 100021290.

CORRELATION LINE

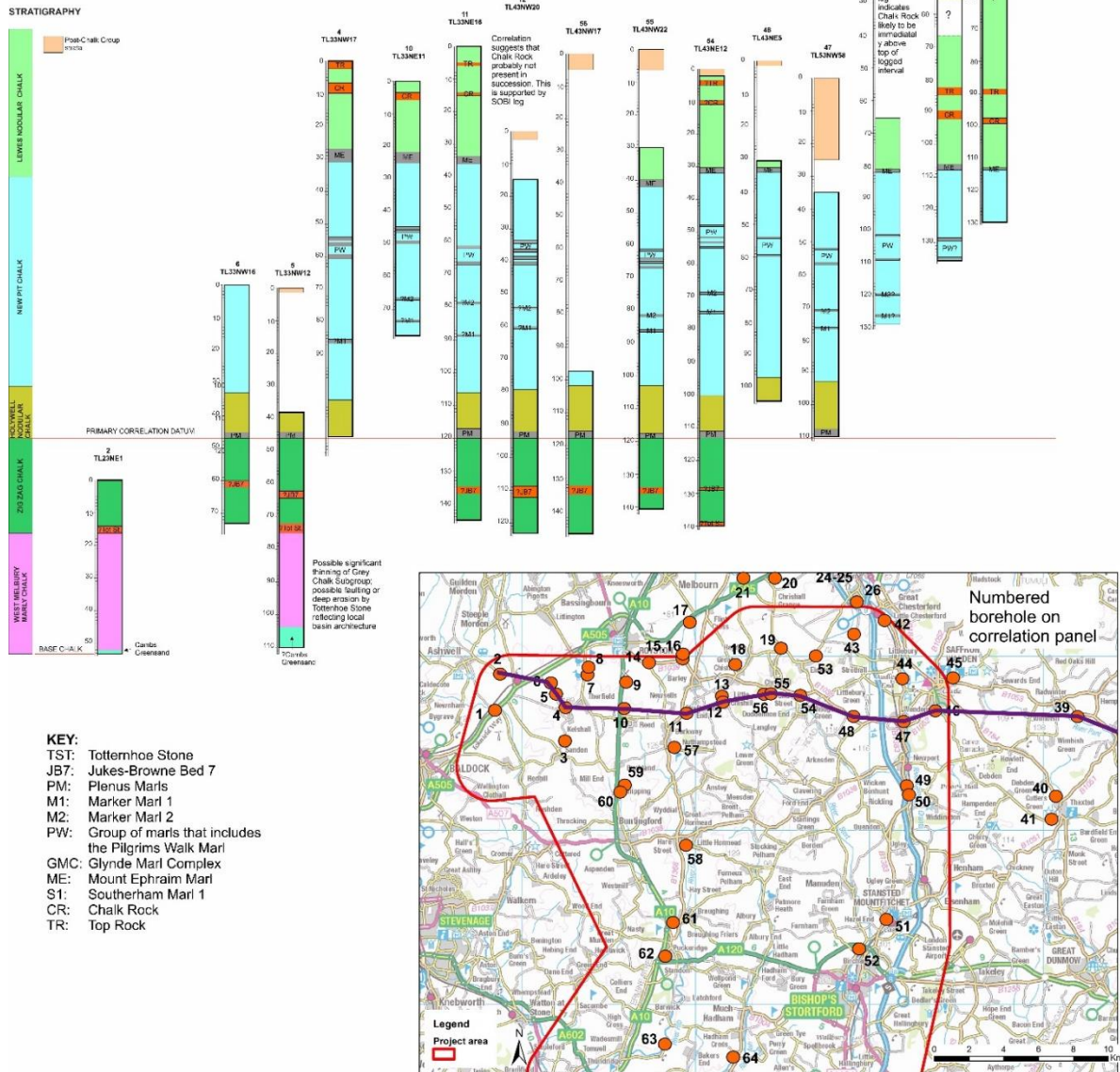


Figure 10. Key borehole correlation aligned east-west across the northern part of the project area. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

2.4.1 Base of the Lewes Nodular Chalk Formation

The criteria adopted for interpreting the base of the Lewes Nodular Chalk Formation in the northern part of the catchment differ from those outlined in previous accounts (Woods & Aldiss, 2004; Woods, 2006; Woods & Chacksfield, 2012). Typically, the base of the Lewes Nodular Chalk Formation can be interpreted by an upward trend of increasing resistivity log values (compared to the typically low resistivity values of the New Pit Chalk Formation) that begins a few metres below the Southerham Marl 1. This is seen in the resistivity log for the Thundridge borehole, south-west of the project area (Figure 8), and corresponds in outcrop with the appearance of nodular and gritty-textured chalk. This change is typically a few metres above the Glynde Marls.

In the Upper Cam catchment in the northeast of the project area, resistivity logs for the equivalent interval (between the Pilgrim's Walk Marl Complex and Mount Ephraim [=Southerham] Marl) are similar to the underlying chalk succession, and do not show any systematic increase in values until above the Mount Ephraim Marl. The interval between the Pilgrim's Walk Marl Complex and Mount Ephraim Marl is also significantly thicker than the interval between the corresponding Glynde Marls and Southerham Marl 1. This evidence suggests a change in the lithological development of the base of the Lewes Nodular Chalk Formation in the Upper Cam district and more widely in East Anglia (Woods & Chacksfield, 2012), with significant expansion of sedimentation corresponding with the uppermost New Pit Chalk and basal Lewes Nodular Chalk formations. In the absence of any significant geophysical log characteristics to interpret the base of the Lewes Nodular Chalk Formation below the Mount Ephraim Marl, this marl seam is used herein to define the base of the Lewes Nodular Chalk Formation. Elsewhere in East Anglia, a concentration of flint-rich strata (Brandon Flint Series), between the Mount Ephraim Marl and Chalk Rock, has been used as a feature to map the base of the traditional 'Upper Chalk'. The lack of surface outcrops in this region presents difficulties in tying the geophysical log responses to surface features.

2.4.2 Features and trends revealed by borehole geophysical log correlations

The geophysical log correlation panels shown in Appendix 2 reveal a number of features of interest relevant to the Chalk Group of the region, although some of the finer details cannot be mapped across the region with any certainty. These comprise:

Variability in the thickness of the lower part of the New Pit Chalk Formation

A pair of low resistivity log inflections, informally named Marker Marl 1 and Marker Marl 2, form useful correlation horizons in the lower and middle part of the New Pit Chalk Formation. Both inflections can be recognised in the Thundridge Borehole, where Marker Marl 2 was identified by Wood (1986) as New Pit Marl 1. It is notable across the Upper Cam catchment that the thickness of New Pit Chalk preserved below Marker Marl 1 is somewhat variable (for example ca. 16 m in borehole 26 and ca. 24 m in the Thundridge Borehole). There is notable local thickening between boreholes 54 and 55 (Appendix 2), in the vicinity of Chrishall and Bridge Green, that does not affect younger marker-beds and might reflect the influence of local structure.

Variability within the upper part of the New Pit Chalk Formation

As noted previously, this interval in the Upper Cam district includes strata that are likely coeval with the basal Lewes Nodular Chalk Formation elsewhere. Variation in the thickness of this interval is quite marked across the project area (16 – 27 m). The trend shown by the geophysical boreholes suggests progressive thinning of the upper New Pit Chalk Formation eastwards out of the project area.

Interval of separation between the Chalk Rock and Top Rock

Typically, the separation of the Chalk Rock and Top Rock across the Cam catchment is c. 10 m. This unit is defined as the Kensworth Nodular Chalk Member. However, locally these narrow to ca. 5 m, for example in a borehole in the Upper Cam valley near Widdington, and in a borehole in the Quin valley near Hare Street. A nearby borehole shows a more typical spacing of Chalk Rock and Top Rock, potentially suggesting a local basin feature or structure that increased restriction of chalk sedimentation. The Chalk Rock and Top Rock are mapped in the northeast of the project area, where they are typically around 8-10 m apart.

2.5 BIOSTRATIGRAPHICAL DATA

Biostratigraphy can provide useful information to augment the mapping. Fossil records from the BGS archives were examined (Woods, 1993, 2000) and reinterpreted based on the modern Chalk stratigraphy.

3 Bedrock Geology

The model area is underlain by the Upper Cretaceous Chalk Group and the Paleogene Lambeth and Thames groups. The 1:10 000 scale bedrock units are listed with their BGS Lexicon (LEX) and lithology codes in Table 1 in stratigraphical order from oldest to youngest. LEX codes can be searched in the BGS Lexicon of Named Rock Units and lithology codes can be searched in the BGS Rock Classification Scheme for further information about the geological units and their lithologies on the BGS website (www.bgs.ac.uk).

Deposit Name	Lithology	LEX code in model
RED CRAG FORMATION	S	RCG
LONDON CLAY FORMATION	CLSSG	LC
LAMBETH GROUP	CLSSG	LMBE
SEAFORD CHALK FORMATION	CHLK	SECK
LEWES NODULAR CHALK FORMATION	CHLK	LECH (above Chalk Rock)
LEWES NODULAR CHALK FORMATION	CHLK	LECH (below Chalk Rock)
NEW PIT CHALK FORMATION	CHLK	NPCH
HOLYWELL NODULAR CHALK FORMATION	CHLK	HCK
ZIG ZAG CHALK FORMATION	CHLK	ZZCH
WEST MELBURY MARLY CHALK FORMATION	CHLK	WMCH

Table 1. List of mapped bedrock formations used in the model.

The new bedrock geology map is shown in Figure 11. Much of the southern half of the catchment is underlain by Paleogene strata, with Chalk exposed in the Rib, Ash and Stort valleys. The Red Crag Formation occurs as a series of poorly constrained outliers in the east. The Seaford Chalk Formation and the Lewes Nodular Chalk Formation above the Top Rock underlie the dip slope. The outcrop of the lower part of the Lewes Nodular Chalk Formation including the Top Rock and Chalk Rock, and the underlying New Pit Chalk Formation are restricted to the Chalk escarpment. The Holywell Nodular Chalk Formation is not exposed at surface within the project area but probably does occur at rock-head at the base of the Upper Cam buried valley.

3.1 CHALK GROUP

Traditionally, the Upper Cretaceous “Chalk” was divided into three units, effectively of formation status; the Lower Chalk, Middle Chalk and Upper Chalk. Named members or beds within these units, such as the Glauconitic Marl, the Melbourne Rock and the Chalk Rock (which occur at the respective bases of the three traditional units) were widely recognised (Table 2). However, following work by Robinson, (1986), Mortimore (1983, 1986) and Bristow et al., (1995, 1997), a more detailed lithostratigraphical subdivision of the Chalk was devised (Hopson et al., 2005). The Chalk Group in the Chilterns is divided into two Subgroups, each with constituent formations (Table 2), which now form the basis for the mapping of the Chalk across southern England, and are used in this study (Rawson et al., 2001).

The lower part of the Chalk Group comprises the Grey Chalk Subgroup. This is defined as the succession from the basal Cenomanian unconformity up to the base of the Plenius Marls Member of the succeeding White Chalk Subgroup. It comprises two formations, a lower West Melbury Marly Chalk Formation and an upper Zig Zag Chalk Formation with the boundary in between placed at the base of the Cast Bed or Totternhoe Stone. The base of the Grey Chalk Subgroup is taken as the base of the Glauconitic Marl Member. Historically, this succession has been included within the Lower Chalk. The upper part of the Chalk Group comprises the White Chalk Subgroup. This is defined as the succession from the base of the Plenius Marls Member of the Holywell Nodular Chalk Formation up to the youngest chalk lithology present beneath the unconformity at the base of the overlying Paleogene or Quaternary deposits. In this area, it comprises four formations. In ascending order, these are the Holywell Nodular Chalk, the New Pit Chalk, the Lewes Nodular Chalk and the Seaford Chalk formations. The Newhaven Chalk Formation is absent in this area.

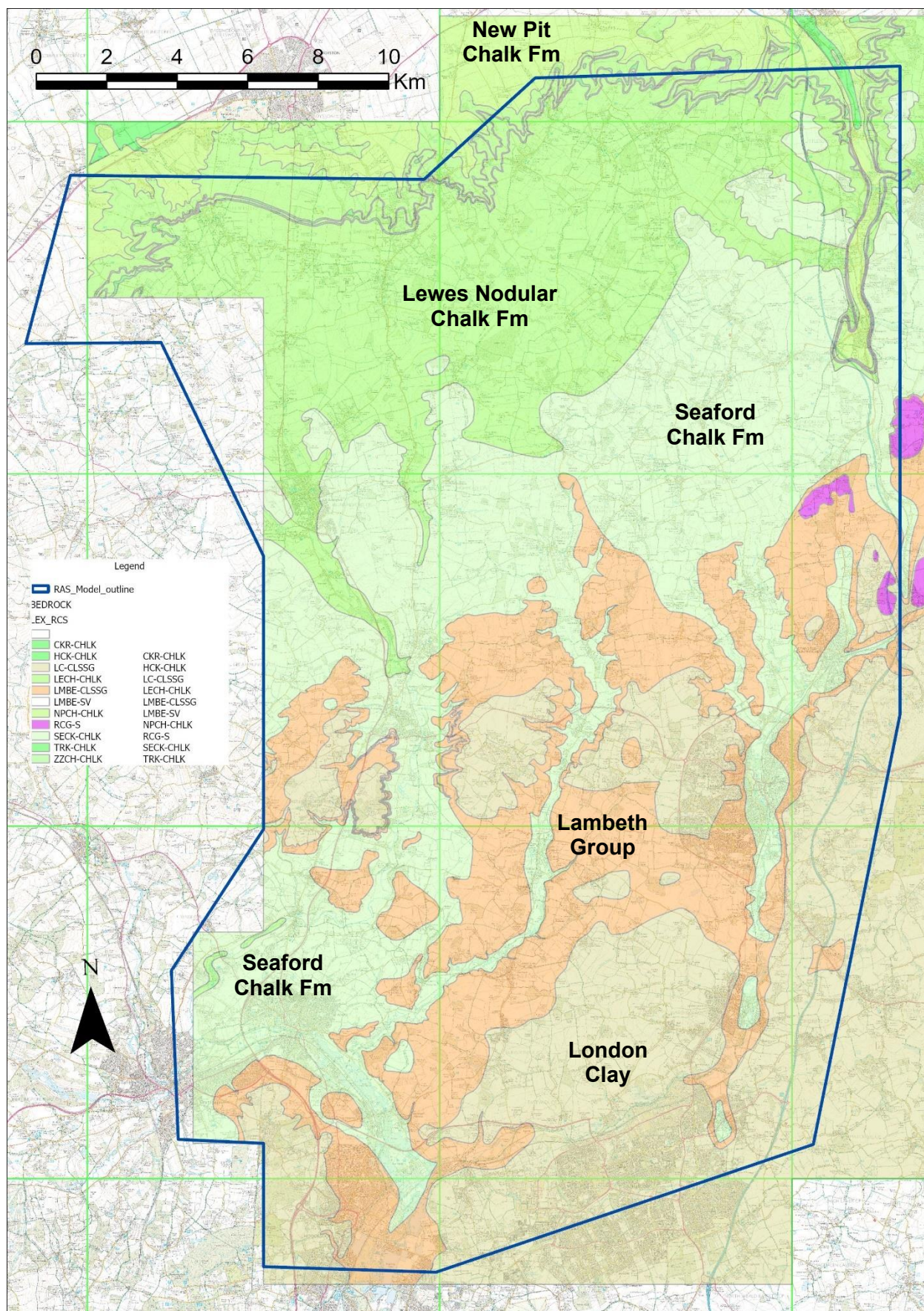


Figure 11. Updated bedrock geology map. The legend shows the lex-rock codes for each unit, for details see <https://webapps.bgs.ac.uk/lexicon/home.cfm>.

Stage	Foraminiferal Zones*		Macrofossil		Traditional southern England subdivisions	North Downs Robinson (1986)	South Downs Mortimore (1986)	Dorset Bristow et al. (1995)	Southern England Bristow et al. (1997)	Southern England Rawson et al. (2001)
	UKB	BGS	Zones	Subzones						
Campanian (pars)	17 & 18 (lower)	21	<i>Belemnitella mucronata</i> s.l.		Upper	Sussex White Chalk	Portsmouth	Upper Chalk	Upper Chalk	White Chalk Subgroup
	16	20	<i>Gonioteuthis quadrata</i>	'post <i>A. cretaceus</i> beds' ' <i>Applithoceras cretaceus</i> 'Hagenovian Horizon' 'abundant <i>O. pilula</i> ' <i>Echinocorys depressula</i>			Culver			
	15 (upper)	19	<i>Offaster pilula</i>				Newhaven			
Santonian	uppermost 14 & lower 15	18	<i>Uvuliceras anglicus</i> <i>Marsupites testudinarius</i> <i>Uvuliceras socialis</i>		Upper	Ramsgate Chalk Formation		Upper Chalk	Upper Chalk	White Chalk Subgroup
	14 (rest)	17	<i>Micraster coranginum</i>				Margate Member			
	13 12 (upper) 12 fl. & m.	16 15 14	<i>Micraster cortestudinarius</i>				Broadstairs Member			
Coniacian	11	13	<i>Sternotaxis plana</i>		Middle	Dover Chalk Fm	Lewes	Middle Chalk	Middle Chalk	White Chalk Subgroup
	10 (upper)	12	<i>Terebratulina lata</i>							
	10 (lower & middle)	11	<i>Mytiloides</i> spp.							
Turonian	10 (basal)	10	<i>Neoscaliscus indidit</i> <i>Meloboceras testudinum</i> <i>Calymene guerickei</i> <i>Acanthoceras jukesbrownei</i> <i>Acanthoceras rhodanense</i> <i>C. interne</i>		Lower	Lower Chalk	New Pit	Lower Chalk	Lower Chalk	Grey Chalk Subgroup
	(modified)	9	<i>Mantelliceras mantelli</i>				Holywell			
	9 (upper) 8 (lower)	8 7 6 5	<i>Stoliczkaia dispar</i>							
Cenomanian	8 (upper) 7 6 5	8 7 6 5	<i>Stoliczkaia dispar</i>		Lower	Lower Chalk		Lower Chalk	Lower Chalk	Grey Chalk Subgroup
	5	4	<i>Stoliczkaia dispar</i>							
	4	3	<i>Stoliczkaia dispar</i>							
Upper Albian (pars)	3 2 1 & 2	3 2 1	<i>Stoliczkaia dispar</i>		Upper	Upper Greensand		Upper Greensand	Upper Greensand	Upper Greensand/Gault
			<i>Stoliczkaia dispar</i>							
			<i>Stoliczkaia dispar</i>							

* Foraminiferal Zones after Hart et al., (1989) (UKB zones) and Wilkinson (2000) (BGS zones). Not to scale.

Table 2. Correlation of biostratigraphical and lithostratigraphical classification schemes for the Chalk of southern England (based on Hopson, 2005).

The Lewes Nodular Chalk Formation contains two distinct, mappable marker beds. These are the Chalk Rock and the Top Rock. The interval between the Chalk Rock and the top of the Top Rock is defined as the Kensworth Nodular Chalk Member. These are visible at outcrop but poorly represented in borehole logs.

The inflection patterns of the geophysical logs allow inference of Chalk Group formations, and the following units and thickness ranges are identified from the geophysical logs. The thickness of the formations may vary from these values away from geophysically logged boreholes. In the Beane catchment, the following thickness were interpreted:

Zig Zag Chalk Formation	26 m
Holywell Nodular Chalk Formation	13 – 17 m
New Pit Chalk Formation	55 – 63 m
Lewes Nodular Chalk Formation	50 m (minimum of ca. 40)
Seaford Chalk Formation	at least 45 m (but cut out by Palaeogene erosion)

In the Upper Cam catchment, the following thickness were interpreted:

West Melbury Marly Chalk:	24 – 27 m
Zig Zag Chalk:	23 – 27 m
Holywell Nodular Chalk:	13 – 17 m
New Pit Chalk:	56 – 73 m
Lewes Nodular Chalk:	ca. 45 m
Seaford Chalk:	at least 58 m inferred.

3.1.1 West Melbury Marly Chalk Formation (WMCH)

The West Melbury Marly Chalk Formation is relatively thin in this area. It is not exposed within the project area but occurs at the surface outside the area to the north. It comprises grey marly chalk interbedded with several hard, grey limestones. Some of these limestone beds, such as the 'Doolittle Limestone' and the 'Dixoni Limestone' form spring lines at the base of the Chiltern Hills escarpment to the west between Hitchin and Princes Risborough. Mapping evidence suggests this unit is 30-40 m thick around Totternhoe, thickening eastwards to around 40-45 m, and locally 50 m north of Luton, but thinning eastwards. Geophysical logs suggest the formation is between 24 and 37 m thick in the Beane catchment, but no geophysical logs penetrate below the base of the Zig Zag Chalk Formation in the project area. This lack of deep boreholes across the model area means that the formation cannot be modelled accurately.

Geophysical logs to the north of the region suggest the formation is between 24 and 37 m thick. Borehole TL44SE90 near Great Chesterfield which suggests a thickness of c. 25 m. For the purposes of the model, the West Melbury Marly Chalk Formation is modelled with a thickness of 25 m thick because of insufficient borehole evidence to constrain thickness variations. 25 m is the typical expected thickness in the absence of borehole data within the project area.

3.1.2 Zig Zag Chalk Formation (ZZCH)

The Zig Zag Chalk Formation is typically composed of soft to medium-hard, pale grey, blocky massively bedded chalk, with some beds of limestone near the base. The basal part of the formation is marked by the Totternhoe Stone, a bed of hard glauconitic phosphatic limestone 0.8-5 m thick. This rests with a slight unconformity on the West Melbury Marly Chalk Formation. No flints are recorded in the Zig Zag Chalk Formation. Like the West Melbury Marly Chalk Formation, the lower part of the Zig Zag Chalk Formation is poorly exposed. In the Hitchin area, it crops out along the base of the Chiltern Hills escarpment. The only area where it crops out at surface in the project area is in the far northwest near Odsey. In the Hitchin area, the Zig Zag Chalk Formation is typically around 15-20 m thick at outcrop. Geophysical logs suggest the Zig Zag Chalk Formation increases in thickness to about 26 m in the Beane Catchment, and is between 24 and 37 m thick in the Upper Cam catchment with significant variability. The cross-sections suggest the Zig Zag Chalk Formation may occur at rockhead in the bottom of the Upper Cam buried valley in the Bordeaux Farm area near Little Chesterford but otherwise does not crop out.

Away from the escarpment relatively few boreholes penetrate into the Zig Zag Chalk Formation, which limits the mapping of thickness variations across the project area. Only a few geophysical logs penetrate through to the base of the Zig Zag Chalk Formation, most of which are in the far north of the project area near the Chalk escarpment. These suggest thicknesses of c. 23-27 m. The lack of deep boreholes across the model area means that the formation cannot be modelled accurately. For the purposes of the model, the Zig Zag Chalk is taken as being 25 m thick. It is likely that the thickness will vary across the region, but there is little evidence to constrain this.

3.1.3 Holywell Nodular Chalk Formation (HCK)

The Holywell Nodular Chalk Formation underlies relatively gently sloping ground in the middle part of the Chiltern Hills escarpment, usually above a positive topographic feature marking the 'Melbourne Rock' at the base of the formation. It crops out along the base of the main escarpment between Baldock and Royston. It does not outcrop within the project area but is present just north of the railway line between Baldock and Steeple Morden where it is possibly faulted against the New Pit Chalk Formation. The Holywell Chalk Formation is lithologically varied, comprising medium hard to very hard, nodular, often shelly white to creamy white chalk with many marl seams consisting of clay-rich chalk including flaser-laminated marls. These nodular chalks are likely to be well fractured.

The basal unit is the Plenus Marls Member, consisting of 1-1.5 m of alternating beds of slightly greenish grey marls and marly limestones, resting with marked colour contrast on the eroded and burrowed surface of the Zig Zag Chalk Formation. The top of the formation is marked by the Gun Gardens Main Marl, which is probably equivalent to the 'Odsey Marl' of the Hitchin memoir (Hopson et al., 1996). There are no flints in the Holywell Nodular Chalk Formation, although just north of the project area an unusual flint-rich zone of the Holywell Nodular Chalk Formation occurs at Steeple Morden (Hopson et al., 1996). The formation is typically around 15 m thick across the catchment, but may vary from c. 13-17 m. Again, thickness variations cannot be accurately mapped away from the escarpment because relatively few boreholes penetrate the Holywell Nodular Chalk Formation.

3.1.4 New Pit Chalk Formation (NPCH)

The New Pit Chalk Formation is composed of massively bedded, white chalks with pairs or groups of conspicuous marl seams, including the Glynde and New Pit 1 & 2 marls. It is generally medium hard but softer than either the Holywell Nodular Chalk or Lewes Nodular Chalk formations, with well-developed conjugate joint systems. The marl seams may cause localised development of dissolutional conduits and perching of groundwater flow. Flints are very sparse, except in the upper part, but some sporadic small flints do occur even to within a few metres of the base, but they are not a conspicuous part of the sequence. The New Pit Chalk Formation is ca. 65 - 70 m thick in the northern part of the catchment, thinning to around 56 m in the Thundridge borehole and 54 m in a borehole at Ware and in the east of the district.

The New Pit Chalk Formation only occurs in the far north of the project area, where it is poorly exposed on the lower slopes of the main Chalk escarpment between Royston and Great Chesterford. There are few exposures along the escarpment, although the Baldock bypass section (Mortimore, 2014; Woods and Chacksfield, 2012) further west formerly exposed the upper 20 m of the formation. Kensworth Quarry in the Ver catchment near Luton exposes nearly all of the New Pit Chalk Formation and the basal part of the Lewes Nodular Chalk Formation (Farrant et al., 2019). It is likely that the New Pit Chalk Formation occurs at rockhead beneath much of the Cam buried valley between Littlebury and Newport.

3.1.5 Lewes Nodular Chalk Formation (LECH)

The Lewes Nodular Chalk Formation has an extensive outcrop in the northern part of the project area. It forms the high ground at the top of the escarpment and crops out in the upper headwaters of the River Quin catchment, extending down the valley as far south as the Great Hormead area. Likewise, in the Rib catchment, the Lewes Nodular Chalk Formation extends down the valley as far south as Braughing. It reappears at surface in the valley floor in the Westmill area near Hertford.

The lower part of the formation comprises weakly nodular flinty chalks with marl seams up to c. 24 m thick. This is overlain by a succession of intensely hard porcellanous chalk and glauconite stained hardgrounds (Chalk Rock), and a second hardground a few metres above (Top Rock). The upper part of the Lewes Nodular Chalk Formation comprises softer, blockier chalk with regular flint and marl seams.

The lower part of the formation is not well exposed. The excavation for the Baldock bypass to the west of the project area (Mortimore, 2014; Woods and Chacksfield, 2012) temporarily exposed a section through the lower Lewes Nodular Chalk Formation (Figure 13) but is no longer available. Further west, Kensworth Quarry near Luton exposes around 15 m of Lewes Nodular Chalk Formation below the Chalk Rock where the base is at the uppermost Glynde Marl. The lower part comprises 8-9 m of blocky massive chalk with scattered flint bands and thin marl seams up to the conspicuously thick Southerham Marl. Above this is 7 m of weakly nodular chalk with flints, some thin hardgrounds and the Caburn Marl, passing up into the Chalk Rock. In the Beane catchment, this interval is about 20-24 m thick based on the Baldock bypass section. This part of the succession is significantly expanded compared to the Kensworth Quarry section where it is about 14 m thick (Figure 13). In the north of the Rib-Ash-Stort region it is estimated to be about 15-20 m thick.

The Chalk Rock (which defined the base of the former 'Upper Chalk'), is a 2-3 m thick succession of highly condensed strata comprising nodular chalk hardgrounds and very hard porcellanous chalkstone. It comprises a series of diachronous hardgrounds, which cuts out and condenses much of the lower part of the Lewes Nodular Chalk Formation. In the Beane catchment, the Chalk Rock predominantly comprises the Hitch Wood Hardground (Bromley and Gale, 1982). It forms a distinct feature along the top of the escarpment between Baldock and Royston and can be traced along the escarpment between Barley and the Upper Cam valley.

Above the Chalk Rock is an interval of softer chalk overlain by a second higher hardground known as the Top Rock. This interval is known as the Kensworth Nodular Chalk Member. The base is defined at the top of the Chalk Rock, and the top is taken at the upper surface of the Top Rock hardground. The thickness of the Kensworth Nodular Chalk Member increases to the north and east (Figure 13). At Kensworth Quarry in the Ver catchment to the west of the area, the Top Rock is only 2 m above the Chalk Rock. Consequently, in the Ver and Mimram catchments, the Chalk Rock and Top Rock become indistinguishable in the field, and instead, a combined Chalk Rock-Top Rock unit was modelled. In the Beane catchment, the thickness of the intervening soft chalk increases to about 4 m in the northwest around Baldock, and to around 5-6 m east of Clothall, where the Top Rock becomes a distinct feature in its own right, and about 8-10 m around Great Chesterford in the Cam valley. North of Bishops Stortford this interval is about 8-10 m thick. In the south of the project area, the interval in the Thundridge borehole is about seven metres. Consequently, it is possible to map the Chalk Rock, the Top Rock and the intervening bed as separate units along the Chalk escarpment. On previous maps, only a single hardground (the 'Chalk Rock') was identified and mapped, but in reality, it was often conflated with the Top Rock. However, the sparse nature of the geophysical borehole data further south meant that the Top Rock could not be reliably modelled across the catchment.

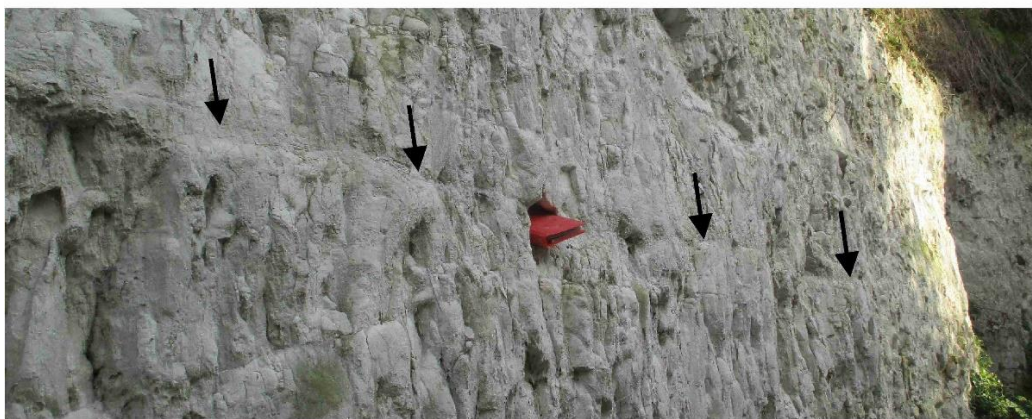
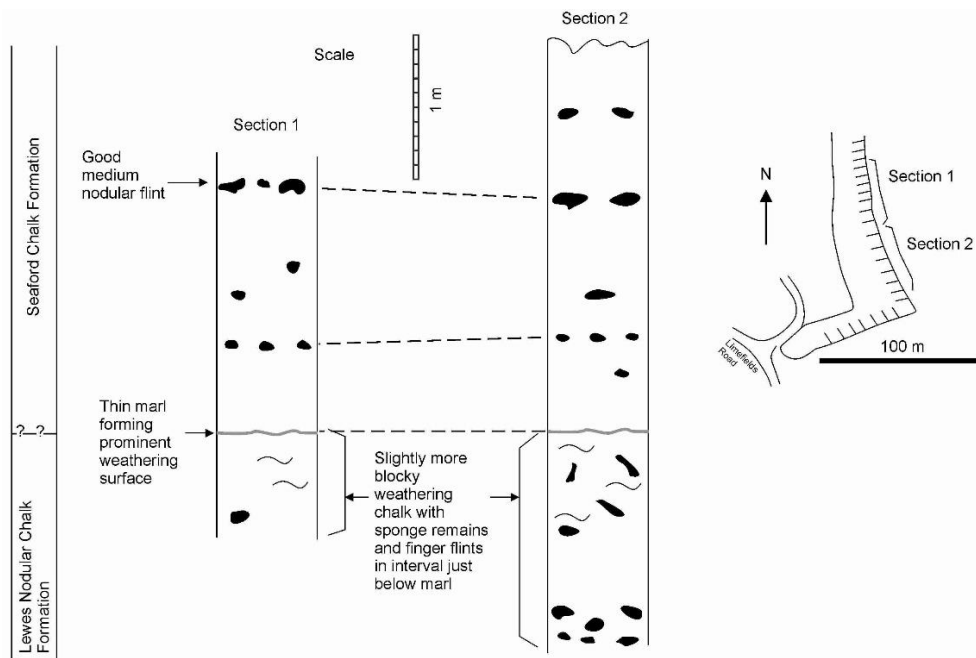
The Top Rock itself is a rather less well-developed hardground than the Chalk Rock, typically 2-3 m in thickness. In the north and east, the Top Rock forms a distinct mappable feature along the northern edge of the project area about 6-8 m above the Chalk Rock between Barley and the Upper Cam valley.

The upper part of the Lewes Nodular Chalk Formation comprises softer blocky smooth white flinty chalk with some hardgrounds and weakly developed nodular chalks. The first regular seams of flint appear above the Chalk Rock and are a conspicuous part of the sequence. Most flints are nodular, but some tabular flints also occur. The flints are typically black or bluish black with a thick white cortex. Carious (rotten or hollow) flints are common at the top of the formation, which is taken at the Shoreham Marl 2.

LOCAL DETAILS:

The top of the Lewes Nodular Chalk Formation is exposed in the Limefields Pit Nature Reserve (TL 541 396) north of Saffron Walden. About 6 m of chalk is presently exposed (the quarry was once much deeper but was partially backfilled in 1988), and around 20 m was visible in 1932. The published memoir (White, 1932) reports numerous fossils collected from this site. Material collected in 1876 was re-examined as part of this project. Specimens include *Micraster cortestudinarium*; *Echinocorys scutata* and *Cremonoceras* sp. Historical fauna from the site unequivocally indicates the *Micraster cortestudinarium* Zone, and the upper part of the Lewes Nodular Chalk Formation. Lithological data from the current exposure (Figure 12) suggests the possible presence of the Shoreham Marl 2 marking the boundary between the uppermost Lewes Nodular Chalk and basal Seaford Chalk.

An old chalk pit on the track to Westley Farm north of Saffron Walden [TL 5363 4016] exposes 3-4 m of blocky soft chalk with a few seams of small-medium nodular flints, and occasional sheet flints (one on a joint). No obvious marl seams or fossils were observed. The lithology is suggestive of the upper Lewes Nodular Chalk Formation, not far below the Seaford Chalk Formation. Similar chalk was seen in the stream gully 350 m to the east. A chalk pit on Reeve Hill near Elmdon [TL 4324 4093] exposes the interval between the Chalk Rock and the Top Rock. Here a two-metre face exposes blocky soft very weathered destructured chalk with a single medium nodular flint band and no obvious fossils. The face also shows several inclined orange-brown clay seams running through face, dipping to the north.



Prominent surface (arrowed) with thin marl seam (? = Shoreham Marl 2) shown in logged sections. Width of red note book in image is 0.12 m.

Figure 12. The Chalk succession at Limefields Pit Nature Reserve, Saffron Walden.

The Chalk Rock is exposed in the Reed and Barkway pits on the escarpment, where it is preserved as glaciotectionic rafts (Hopson, 1995; Bromley and Gale, 1982). A quarry at Anstey [TL 395 329] which has now been backfilled exposed 17.2 m of chalk with 18-20 discrete flint bands and a thin marl seam near the top. This section is described in Hopson et al., (1996) and Bailey and Wood, (2010). Specimens of *Micraster coranguinum* suggest a level in the upper part of the Lewes Nodular Chalk Formation. Microfossils confirm this and suggest the thin marl may be the Shoreham Marl 2 at the base of the Seaford Chalk Formation. Nannofossils suggest a lower Middle Coniacian age (Bailey and Wood, 2010). The quarry thus exposes the top Lewes Nodular Chalk and basal Seaford Chalk formations.

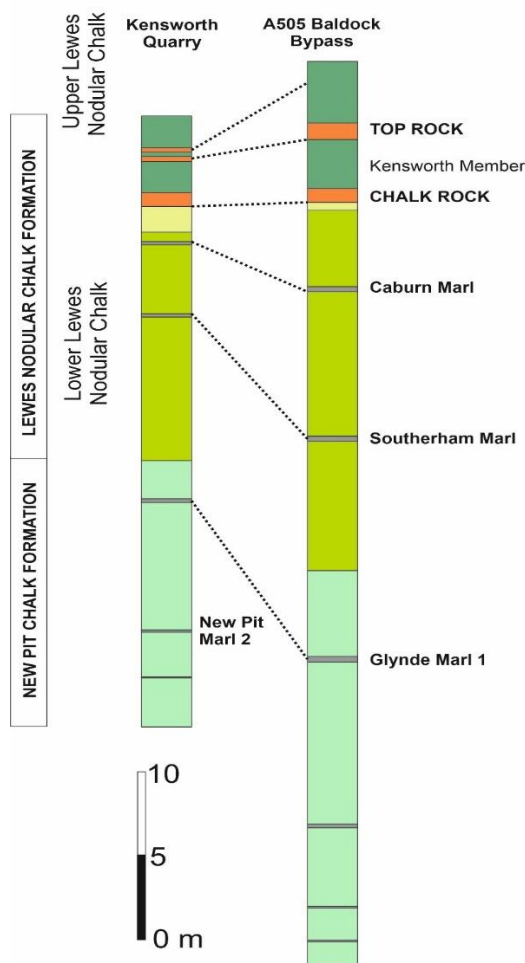


Figure 13 shows the expansion of the top New Pit Chalk Formation and the basal Lewes Nodular Chalk Formation northwards from Kensworth to Baldock in the Chiltern Hills, illustrating the progressive increase in the thickness of the Kensworth Member dividing the Top Rock from the Chalk Rock, and the expansion of the sediment between the marker marl seams.

Figure 13. Logs of the upper New Pit Chalk and the lower Lewes Nodular Chalk formations in Kensworth Quarry and Baldock bypass sections. Based on Mortimore (2014).

3.1.6 Seaford Chalk Formation (SECK)

The Seaford Chalk Formation occurs in the southern half of the project area, although superficial deposits often obscure the outcrop. In the northern part of the catchment, erosion has removed much of the Seaford Chalk Formation. It is absent north of a line between Westmill-Wyddial-Great Hornead-Ansty-Little Chishill and Wendens Ambo. The Seaford Chalk Formation is composed mainly of soft white chalk with common seams of small to very large flint nodules, and of tabular flint. Some of these are semi-continuous and may cause localised perching of groundwater flow. The Shoreham Marl defines the base of the formation.

The lower third of the Seaford Chalk Formation up to the Seven Sisters Flint comprises the Belle Tout beds, which are typically around 20 m thick. These are characterised by soft chalks with thin marls (the Belle Tout marls) and distinctive inoceramid fossils including *Platyceramus* and *Volvicceramus*, which form useful biostratigraphical markers. Fossil shell debris in the brash and animal burrows make useful field markers and informed the mapping of the base of the formation. The Seven Sisters Flint is a regional marker bed that divides the Belle Tout beds

from the overlying Cuckmere Beds in the middle Seaford Chalk Formation. The Cuckmere Beds are composed of soft flinty chalk with no marl seams and few fossils. In the middle of the formation is the Bedwell's Columnar Flint, which is associated with two horizons containing *Cladoceramus unduloplicatus*.

Paleogene erosion prior to the deposition of the Lambeth Group removed much of the upper Seaford Chalk Formation. The maximum preserved thickness of the Seaford Chalk Formation is in the southeast of the district around Ware and Hertford where up to 45 m of Seaford Chalk Formation occurs beneath the Paleogene Collier's End outlier and 50 m beneath the Westland Green Terrace gravels at Bull's Green. Higher stratigraphical levels may be present in the sub-crop in the far southeast around Harlow, where over 55 m may be present and east of the M11 where up to 60 m may be present. Biostratigraphical evidence suggests the highest level preserved in the Seaford Chalk Formation varies across the catchment (Woods, 1993). A micropalaeontological sample obtained from the Plashes Lane section [TL 3750 1979] just below the Paleogene unconformity in the southeast of the catchment near Collier's End indicates the top of the Seaford Chalk Formation is at a level in the Late Coniacian Cuckmere Beds somewhere between the Cuckmere Sponge Bed and the Michel Dean Flint (Lovell et al., 2023). The fossil data suggests a level possibly not far above the Cuckmere sponge bed, which is approximately 5 m above the Seven Sisters Flint.

Fossils collected from 6.1 m of Chalk penetrated in the Cobbin's Brook No.1 Borehole 8 km south of Harlow [TL 4160 0238], just below the Paleogene unconformity included thin pink shell fragments of *Cladoceramus unduloplicatus* (Millward et al, 1987). This indicates a level at about the Bedwells Columnar Flint in the middle Seaford Chalk and suggests the upper part of the Seaford Chalk Formation (Haven Brow beds) and Newhaven Chalk Formation do not occur in the project area.

LOCAL DETAILS:

The Belle Tout beds crop out in many places in the middle part of the catchment. Deep ravines up to 5 m deep are a common feature of streams draining off the glacial till onto the chalk. Several of these ravines expose sections in the Belle Tout beds, with locally abundant *Platyceramus* and *Volvicceramus*. The upper part of the Belle Tout beds crop out in the stream gully 400 m southeast of Gatesbury [TL 3954 2371] with *Platyceramus* and *Volvicceramus*. Similar soft blocky smooth chalk with large nodular flints and fragments of *Platyceramus* and *Volvicceramus* occur in an old partly backfilled pit at Ford Bridge, Standon [TL 3921 2441].

The disused Chadwell Quarry [TL351 136] on the south side of the Lea valley near Ware contains the entrance to a chalk mine, in the roof of which is a thick semi-tabular flint band, possibly the Seven Sisters Flint. Nannoplankton analyses suggest an early Late Coniacian age (Bailey and Wood, 2010). Numerous large fragments of *Platyceramus* and *Volvicceramus* confirm the presence of the Belle Tout beds in the lower Seaford Chalk Formation. Bailey and Wood (2010) suggest that the Lines Pit and Greens Pit [TL 346 134] further southwest along the Ware Road are in the overlying Cuckmere beds.

The Cuckmere beds are exposed in several places in the south of the project area, notably in old pits and stream gulleys, although very few good sections are exposed. An old pit on the east side of the Rib valley just north of Standon [TL 3960 2289] exposes a 4-5 m section in massive soft blocky chalk with sporadic large nodular flints, but with no obvious fossils or stratigraphical markers. This exposure is characteristic of the Cuckmere beds in the middle Seaford Chalk Formation. Similar, but highly weathered and destructured chalk, sometimes with very large nodular flints (Figure 17) is exposed in the Nimney Bourne where it has incised a ravine up to 8 m deep between [TL 402 175] and the Church at Babb's Green [TL 394 159]. Unfossiliferous, weathered destructured chalk was also observed in stream gulleys near Nether Street [TL4199 1626] and off Danebridge Road, Hadham Cross [TL 4343 1869]. A kilometre north of Patmore Heath, an old chalk pit exposes a 2-3 m face in blocky soft chalk with some large nodular flints, but no obvious fossils or other stratigraphic markers. The chalk is locally very weathered with some dissolution pipes infilled with flinty grey clay and orange-brown pebbly clay.

A quarry 300 m north of the crossroads at Little Hadham [TL 4403 2300] has largely been degraded and partially built over. Sections show up to 3.5 m of soft blocky white chalk with

scattered black nodular flints, with a major flint band at the base of the section and again at 1.25 m above the base and near the top (Bailey and Wood, 2010). Another quarry 350 m ESE of the crossroads no longer shows any sections, but animal burrow spoil contains much soft blocky white chalk with large nodular flints. Neither quarry yielded any obvious fossils.

The Belle Tout beds crop out in many places in the Upper Cam valley and its headwaters. Several quarries expose parts of the Seaford Chalk Formation. The best exposure is Newport Quarry [TL 52 33] 0.6 km southeast of Newport railway station. This quarry exposes about 12-13 m of chalk spanning the Belle Tout beds up to the overlying Cuckmere beds (Figure 14). Common fragments of *Platyceramus* and *Volvicceramus* suggest a major semi-tabular flint band seen in the quarry is the Seven Sisters Flint at an elevation of about 75 m OD. One of the Belle Tout marls was exposed in the quarry floor [TL 5262 3312] (Figure 15). Several steeply inclined sheet flints were observed, suggesting synsedimentary movement. One minor fault was observed with a throw of <1 m. The same beds can be seen in a partially backfilled quarry 300 m to the northwest [TL 525 334]. The top of the quarry exposes the Kesgrave Catchment Subgroup sand and gravel and the Lowestoft Till Member, overlying a very irregular rockhead with numerous large dissolution pipes. Head deposits in the northwest corner of the quarry yielded *Ostrea bellavacensis* derived from the 'Woolwich and Reading Beds', which indicates that Paleogene strata were once present in the area.

A small quarry on the Radwinter Road east of Saffron Walden [TL 5538 3845] exposes several metres of the lower Seaford Chalk Formation with medium and large nodular flints and common fragments of *Platyceramus* and *Volvicceramus* indicative of the Belle Tout beds, probably below the Seven Sisters Flint (Figure 16). A loose specimen of *Gryphaea dilatata* was collected above Anglian till overlying the Chalk a few hundred metres east of the chalk pit. Another pit, on the Ashdon Road northeast of Saffron Walden [TL 5579 3920], exposes the contact of the Seaford Chalk Formation with the overlying till. The back face of this pit shows 1.5 m of very chalky till overlying 2.5-3 m of weathered blocky smooth chalk with occasional nodular flints and common fragments of *Platyceramus*. The upper 0.5 m comprises destructured putty chalk and no obvious marl or flint bands were present in the section. The overlying till is very chalky with fragments and pebbles of hard chalk in pale grey chalk matrix, slightly greyer than chalk bedrock below.

An old chalk pit 800 m northwest of Wicken Bonhunt Church [TL 4917 3367] exposes a 5-6 m face of weathered blocky smooth chalk with many fragments of *Platyceramus*, possible *Volvicceramus involutus* fragments (right valve) and *Acutostrea incurva*, indicative of the lower Seaford Chalk Formation (Belle Tout beds). This exposure is notable for the relative absence of flint bands except for one band of rounded nodular flints near the top of the face. The face is cut by several high angle sheet flints and there is no evidence of marl seams. A few small dissolution pipes infilled with very dark brown flinty clay occur near the top of the face.

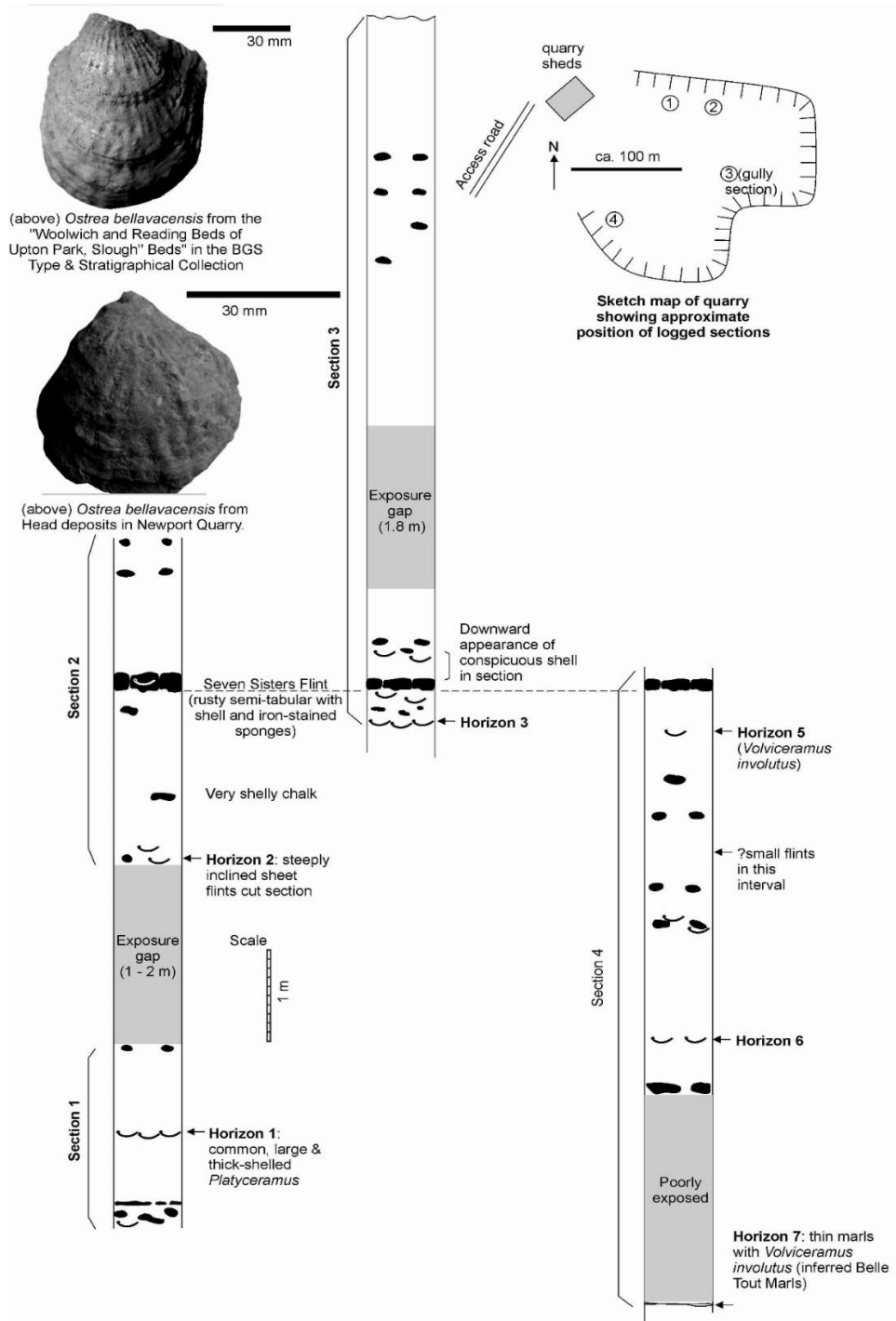


Figure 14. The Chalk succession in Newport Quarry, near Saffron Walden, Essex. Horizons 1 - 3 & 5 - 7 are fossil collecting horizons (NB: no Horizon 4).



Figure 15. One of the Belle Tout marls, lower Seaford Chalk Formation, exposed in the floor of the Newport Quarry [TL 5262 3312].

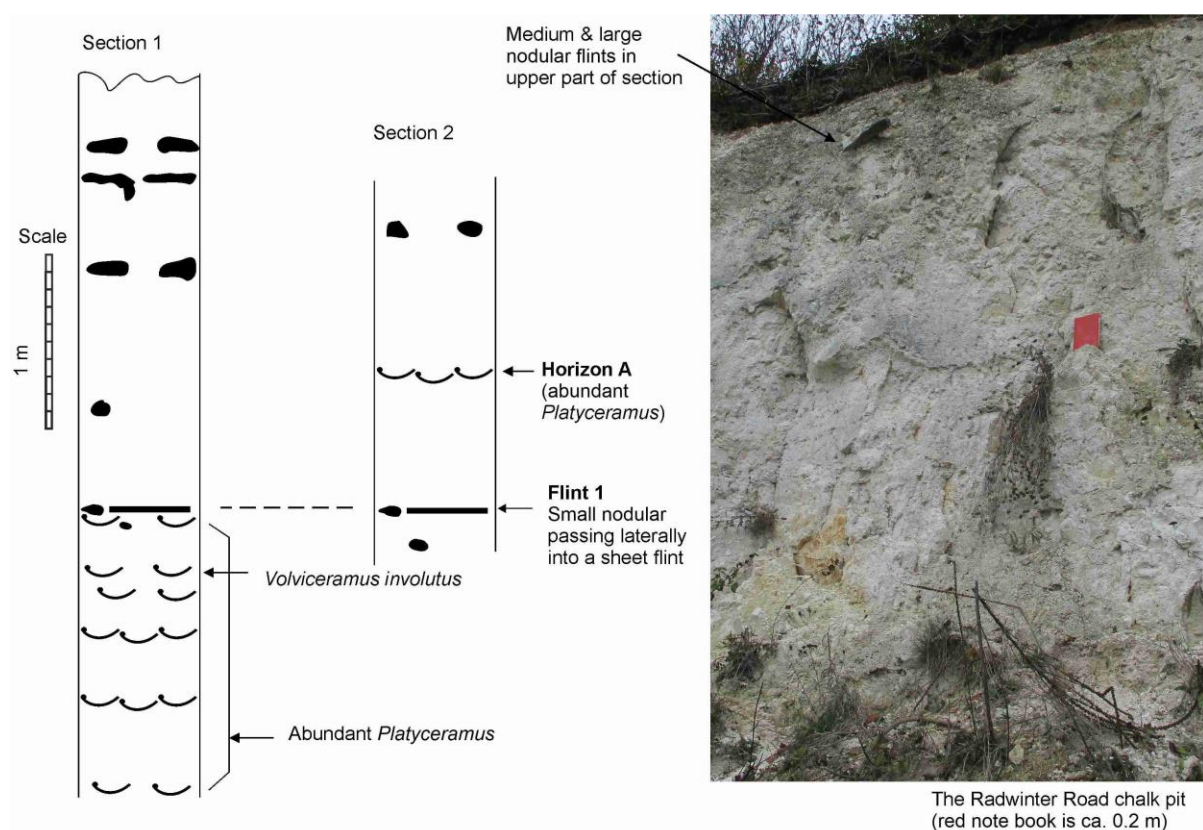


Figure 16. The Chalk succession in the Radwinter Road chalk pit, near Saffron Walden, Essex. Horizons 1 and Flint 1 are fossil collecting horizon reference datums.

3.1.7 Exposures of the Chalk-Paleogene unconformity.

The top of the Chalk just below the Paleogene erosion surface can be seen in a number of places. The largest section was a temporary exposure created during the widening of a road to Plashes Farm near Collier's End [TL 3751 1982]. Excavations revealed a section 320 m long and up to 2 m high extending from Plashes Lane to the crest of the hill, rising 26 m in elevation. The section comprised a sloping bank cut up to 2 m below the ground surface to expose the

entire basal Paleogene succession from the Chalk to the base of the London Clay Formation. The Chalk Group was exposed in the lower part of the track section consisted of a 20 m wide zone exposing approximately 1-2 m of weak, low to medium density destructured putty chalk with scattered large nodular flints. A few dissolution pipes and sediment filled fissures occur, infilled with orange-brown flinty pebbly clay with rounded grey-black flints. No obvious macrofossils were found, but micropaleontological evidence from foraminifera and nannoplankton shows with confidence that the exposed chalk is part of the Late Coniacian Seaford Chalk Formation (Haydon Bailey pers. comm.). The chalk below the unconformity at Plashes Farm is at the acme *Helicolithus trabeculatus* level in the Late Coniacian, lying between the Cuckmere Sponge Bed and Bedwell's Columnar Flint, representing the Cuckmere Member and the basal Haven Brow Member of the Seaford Chalk Formation, just into the former on the strength of *Broinsonia parca expansa* and *Stensioeina granulata granulata*, below the Michel Dean Flint at the base of the Haven Brow Member.

The absence of *Stensioeina granulata polonica*, plus common *S. granulata granulata* together with abundant *Gavelinella arnagerensis* in the fauna places it below the Michel Dean Flint. The chalk at Plashes Farm may not be far above the Cuckmere sponge bed, given that *S.g.polonica* occurs in single specimens very rarely above this.

In the south of the district, an old pit on the road north of Stansted Abbots [TL 3838 1275] shows a degraded section in Paleogene sediments overlain by gravel, but occasional chalk occurs in the base of the pit. At the confluence of the River Ash with the Lea valley, an old pit 215 m northwest of the old railway bridge on Hollycross Road, Ware, [TL 3737 1361] reveals 2-3 m of soft weathered destructured chalk with some large nodular flints, but no obvious fossils (Figure 17). This is overlain by up to 0.3 m orange-greenish-brown silty sand with dark possibly glauconite stained nodular flints at top of the section, locally channelled or piped into the Chalk. In 'The Bournes' valley near Watersplace Farm [TL 3860 1403], a degraded pit shows massive blocky smooth soft chalk with large nodular flints, occasional oysters and *Spondylus*, but no obvious inoceramids. Clean fine-medium grey-brown silty sand with occasional flint pebbles occurs immediately above, which may be the Thanet Formation. Similar chalk can be seen 300 m to the northeast [TL 3872 1432]. On the opposite side of the Rib valley, an old pit near Mardock's Mill [TL 3926 1488] exposes soft weathered chalk with large nodular flints brought up in burrow spoil just below the Paleogene unconformity. The rear of the pit exposes clean orange-brown sands.

A small exposure of chalk heavily piped with Lambeth Group mottled silty sandy clay occurs in the base of a 5-6 m deep ravine in Godwyn's Wood near Widford [TL 4133 1640]. On the opposite side of the valley in the road cutting south of the old Widford railway station, Whitaker et al., (1878) noted chalk overlain by fine light green sand, lower part clayey, with green coated flints at the base.

Near Hadham Ford, the Paleogene unconformity is exposed in a stream gully at Bridgefoot [TL 4343 2098]. Here, a piped irregular contact occurs between soft weathered chalk and overlying orange-red-brown mottled silty sand and olive grey green silty sandy clay. The contact is marked by large nodular flints, some of which are stained dark green with glauconite. Similar soft blocky weathered chalk with large nodular flints overlain by soft fine-medium orange-yellow-brown sand with black flint pebbles can be seen in an old pit 200 m northeast of Hadham Ford [TL 4374 2200]. On the west side of the Ash valley at Hadham Ford, a small degraded pit [TL 4330 2224] contains soft blocky chalk in burrow spoil in the floor of the pit, with orange-brown silty sandy clay with many small black flints at the top of the pit.

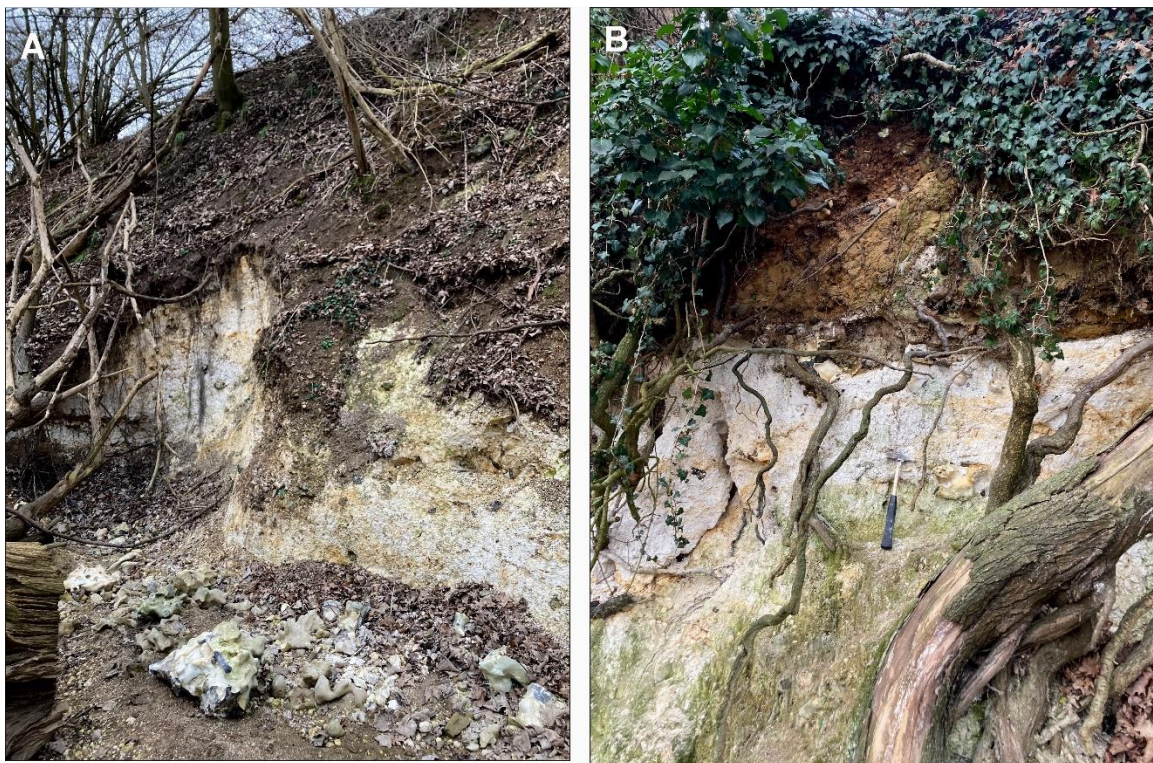


Figure 17. A. Soft destructured chalk with very large nodular flints exposed in the Nimney Bourne ravine [TL 4012 1720]. B. The Chalk-Lambeth group unconformity at Widbury, near Ware [TL 3737 1363].

The base of the Lambeth Group is exposed in a new drainage ditch on the west side of the Hadham-Clapgate road just north of the bypass [TL 4443 2362] at an elevation of c. 85-86 m OD. Here soft blocky chalk with occasional large nodular flints is overlain by orange-brown silty sand with many small black & green glauconite stained nodular flints & flint pebbles. A short distance to the north, orange-red-brown mottled clay, clean yellow-orange sand, and very pebbly sand with many small black flints can be seen in the ditch. This may be the Collier's End Pebble Bed. The Paleogene unconformity can also be seen in the new Little Hadham bypass drainage ditches on the east side of the Ash valley at c. 84-85 m OD where soft weathered destructured chalk with large nodular flints underlies about 1 m of green-brown glauconitic silty sandy clay with small black rounded flint pebbles. A thin 0.3 m thick pebble bed was observed just above the unconformity at TL 4503 2330 at c. 87.5 m OD, which again, may be the Collier's End Pebble Bed.

Around Patmore Heath, two chalk pits expose the Paleogene unconformity. The first at [TL 4448 2547] exposes soft blocky chalk with large nodular flints, with no obvious fossils, with orange-brown mottled clay above with many small black rounded flint pebbles. Similar chalk was seen in the second pit on the other side of the valley [TL 4479 2597] with olive grey-green silty clay above. Several other small degraded chalk pits occur immediately beneath the unconformity on the east side of the valley between Patmore Hall Woods and Upwick Green, but do not provide any exposure. At Albury Hall, a partly infilled pit [TL 4321 2550] exposes blocky soft chalk with some large nodular flints, but no obvious fossils. Orange-brown fine-medium grained pebbly sand occurs immediately above the pit.

In the Rib valley, the basal Paleogene-top chalk unconformity is exposed in a stream gully 950 m southeast of Standon Church [TL 4025 2154] where the contact is marked by a 10 cm thick semi-tabular flint. Chalk brash with many small black and green glauconite stained flint pebbles marking the base of the Paleogene can be observed on the ridge east of Standon Church [TL 3998 2241] and on the next two ridges to the north [TL 3999 2282], [TL 5400 2306] and [TL 4007 2339]. A short distance to the northeast, the top chalk and basal Paleogene succession were exposed in a pit in Darney Wood [TL 4057 2343] where soft chalk with large nodular flints occurs in burrow spoil in the base of pit. Yellow-brown silty sandy clay and coloured mottled silty clay occurs in the back of the pit, with a bed of very pebbly clay with many small black flint pebbles at the top, possibly the Collier's End Pebble Bed.

3.2 PALEOGENE STRATA

Paleogene and Neogene strata occur across the south and east of the Rib-Ash-Stort catchment area where the Thanet Sand, Lambeth Group, London Clay Formation and sometimes the Red Crag Formation are locally preserved beneath the palaeo-Thames terraces and Anglian glacial deposits. The most complete section through the Paleogene succession is the Dowsett's Farm borehole [Borehole TL32SE38, NGR TL 3806 2079] in the southwest of the project area, which proves 25.24 m of Paleogene strata. This is described in detail in Hopson et al. (1996).

3.2.1 Thanet Formation (TAB)

The Thanet Formation comprises brown and grey glauconitic silty fine-grained sand with a bed of large dark green stained or black nodular flints at the base (the Bullhead Bed). The Thanet Formation is mostly absent in the project area, except for the south and east of the area, south of Harlow, where it reaches a maximum thickness of around 7-8 m. In the area between the River Ash and the River Rib, around Widford, Sawbridgeworth and Ware, the Thanet Formation is likely to be very thin and discontinuous and is probably only locally preserved in dissolution pipes. In the east of the district, in the Upper Cam catchment, Baker (2019) recorded a thin, discontinuous veneer of Thanet Formation less than 1-2 m thick in the base of an old sand and gravel pit at Widdington [TL 530 310], overlying a level but pitted Chalk surface at about 88–89 m OD. The Thanet Formation was also locally recorded in excavations for the M11 motorway near Stansted Mountfitchet around [TL 530 255] (Lake and Wilson, 1990). The Thanet Formation has not been mapped or modelled in the project area because of its thin, discontinuous nature and uncertainty surrounding its presence outside of dissolution pipes.

3.2.2 Lambeth Group (LMBE)

The Lambeth Group (termed the 'Woolwich and Reading Beds' in Lake and Wilson, 1990), consists of the Upnor and Reading formations. The base of the Upnor Formation is often composed of rounded black or green glauconite-stained flints. Above this the Upnor Formation (often described as the 'Woolwich and Reading Bottom Bed') is typically composed of glauconitic fine- to medium-grained sand with variable clay and silt content. Locally thin beds, lenses and stringers of well-rounded, black flint gravel occur with minor thin clays and are commonly interbedded with glauconitic sand laminae and lenses. These sands and pebbly gravels are generally thin, c. 1-2 m thick and very poorly exposed, and in some places are absent. The Upnor Formation is typically very thin, often only 2-3 m thick. The lack of exposure, lithological variability, similarity with the Reading Formation and limited thickness of the Upnor Formation means that it cannot be mapped systematically and reliably in the Chilterns.

The overlying Reading Formation comprises red-orange-grey-brown mottled silty clay with sand beds and lenses, and localised pebble beds especially in the lower part. These pebble beds locally form a mappable unit, notably the Collier's End Pebble Bed in the west of the district (Lovell et al., 2023). In places the Reading Formation is cut down into the Upnor Formation (Tubb, 2016). The well-rounded black and dark grey-blue flint pebbles from the Lambeth Group are distinctive and are often reworked into the Quaternary superficial deposits. The upper part of the Reading Formation typically comprises fine-medium grained, 'clean' orange-yellow-brown micaceous sand with scattered flint pebbles, locally with interbedded silty colour mottled clay. Areas previously mapped as 'Pebbly clay and sand' on the old Aylesbury and Hertford map sheets are in part degraded pebbly Paleogene outliers. Across much of the district, especially on the interfluvies, much of the Paleogene outcrop is obscured by glacial till and other superficial deposits.

The Lambeth Group is typically around 10-15 m thick. In the Dowsett's Farm borehole [TL32SE/38 at TL 3806 2079], the Upnor Formation comprises approximately 3 m of pale grey, yellow and green, occasionally mottled clayey, silty, fine sand and sandy clayey silt with glauconite and discrete seams of stiff silty clay. At Standon, the Upnor Formation comprises green silt overlain by abundant well-rounded black flint pebbles.

The basal Paleogene was noted in a road cutting south of the old railway station at Widford [TL4082 1585], where Whitaker et al., (1878) noted 'fine light green sand from a foot to 3 feet

thick, the lower part clayey, with green coated flints' on Chalk, probably representative of the Upnor Formation.

By far the best exposure was a temporary section along a farm track leading to Plashes Farm [TL 3750 1979] near Collier's End in the far east of the model area (Lovell et al., 2023). Here the basal Paleogene Upnor Formation consists of pebbly orange-brown-greenish grey mottled silty clay with well-rounded blue-grey flint pebbles resting on an irregular erosion surface of chalk. The unconformity at this site appears to be modified by the formation of dissolution pipes. Outcrops 15-20 m further up the track expose mottled red-orange-brown greenish-grey clay with lenses of pale grey sandy pebbly gravel with well-rounded black flint pebbles, typically 1-5 cm diameter, with lenses and pockets of fine-grained black pea-gravel. Some chalk pinnacles indicate a very irregular rockhead. This is overlain by a distinct pale grey sandy matrix-supported pebbly gravel estimated to be about 1.5 m thick. The clasts are dominated by many well-rounded black, and grey flint pebbles with some angular fragments, typically 1-5 cm diameter, and occasionally some cobbles up to 8-10 cm diameter. This is the Collier's End Pebble Bed, which occurs at the top of the Upnor Formation. The top of the pebble bed marks a change to a uniform orange-brown sticky clay, above which there is a 60 m gap in the section.

The Paleogene-Cretaceous unconformity and the pebble bed above was observed in a drainage ditch cut on the eastern side of the A10 Collier's End bypass. At this locality the basal Paleogene consists of fine sand and pebbles overlying an irregular chalk surface. Fine sand is also seen along strike c. 1 km to the south, as matrix in the Hertfordshire Puddingstone recovered from the A10 cutting west of Plashes Farm (Lovell and Tubb, 2006).

3.2.2.1 COLLIER'S END PEBBLE BED

The Collier's End Pebble Bed was well exposed in the Plashes Lane section (above, Figure 19) and can be traced north through Plashes Wood to Standon (Lovell and Tubb, 2006; Green et al., 2016; Tubb 2016, Lovell et al., 2023). The outcrop map is shown in Figure 18. Fragments of 'Hertfordshire Puddingstone', which represents the cemented Colliers End Pebble Bed, were recovered from a 200 m stretch of the A10 bypass north from Plashes Wood underpass. Very pebbly soils can be identified in the woods between the A10 and Plashes Farm and around Bowls Dell [TL 382 224] south of Standon. In the copse at Bowls Dell lie pits with angular fragments of puddingstone, remains of a Roman quarry for hard stone to make querns (Lovell and Tubb, 2006). Trial pits and boreholes on the A10, for example borehole TL 32SE56 [TL 3749 2073] record up to 2 m of firm to stiff mottled green-grey-orange slightly sandy clayey silt overlain by fine to coarse flint gravel with well-rounded flint pebbles in a mottled clayey silt matrix.

The pebble bed was exposed during road widening at Standon Hill [TL 385 225], 2.9 km north of Plashes Farm. Widening of the A120 road at this northeast tip of the outlier took place in 1965 and in 1971 (Catt and Doyle, 2010; Tubb, 2016). The 1971 section at Standon Hill revealed shallow channels infilled with pale grey flint pebbles cut into greenish-grey sandy clay of the Upnor Formation. As at Plashes Farm, the pebble bed at Standon Hill has an erosional base, but with a deeper cut. The overlying Reading Formation mottled clays are absent at Standon Hill. The pebble bed can be traced around the eastern margin of the Collier's End outlier at c. 90 m OD and in the Dowsett's Farm borehole. In the borehole the pebble bed is associated with possible desiccation cracks (Hopson et al., 1996, their Fig. 19). From Standon Hill, the exposure of the pebble bed can be mapped continuously to the south, via the puddingstone-bearing rocks nearby (Lovell and Tubb, 2006).

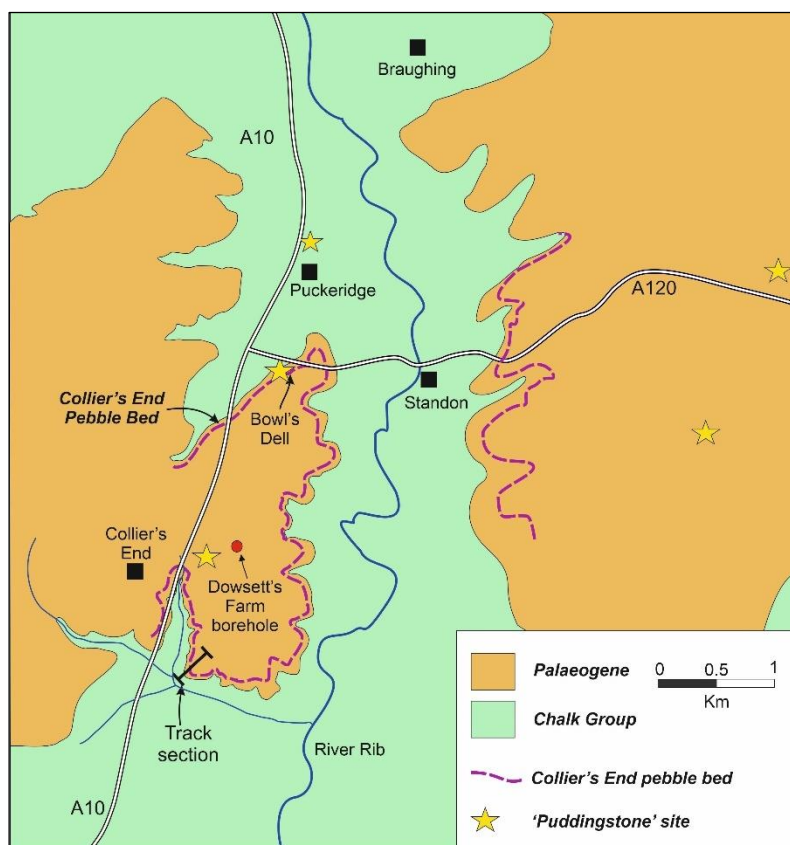


Figure 18. The outcrop of the Collier's End Pebble bed.

On the east side of the Rib valley, the Collier's End Pebble Bed can be traced around Standon and Braughing. Up to 1 m of very pebbly grey silty clay with many small black and grey rounded flint pebbles overlying 0.4 m of orange-grey-red-brown-grey mottled silty clay was exposed in a stream channel 1 km southeast of Standon [TL 404 215], Figure 19. Very pebbly flinty soils associated with the crop of the pebble bed occur 1 km east of Standon [TL 405 224] and [TL 405 231] where they were once worked in a shallow pit. A short distance further north, the pebble bed is poorly exposed at the top of an old pit in Darney Wood [TL 406 233], which also exposes the basal Lambeth Group and the Chalk. To the north, the Paleogene strata has been truncated by the palaeo-Thames Westland Green terrace gravels at c.102 m OD. Similarly, to the south and east of Latchford, the Lambeth Group has been removed by glacial erosion. This bed was not modelled as it could not be identified in borehole logs further east.

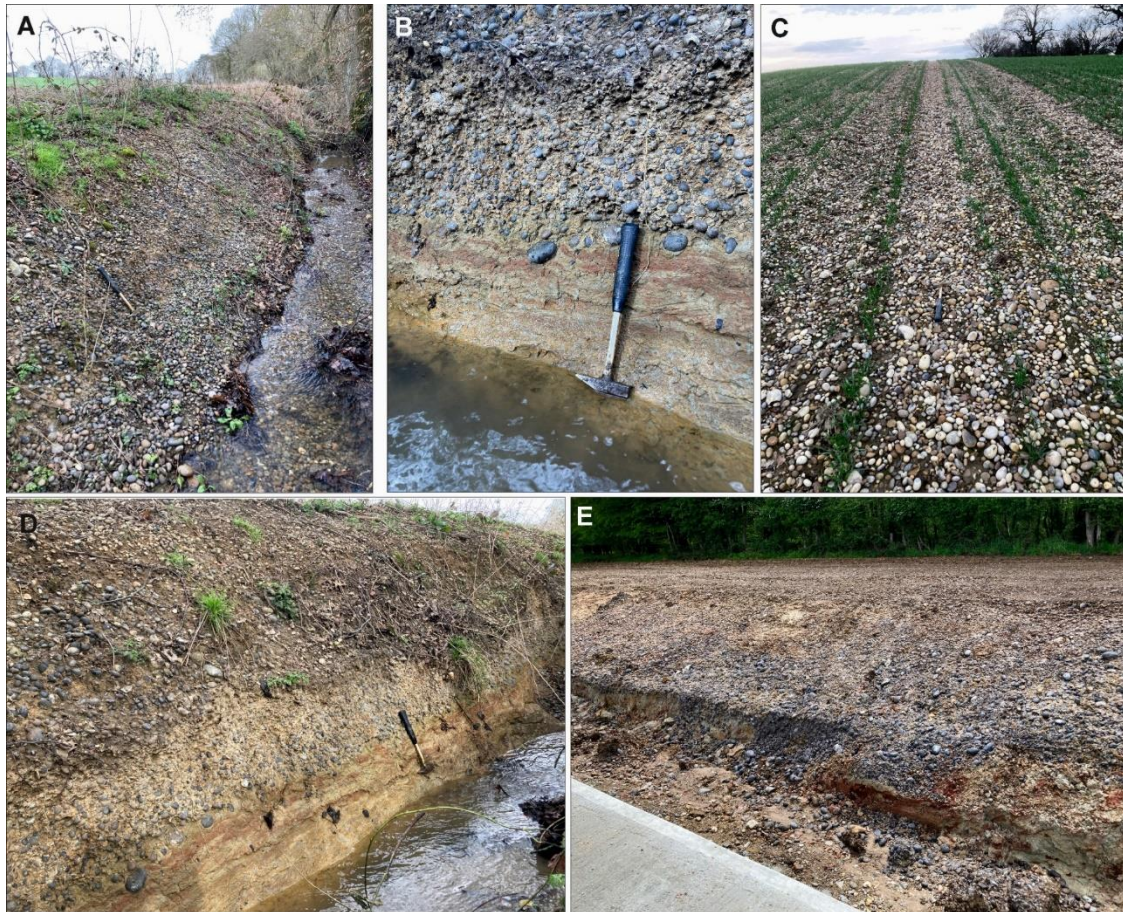


Figure 19 Examples of the Collier's End Pebble Bed. A, B & D. In a stream channel 1 km southeast of Standon, C. Pebbly soils north of Standon [TL 405 231] E. Plashes Lane section, Collier's End.

3.2.2.2 HERTFORDSHIRE PUDDINGSTONE

In some parts of the Chiltern Hills, the pebble beds within the lower part of the Lambeth Group have been cemented to form siliceous conglomerates, known colloquially as 'Hertfordshire Puddingstone'. Occasional erratics of this are found in the Upper Cam area, most notably the war memorial in St. Mary's churchyard, Arkesden [TL 4821 3456] which consists of a very large, single boulder of puddingstone 1.7 x 1.7 x 0.8 m in size. Other puddingstone erratics have been found associated with fluvio-glacial outwash gravels in the Ash valley, notably on New Road, Hadham Ford [TL 4308 2109] & [TL 4308 2104]. A number of isolated specimens of puddingstone were noted during construction of a 200-metre-long section [TL 374 207 to TL 374 205] of the A10 bypass east of Colliers End.

3.2.3 Thames Group (London Clay (LC) and Harwich (HWH) formations)

The Lambeth Group is overlain by the Thames Group, comprising the Harwich Formation and London Clay Formation. As with the Upnor Formation, the lack of exposure, lithological similarity and limited thickness of the Harwich Formation means that for mapping and modelling purposes it is grouped with the London Clay Formation.

LOCAL DETAILS:

The Harwich and London Clay formations occur in the Collier's End outlier. However, they are very poorly exposed and largely obscured by superficial deposits. The lack of exposure meant that it was not possible to map the Harwich Formation separately. It is therefore included within the London Clay Formation on the map and in the model.

In the Dowsett's Farm borehole, the Harwich Formation is represented by about 3.5 m of dark greenish grey clay and olive green glauconitic heavily bioturbated clayey fine sandy silt, with some silty sand seams and thin shell beds. The overlying London Clay Formation consists of up

to 12.7 m of grey-brown silty clay, oxidised to an orange-brown colour at the surface. The London Clay Formation is exposed along a farm track leading to Plashes Farm [TL 3750 1979] near Collier's End. The upper part of the section reveals a few metres of stiff non-calcareous grey-blue-brown clay. A micropalaeontological sample obtained from the lowest level was barren for nannoplankton and contained no obvious in-situ micro faunal elements or diatoms (Haydon Bailey pers. comm.). A few very rare Late Santonian - Early Campanian radiolaria were present in the fines. Based on the radiolaria, the clay is tentatively identified as the basal London Clay Formation.

No other exposures of the London Clay Formation were observed, although it is present in many boreholes and can be augured where it is exposed. The formation varies in thickness across the outcrop due to the erosion and the variable superficial cover. It is thickest in the far southeast of the region where it reaches up to c. 60-65 m thick.

3.2.4 Crag Group (CRAG)

The Crag Group deposits of East Anglia are Pliocene - early Middle Pleistocene (c.3.8-0.5 Ma) shallow marine sediments laid down along the western margin of the southern North Sea basin of the time. They are divided into four units, the Coralline Crag, Red Crag and Norwich Crag formations and the Wroxham Crag Formation, which occurs in eastern Norfolk and Suffolk. The Coralline Crag Formation does not occur in the Rib-Ash-Stort project area. The Red Crag Formation comprises a basal pebble bed overlain by reddish brown, poorly sorted cross-bedded medium- to coarse-grained pebbly quartzose sand, with pebbles of flint, some quartzite, ironstone and sandstone (Lake and Wilson, 1990). The sand is greyish-green in its unweathered state owing to its high glauconite content but oxidises to an orange-brown colour at or near to the surface. The overlying Norwich Crag comprises well sorted, fine- to medium-grained micaceous, glauconitic, locally shelly sands (Chillesford Sand Member) with occasional discontinuous beds of clay (Chillesford Clay Member) and gravel (Westleton Beds).

The Crag Group only occurs in the extreme northeast of the project area, having been tentatively identified in several boreholes in the Upper Cam catchment around Widdington, Elsenham and Stansted Mountfitchet, and from former quarries (Mathers and Zalasiewicz, 1988; Baker, 2019). Like the Paleogene deposits, both the Red Crag and Norwich Crag formations are thin and very poorly exposed, being largely concealed beneath superficial deposits but interdigitated with river deposits of the ancestral Thames. Both the Red and Norwich Crag formations were formerly exposed in the sand quarry at Widdington [TL 530 310], where Baker (2019) identified a 1.8 m bed of cross-stratified pebbly sands resting on an irregular surface of Thanet Formation and Upper Chalk, overlain by 1.5 m of uniform, fine-grained sands interpreted as the Chillesford Sands. Likewise, at the Elsenham Pit [TL 550 265] about 1 m of iron-stained, poorly sorted sand was interpreted as Red Crag Formation by Hopson (1981) and subsequent investigations revealed that the basal pebble bed is also present. This is overlain by 5-6 m of the Chillesford Sands (see Figure 9 of Mathers and Zalasiewicz, 1988). Neither of these sections are accessible today.

The Crag Group was tentatively identified at outcrop in the south of the area just east of Elsenham railway station and on the east side of the Cam valley near Widdington, where dark orange-brown-red medium to coarse grained gritty sand with small quartz and flint pebbles were seen in ploughed fields. Elsewhere the Crag Group is only known from boreholes and former quarries.

The poor quality of the outcrop, coupled with the thin nature of the deposits and possible conflation with other sand-rich units (Lambeth Group and Westland Green terrace gravels), and post depositional disturbance due to dissolution and cryoturbation mean that the extent of the Red Crag beneath the superficial deposits is poorly constrained. Whilst it has been modelled, the true nature and extent of the Red Crag outcrops beneath the glacial till is very uncertain and remains poorly understood.

4 Superficial Deposits

The Quaternary superficial (drift) deposits on the Hertford, Biggleswade and Saffron Walden 1:50 000-scale geological map had not been mapped or updated since the original six-inch scale (1:10 560) surveys. The superficial geology on the Great Dunmow, Hitchin and Epping sheets was mapped more recently at 1:10 000 scale (for details, see Lake and Wilson, 1990; Hopson et al., 1996 and Millward et al., 1987). However, mapping in the Beane catchment (Farrant et al., 2022a) and for this project demonstrated that the high-level Thames terrace gravels (Westland Green Terrace) on the Hitchin sheet had been mapped as glaciofluvial gravels rather than terrace deposits. In addition, in some areas solifluction mass-movement deposits (Head) had been misinterpreted as in-situ terrace deposits, leading to an erroneous definition of the base of the terrace gravels. Similarly, some of the glaciofluvial outwash sands & gravels were mapped inconsistently, sometimes interpreted as 'head gravel'. Many solifluction deposits (Head) had not been mapped or in some cases incorrectly mapped as in-situ glaciofluvial deposits. Locally some areas of chalk-rich till have been erroneously mapped as bedrock.

Some improvements were made in the depiction of the Kesgrave Catchment subgroup terrace gravels, the buried valley fills, and the extent of the periglacial deposits. For this project, the superficial linework was revised through a combination of field mapping and fitting the existing geological linework and data to the modern DTM. Aerial photographs and Lidar data were used in some areas as they clearly showed the distinction in soil types developed on gravelly river terrace and glaciofluvial deposits and areas of more clay-rich bedrock or glacial till. Modelling also helped identify the palaeo-Thames terrace gravels beneath the till. The list of modelled superficial units and the list of BGS Lexicon codes (Lex-RCS codes) used in this model is given in Table 3.

LEX code in model	LEX Translation or Description	RCS code	RCS Translation
HEAD	Head	XCZSV	Clay, silt, sand and gravel
ALV	Alluvium	XCZSV	Clay, silt, sand and gravel
HEAD1	Head 1	XCZSV	Clay, silt, sand and gravel
SHGR	Shepperton Gravel Member	XSV	Sand and gravel
KPGR	Kempton Park Gravel Member	XSV	Sand and gravel
TPGR	Taplow Gravel Member	XSV	Sand and gravel
BPGR	Black Park Gravel Member	XSV	Sand and gravel
GFDUA	Glaciofluvial deposits (Anglian)	XSV	Sand and gravel
LOFT	Lowestoft Formation	DMTN	Diamicton
GFDUA_1	Lower Glaciofluvial deposits (Anglian)	XSV	Sand and gravel
GLLDA	Glaciolacustrine deposits (Anglian)	XCZ	Silty clay
LOFT_2	Lowestoft Formation (Lower)	DMTN	Diamicton
WIHG	Winter Hill Gravel Member	XSV	Sand and gravel
GCGR	Gerrards Cross Gravel Member	XSV	Sand and gravel
BDGR	Beaconsfield Gravel Member	XSV	Sand and gravel
SWGR	Satwell Gravel Member	XSV	Sand and gravel
WGGR	Westland Green Gravel Member	XSV	Sand and gravel
STGR	Stanmore Gravel Formation	XSV	Sand and gravel
CWF	Clay-With-Flints Formation	XCZSV	Clay, silt, sand and gravel

Table 3. Superficial deposits used in the model.

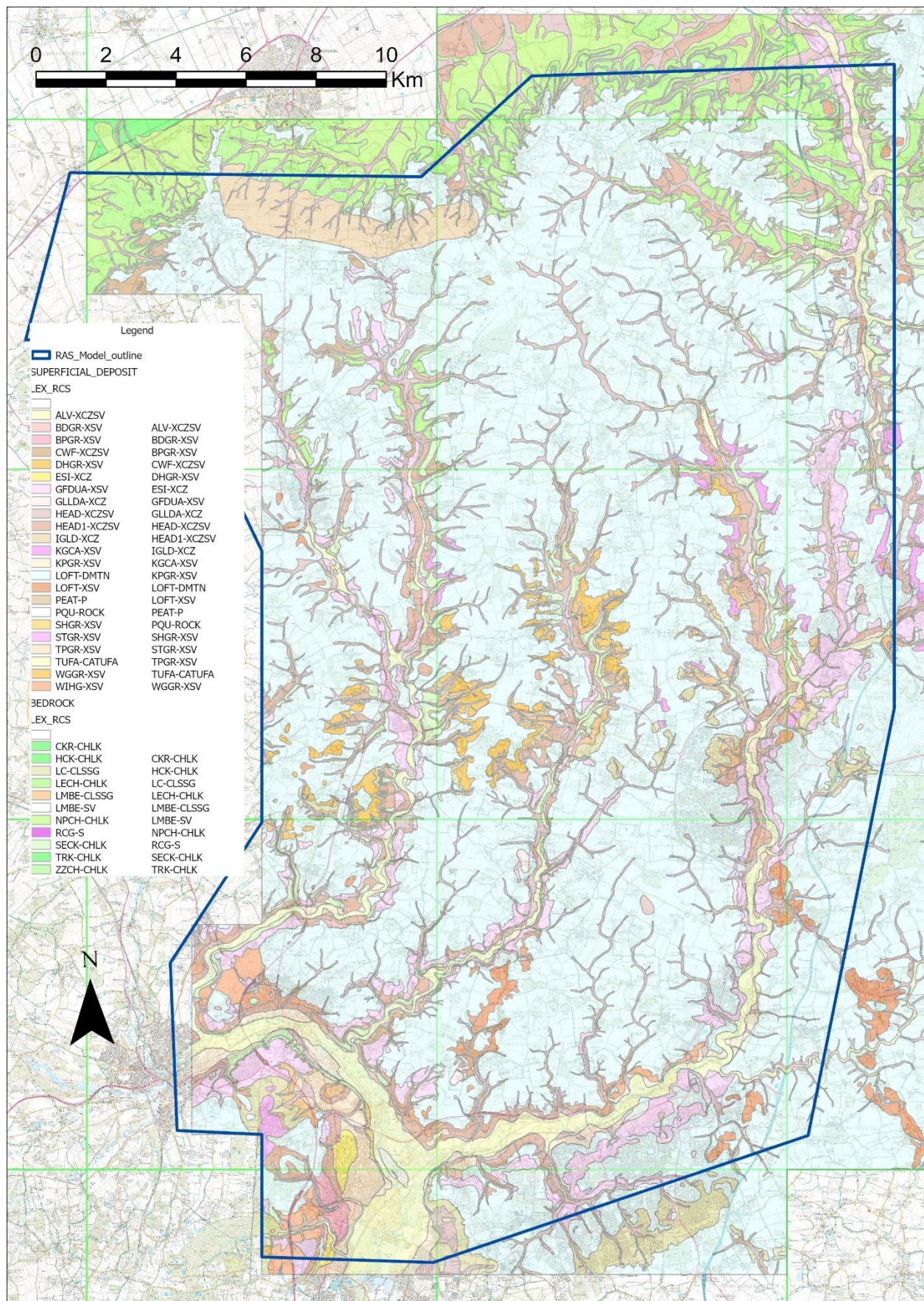


Figure 20. Updated combined bedrock and superficial geology map. The legend shows the lex-rock codes for each unit, for details see <https://webapps.bgs.ac.uk/lexicon/home.cfm>.

Superficial deposits cover much of the Chalk outcrop across the whole catchment, with only the Chalk escarpment and some of the valley sides being free of superficial material. The most widespread superficial deposits are Anglian glaciogenic deposits, including till, glaciofluvial and

glaciolacustrine deposits. Several major buried valleys cross the region. A buried valley is a valley that has little or no expression within the modern landscape but is largely infilled and concealed by more recent superficial deposits. The depth of these buried valleys can locally exceed 100 m thereby altering the regional juxtaposition of geological units. Two major buried valleys have been identified in the Rib-Ash-Stort area; the Upper Cam buried valley extending from Stansted Mountfitchet north towards Cambridge, and the Stort buried valley, which is the southward extension, from Stansted Mountfitchet south to Harlow. Other significant glaciofluvial outwash channels occur in the Ash and Rib valleys, but only locally are preserved beneath the valley floor. For the most part these occur as terrace fragments on the valley sides and are infilled with a mix of glaciofluvial gravels, silts and glacial till. These glacial valley systems are described in Hopson et al., (1996) for the Hitchin sheet area, in Millward et al., (1987) for the Epping sheet area and Lake & Wilson (1990) for the Great Dunmow sheet. The buried valleys were not previously mapped on the Hertford sheet. The extents of these buried valleys were mapped as part of this project and the buried valley fills modelled. Periglacial and residual deposits are common. These include Head, often occurring as valley bottom deposits, solifluction deposits on the valley sides ('Head 1') and the Clay-with-Flints Formation, which caps the interfluvies (Hopson et al., 1996) in parts of the catchment.

Several discrete river terrace gravel sequences can be recognised. These can be subdivided into those belonging to the pre-diversionary Thames, and those related to the tributaries of the post-Anglian River Thames including the Lea, Rib, Ash, Quin and Stort rivers. The oldest, pre-Anglian terraces comprise the Kesgrave Catchment Subgroup. These are lithologically variable with significant quantities of quartz and other non-local lithologies. There is a significant amount of published research on these terrace deposits, including detailed lithostratigraphical analyses (Gibbard, 1985; Rose et al., 1999; Maddy et al., 2001; Catt, 2010 and references therein). Their spatial extent is largely based on field mapping and the analysis of digital terrain models, complemented by borehole data and existing records. In this area, many of these pre-Anglian terrace gravels are preserved beneath the till across the central and southern parts of the catchment and their presence is often only known from borehole records. Alluvium is present in the river valleys, locally interbedded with Peat and Tufa.

4.1.1 CLAY-WITH-FLINTS FORMATION (CWF)

The oldest superficial deposit in the Rib-Ash-Stort catchment area is the Clay-with-Flints Formation. This is primarily a remanié deposit resulting from the modification of the original Paleogene cover through the in-situ weathering, decalcification and cryoturbation, coupled with the dissolution of the underlying chalk. The dominant lithology is orange-brown and red-brown sandy clay with abundant nodules and rounded pebbles of flint but can be locally sandy in nature. This has a limited extent in the far northwest of the project area, capping the Chalk escarpment around Kelshall. Its thickness is usually less than 5 m, but thicker deposits may be locally preserved in dissolution pipes.

4.2 KESGRAVE CATCHMENT SUBGROUP

The Kesgrave Catchment Subgroup comprises fluvial, lacustrine and organic deposits laid down by the pre-diversionary River Thames, which originally flowed through the Vale of St Albans before being diverted by the Anglian ice sheet. The Kesgrave Catchment Subgroup can be divided based on lithology and altitude into two formations: the higher older Sudbury Formation and the lower younger Colchester Formation, each with individual named terrace aggradations (members) typically 5 - 12 m thick. These members comprise bodies of cross-bedded and massive, moderately sorted sand and gravel. It is these terrace aggradations that have been mapped and modelled.

The Sudbury Formation represents the first significant input of far-travelled materials into the Thames river sediments and is characterised by quartz and quartzite from Triassic, Carboniferous and Devonian rocks of the West Midlands, Welsh borders and possibly southwestern Pennines, and felsic volcanic rocks from north Wales. The presence of mega-erratics and glacially fractured sand grains indicate glacial erosion in the headwater regions of the river. The fluvial gravels occupy terrace levels, and the members are defined based on

altitude and pebble clast content. The members comprise bodies of cross-bedded and massive, moderately sorted sand and gravel.

The Colchester Formation comprises fluvial gravels characterised by quartz and quartzite from the Triassic, Carboniferous and Devonian rocks of the West Midlands, Welsh borders and possibly the south-western Pennines, and felsic volcanic rocks from north Wales. These lithologies form a lower percentage than in the Sudbury Formation and are believed to be in part derived from that formation, but mega-erratics and felsic volcanic rocks from Wales and the Welsh borders occur with a generally greater frequency than in the Sudbury Formation. The fluvial gravels occupy terrace levels, and the members are defined based on altitude and pebble clast content. The members comprise bodies of cross-bedded and massive, moderately sorted sand and gravel. The aggradations are generally entrenched into bedrock. Intraformational ice wedge casts and pollen indicate periglacial, cool temperate and warm temperate climates.

Gibbard (1977, 1985) identified five river terrace gravels in the Vale of St Albans. From highest (oldest) to lowest (youngest) these are the Westland Green, Satwell, Beaconsfield, Gerrards Cross and Winter Hill Gravel members. Geological mapping in the Chorleywood area in the Gade catchment has identified a sixth terrace between the Satwell and Beaconsfield terraces that Gibbard (1985) did not recognise. This is termed the Chorleywood Gravel Member. All except the Winter Hill Gravel Member belong to the Sudbury Formation.

Of these, all are present in the Rib-Ash-Stort catchment area, with the exception of the Chorleywood Gravel Member. Only two, the Westland Green and Winter Hill Gravel members are exposed at surface, the rest are buried beneath the glacial till. All the terraces are likely to have an irregular base where they overlie the Chalk with dissolution pipes and cryogenic disturbance.

4.2.1 Westland Green Gravel Member (WGGR)

This is the highest of the recognised pre-diversionary Thames terraces in the Rib-Ash-Stort catchment. This terrace has been largely removed by subsequent erosion, but several significant areas remain capping the Paleogene around Colliers Green, Standon, Westland Green, Patmore Heath, Upwick Green and Manuden. These all occur at an elevation of around 104-105 m near Puckeridge, decreasing to the east to around 102 m at Westland Green and Patmore Heath.

The deposits comprise coarse, poorly sorted, well-rounded flinty sandy gravel in a dark red-orange-brown gritty sand matrix, fining eastwards to a pebbly, gritty, coarse poorly sorted gravelly sand at Westland Green. In the east, in the Upper Cam catchment, the terrace deposits comprise moderately sorted yellowish brown to grey, pebbly, predominantly medium-grained quartzose sand and sandy gravel. Locally it is capped by a reddish brown silty sandy clay which equates to the Valley Farm Soil which is developed widely across these river terrace deposits. The clasts are predominantly worn, brown stained flint chips, and worn nodular flints but with some rounded flint pebbles reworked from the Lambeth Group, a significant amount of small, rounded vein quartz pebbles, together with some quartzite and sandstone pebbles including 'Bunter' quartzite. The clast size gradually decreases from west to east. In the west, around Hebing End and on the Collier's End outlier, the clast size is typically 2-5 cm in diameter, although some larger clasts up to 10 cm across are present, but in the east the deposit is sandier and clasts are rarer. Localised sand and clay lenses may occur. The thickness of the gravels is typically 5-7 m, thinning round the edge of the deposit, but can locally be up to 10-11 m thick. All the outliers have been worked for gravel in places, although no extensive workings are present. No sections were identified during the survey, but the terrace gravels form a distinctive pebbly sandy gravelly soil distinct from the younger glaciofluvial gravels. The type section of the Westland Green Gravel Member is a gravel pit at Westland Green, which is no longer exposed.

4.2.2 Satwell Gravel Member (SWGR)

This terrace gravel is not exposed at surface in the catchment area, but interpretation of the borehole logs, in particular the BGS Industrial Minerals Assessment Unit (IMAU) logs, and 3D modelling suggests this terrace is present in the subsurface beneath the glacial till. It occurs in a

belt across the middle of the catchment between Barwick, Hadham Cross and Bishops Stortford. The base of the terrace is at an elevation of between 66-72 m in the west, decreasing to about 64-67 m in the east. The thickness is variable depending on how much is preserved beneath the till, but up to c. 10 m may be present locally.

4.2.3 Beaconsfield Gravel Member (BDGR)

As with the Satwell Gravel Member, the Beaconsfield Gravel Member terrace gravel is not exposed at surface in the catchment area, but interpretation of the borehole logs and 3D modelling suggests this terrace is present in the subsurface beneath the glacial till. It occurs in a belt across the middle of the catchment between Ware, Widford and Thorley Street, just south of the Satwell terrace sub-crop. The base of the Beaconsfield Gravel Member is typically at an elevation of 56-60 m. The thickness is variable depending on how much is preserved beneath the till, but up to c. 8 m may be present locally.

4.2.4 Gerrard's Cross Gravel Member (GCGR)

The Gerrard's Cross terrace gravel is also not exposed at surface in the catchment area. Borehole logs and 3D modelling suggest it is present beneath the till in a belt across the south of the catchment between Hunsdonbury, Sawbridgeworth and Little Hallingbury. The base of the terrace is typically at an elevation of 56-60 m. The thickness is variable depending on how much is preserved beneath the till, but up to c. 8 m may be present locally.

4.2.5 Winter Hill Gravel Member (WIHG)

The Winter Hill Gravel Member is the youngest of the ancestral Thames terrace gravels. It is coeval with the onset of the Anglian glaciation and forms part of the Colchester Formation. This terrace deposit has been correlated with the Westmill Lower Gravel Member in the Hertford area (Gibbard, 1977, 1985). Palaeo-current directions indicate flow to the northeast. Up to 8.8 m was formerly exposed in Westmill Quarry (TL 34 15) and 8 m at the Watton Road quarry [TL15 03]. Many other quarries worked these gravels. Details of these old pits, most of which are degraded, backfilled or built over are documented in Clayton and Brown (1958), Gibbard, (1977, 1985); Cheshire (1986) and in the BGS Hertford memoir (Sherlock and Pocock, 1924). The maximum thickness is likely to be around 8-12 m.

The Winter Hill Gravel Member forms a sinuous outcrop on the north side of the Lea valley along the southern margin of the model area. It is largely buried beneath Anglian glaciogenic deposits, but locally exposed around Hertingfordbury, forming a terrace surface at 45-50 m OD.

The Winter Hill terrace gravels were quarried from extensive gravel workings north of Hertford and at the Westmill and Watton Road quarries just outside the model area. They are well exposed in old gravel pits at Waterford Heath (now a nature reserve), where several small exposures can be seen (see Farrant et al., 2022a).

The gravels are likely to be of early Anglian age as they are linked to the earliest advances of ice into the Vale of St Albans. The presence of till beneath the terrace gravels in some of the old pits (Clayton and Brown, 1958), and in borehole logs at Bragbury and just east of Watton-on-Stone, suggests an early lobe of ice extended southwards through the Stevenage Gap as far as Hertford. The Winter Hill gravels may represent the outwash from this ice lobe as it melted.

4.2.6 Stanmore Gravel Member (STGR)

The Stanmore Gravel Member comprises flinty gravel and sand with a little quartz, quartzite and Lower Greensand chert in the fine fractions. The matrix is typically orange-brown, pale grey, red mottled clay and sandy clay, with pockets of coarse sand. It caps the ridge around Hertford Heath at an elevation of c. 95 m OD and is typically less than 5 m thick. It has been ascribed to the Crag Group but may be fluvial in origin.

4.3 ANGLIAN GLACIOGENIC DEPOSITS

Glaciogenic deposits associated with the oscillating advance and retreat of the Anglian ice sheet occur across the Rib-Ash-Stort catchment. These include glacial till, glaciolacustrine and

glaciofluvial outwash deposits. The catchment is situated close to the limit of the Anglian ice sheet, which led to the deposition of a complex suite of glacial and glaciofluvial deposits (Sherlock, 1924; Sherlock and Pocock, 1924; Gibbard, 1977, 1983, 1985; Little, 1984; Cheshire, 1986; Hopson et al., 1996) and the formation of a series of deeply incised buried valleys. The Anglian ice sheet dammed the River Thames and diverted its course away from the Vale of St Albans to a new route to the south, as documented by Gibbard (1974, 1977, 1978a, 1978b, 1979, 1983, 1999), Cheshire (1981, 1983a, 1983b, 1986), Rose (1983), Rose and Gibbard (1978); Little, (1984), Bridgland (1994), and Bridgland and Cheshire (1994).

At the onset of the Anglian glaciation, the ice front advanced southwards through the pre-existing Hitchin-Stevenage Gap, which was incised by a tributary of the Thames draining the area to the north of the Chalk escarpment. The Anglian ice front excavated the Stevenage buried channel and a lobe of ice extended southwards through the Beane valley as far as Hertford in the southeast corner of the model area (Clayton and Brown, 1958; Hopson et al., 1996). The ice deposited by this first advance is modelled as LOFT_2 and is present in the area north of Hertford. The first ice advance appears to have been confined to a pre-existing proto-Beane valley. It is likely that a similar ice lobe pushed into the Stort valley, depositing till as far south as Harlow. As this ice retreated, the meltwater carried outwash gravel down the Beane valley to feed into the Winter Hill terrace aggradation. Similar spreads of glaciofluvial gravels were deposited in the Harlow area and in places along the Stort buried valley, modelled as GFDUA_1. It is possible that some of the glaciofluvial gravels preserved in the Rib and Ash valleys are related to this first ice retreat.

A subsequent westward advance of the Anglian ice front along the Vale of St Albans as far as Ware blocked the ancestral River Thames (Winter Hill terrace system) around Hertford, leading to the creation of a meltwater lake termed 'Lake Hertford'. Within Lake Hertford, glaciolacustrine deposits (the 'Watton Road Laminated Silt' of Gibbard 1977) were laid down in the lower Beane valley and around Hertford. The meltwaters overspilled to the south via the lower Lea valley and into the proto-Medway system. Lake Hertford was short-lived and was overridden by the continued advancing ice front, which deposited till on top of the glaciolacustrine deposits. The ice sheet deposited till across much of the Rib-Ash-Stort catchment area, in places over 20 m thick, and carved out the buried valleys across the region. As the ice sheet retreated, glaciofluvial outwash deposits laid down in each of the main valleys, either within the buried valleys or as terrace remnants on the valley sides.

4.3.1 Lowestoft Formation (LOFT)

The Anglian ice sheet extended throughout the Rib-Ash-Stort catchment, depositing a characteristic blue-grey or dark grey chalky till (Figure 22). The till usually comprises unsorted, matrix dominant, stony clay, typical of a lodgement till. Small chalk fragments, flint and other exotic clasts including 'Bunter sandstone', fragments of Jurassic limestones and quartz occur, and *Gryphea* fragments are relatively common in the north of the project area. In places, the till is dissected by fluvoglacial outwash gravels and post-Anglian erosion. Two distinct till units can be identified from sections and borehole records.

LOWESTOFT FORMATION (DMTN)

This modelled unit is the most extensive glacial deposit in the Rib-Ash-Stort catchment and is equivalent to the East End till of Gibbard (1977). It extends across the interfluvies where it rests on the Clay-with-Flints Formation or bedrock (Hopson et al; 1996; Millward et al., 1987). It is possible that some of this deposit may be till deposited during earlier advances. The Lowestoft Till Member is characterised by grey or blue-grey, stiff, matrix supported, silty clay with numerous clasts, often sub-rounded or sub-angular, ranging from a few millimetres to boulder size. Clasts are predominantly chalk (including well-rounded hard chalk pebbles), and include flints, Jurassic limestones and fossils, quartz, quartzite, occasional igneous and metamorphic clasts. In the north of the catchment, the basal till may be more clay rich, incorporating material from the Clay-with-Flints Formation, which can make it difficult to distinguish between the basal till and in-situ Clay-with-Flints Formation.

The outcrop is characterised by a heavy stiff clay-rich soils, often saturated, with surface runoff in wet conditions. Till was often observed in stream sections, field ditches, road cuttings,

temporary sections and auger holes. Several sections were examined, notably in a 3-4 m deep stream gully near Hill Green [TL 4782 3266]; Clavering Castle [TL 4708 3203] and Newport Quarry [TL 5286 3313]. At Deben Park Lake [TL 5442 3372] the dam spillway cuts a 2-4 m deep ravine into pale grey very chalky till where a 2-3 m high section reveals 1.5 m of pale grey chalky till overlain by 1-2 m of Head. Dark blue-grey till with numerous chalk fragments including well-rounded chalk pebbles was seen in a temporary excavation at Joyce Frankland Academy, Newport [TL 5187 3465], overlain by orange-brown flinty gravelly Head deposits (Figure 22).



Figure 21. Typical pale grey chalky Lowestoft Till overlain by darker orange-brown gravelly Head deposits, Joyce Frankland Academy, Newport [TL 5187 3465].

The till and the contact with the underlying chalk (Figure 23) was exposed in the Plashes Farm track section, Collier's End [TL3747 1977] where the lowest 50 m of the section exposes Anglian glaciogenic deposits (Fig. 6). At this locality the Lowestoft Till Member comprises stiff dark blue-grey clay with chalk clasts and pebbles, with scattered erratic clasts including sandstone, quartzite and Jurassic limestones and fossils including *Gryphaea*, which continues to the southern end of the exposed section. Up section, this passes laterally into a 5 m wide zone of pale orange-brown poorly sorted, clayey sandy fine glaciofluvial gravel with small chalk and quartz pebbles and sub-angular flint clasts typically 0.1-3 cm in diameter. The contact with the underlying Chalk is marked by a sharp sub-vertical surface with bands of orange-brown and grey-green-brown silty pebbly clay with many dark grey rounded flint pebbles. Lowestoft Till Member covers much of the opposite valley side to the south. The thickness of the deposit varies markedly across the region, depending on the pre-Anglian topography upon which the till was deposited and the level of post Anglian erosion and valley incision.



Figure 22. Typical Lowestoft Till Member, with many chalk fragments including well-rounded chalk pebbles in dark blue-grey clay. Plashes Farm section.



Figure 23. The contact between the Chalk and the Lowestoft Till Member at Plashes Farm, marked by gravel passing laterally into till (grey clay beside the track)

4.3.1.1 CALCRETE

Locally the chalk beneath the Lowestoft Till Member has been cemented by carbonate-rich water percolating through the till to create localised calcretes, which superficially look very similar to the Chalk Rock or Top Rock hardgrounds. These calcretes comprise extremely hard chalk breccias, often found as broken clasts in ploughed fields. They were identified in many places around the edge of the till outcrop, notably at Lower Pond Street [TL 4618 3762 and TL 4604 3804]; adjacent to the M11 at Heavy Hill near Little Chesterford [TL 5034 4075 and TL 4981 4071], Windmill Hill [TL 5262 3966] near Saffron Walden, and on the hill northwest of Wendens Ambo [TL 5010 3769]. However, none were seen in section. The calcretes are highly localised and only found around the margins of the till outcrop, suggesting that they occur at the base of the till at the contact with the underlying chalk, typically at the feather edge of the till deposit where it is thin enough to permit water flux through to the Chalk. The calcretes are likely to be very thin (<1-2 m).

LOWESTOFT FORMATION GLACIOFLUVIAL DEPOSITS (SAND AND GRAVEL)

Several areas have been mapped as lenses or beds of sand and gravel within the Lowestoft Till Member. These are generally very small outcrops of coarse-grained, poorly sorted flinty gravel with a sandy clayey matrix. None are well exposed, but some can be identified from borehole records, aerial photographs or changes in soil type. Such gravels occur on Mill Hill south of Wenden's Ambo [TL 515 255], around the airfield on the ridge southwest of Saffron Walden [TL 527 266], Windmill Hill north of Saffron Walden [TL 531 393] and north-west of Littlebury [TL 511 403]. More significant areas of sand and gravel associated with the till are generally mapped as glaciofluvial deposits.

A linear tract of gravel within the Lowestoft Till Member can be traced from Little Hallingbury south-southeast of Hatfield Heath and Matching Green and another between Widford and Hunsdon. These were formerly mapped as Head gravel and are described in Millward et al., (1987). These gravels were included with the Lowestoft Formation (till) in the model as there was insufficient data to accurately constrain their thickness.

LOWESTOFT FORMATION (LOWER, DMTN)

A stratigraphically lower unit of Lowestoft Till Member has been mapped around Harlow, in the area north of Hertford and Ware, and locally in the Stort buried valley, overlain by glaciofluvial sand and gravel. This till is typically a few metres thick north of Hertford, around 8-12 m thick in the Harlow area, and locally significantly thicker, potentially over 30 m, in the Stort buried valley. This lower till unit is likely to be present in other areas in the Lea valley, for example in the now backfilled Hoddesden (St Alban's) pit [TL 3557 0776] but is too thin to model.

4.3.2 Glaciofluvial Deposits (Anglian) (GFDUA)

Anglian glaciofluvial outwash deposits occur extensively in the Rib-Ash-Stort project area. These are equivalent to the Upper Westmill Gravel described by Gibbard (1977) and are in part intercalated between two till units described by Gibbard (1977) as the Ware and Eastend tills. The glaciofluvial deposits comprise coarse poorly sorted gravels, with some lenses and beds of finer sand and fine gravel which is often chalky. The gravels mostly consist of flint pebbles and cobbles comprising a mix of brown stained worn rolled flints, some fresher nodular flints, and well-rounded dark grey 'Paleogene' flints. Lesser proportions of other clasts include well-rounded chalk pebbles, vein quartz, 'Bunter' sandstone, Carboniferous sandstones, Jurassic limestones and occasional igneous and metamorphic clasts. The often very coarse nature of the gravels, plus the occurrence of well-rounded chalk pebbles and some large, relatively 'fresh' nodular flints strongly suggest a glaciofluvial origin and are distinct from the finer-grained Westland Green terrace gravels in terms of grain size, sorting and clast content. The Westland Green terrace gravels were often interpreted as 'glaciofluvial gravels' on the Hitchin sheet but can be distinguished from the glaciofluvial deposits.

For modelling purposes, two distinct glaciofluvial outwash deposits can be identified. A lower unit, which is intercalated between two glacial till units occurs in the southwest of the model area (the Upper Westmill Gravel of Gibbard, 1977) and around Harlow. In the Harlow area, the

gravels are typically around 4-6 m thick. The second unit is younger than the main ice advance and cuts down into the till sheet along the main valleys. In some areas this forms a deep buried valley filled with glaciofluvial gravel, but in some areas, in particular the downstream parts of the main valleys, these glaciofluvial gravels form terraces along the valley sides. These are described by fluvial catchment below.

4.3.2.1 RIB VALLEY

The most extensive area of glaciofluvial sand and gravel is associated with the outwash channel that extends down the River Rib valley and the surrounding tributary valley systems that drain into it. The gravels were deposited by meltwater emanating from the main Anglian ice sheet as it advanced and retreated across the catchment.

A recently worked sand and gravel pit in the Rib valley south of Sawtrees Farm, Barwick Ford [TL3852 1768] exposes 6-8 m of cross bedded flinty sandy gravel and gravelly sand (Figure 24). The gravels are poorly sorted, matrix supported and arranged in planar beds with a coarse sand to fine gravel matrix. The clasts are mainly fresh-worn nodular flints, with more extensively worn brown flints and nodular flint chips and many small, rounded chalk pebbles. Occasional clasts of 'Bunter' quartzite, quartz and a few black-grey rounded flints are present. The gravels are interbedded with lenses and thin beds of cross-bedded chalky flinty pale grey-brown quartz sand. The sands are cross bedded to the south. The typical maximum clast size is c.10x5 cm (mainly nodular flints). This deposit continues through Sawtrees Wood where very gravelly soil underlies the steep wooded slopes and north of the road leading to Barwick Ford where old gravel pits occur [TL 388 189].



Figure 24. Cross-bedded & imbricated, flinty, quartzose poorly sorted glaciofluvial sand and gravel with chalk pebbles, Sawtrees Farm, Barwick Ford.

A second active gravel pit is present in Biggin's Wood near Barwick Ford, Standon [TL3880 1926], which exposes a 6-8 m section in sandy flinty gravel and gravelly sand (Figure 25 and Figure 26). The gravel is crudely bedded with sand lenses and thin beds of finer gravel and pale brown-grey, cross stratified gravelly sand, with a matrix of mostly poorly sorted, pale brown fine-medium grained quartz sand and fine flint gravel. The clasts are locally imbricated, indicating flow direction to the south. The clasts are mostly worn nodular flints and nodular flint chips,

often stained white, with a few black/grey round flint pebbles derived from the Lambeth Group, plus rare 'Bunter' quartzite, sandstone and quartz pebbles. Rounded chalk pebbles are relatively common. The typical maximum clast length is c.10-15 cm (mainly nodular flints).



Figure 25. Glaciofluvial sand and gravel in a pit, Biggins Wood, Barwick.



Figure 26. Close up of cross-bedded & imbricated, flinty, quartzose poorly sorted glaciofluvial sand and gravel with chalk pebbles, Biggins Wood, Barwick.

The same deposit occurs further north around Standon, but is less well exposed. Gravelly soils and old gravel pits were noted around Sophie's Wood [TL388 206]; near the Standon sewage works [TL 395 221], on the east side of the valley north of The Lordship [TL 391216 & TL 391 221] and by the Church [TL 395 220]. North of Standon, old gravel pits 3-4 m deep with coarse flint gravel with nodular flints & brown flint chips, plus round flint, quartz and bunter quartzite pebbles occur along the eastern bank of the River Rib [TL 393 234].

4.3.2.2 ASH VALLEY

In the Ash valley, glaciofluvial gravels were observed at many localities on both sides of the river. These form part of a now dissected spread of glaciofluvial gravel that extends along the valley, descending from c. 80 m OD near Clapgate to 75 m at Hadham Ford and 65 m at Hadham Mill. Near Wareside, in the south of the catchment, very gravelly soils were noted on the east side of the Nimney Bourne [TL 393 160], with many large relatively fresh nodular flints, rounded flints and worn flint chips plus 'Bunter' quartzite and quartz pebbles. Similar gravels were noted around Widford [TL 413 162, TL 414 164]. Orange-brown gritty gravelly sand with nodular flints, worn flint chips, chalk pebbles, along with grey/black flint pebbles caps the spur southeast of Camwell Hall [TL 423 175] and the same gravels can be seen at the top of Sidehill Wood, Hadham Cross [TL 431 183]. It is probable that this gravel deposit is the same that extends up the Bury Green tributary which was worked in several old pits [TL 435 189; TL 439 193 and TL 442 196].

Further north, glaciofluvial deposits were worked around Hadham Ford, notably in a pit on New Road [TL431 211] and on the east side of the valley [TL 435 214]. Some large Hertfordshire Puddingstone boulders were recovered from this area. Poorly sorted sandy gravel with worn flint chips, nodular flints, black round flints, quartz and chalk pebbles in a gritty sandy gravelly matrix occurs on the east bank of the Ash valley between Hadham Ford and Little Hadham at an elevation of c. 77-82 m OD. North of Little Hadham, an old gravel pit [TL 4422 2326] exposes 4 m of sandy gravel with many worn brown flint chips, nodular flints, round grey/black/brown flint pebbles, along with rounded chalk pebbles, quartz and occasional exotic clasts in an orange sandy gravelly matrix. Similar gravels are exposed in a new drainage ditch adjacent to the new bypass [TL 4434 2345]. This deposit extends north on the west side of the Clapgate road as far as Nimno Wood. It is also present on the east side of the valley west of Gravesend [TL438 255 & TL 436 259] where very flinty gravelly soils cap small knolls, with many medium- to large nodular flint pebbles, plus worn flint chips, rounded flint pebbles, quartz and chalk pebbles.

4.3.2.3 STORT VALLEY

Glaciofluvial deposits are associated with the buried valley in the Stort valley, which is in effect the southern continuation of the Upper Cam buried valley. The spatial distribution and thickness of these deposits is likely to be highly variable. Gravel deposits have been mapped on the valley flanks, and along the axis of the buried valley, where boreholes prove locally in excess of 60 m of gravel dominated sediment in the Bishops Stortford area. Over 30 m is proved in boreholes in the valley near Thorley Street. Around Harlow, glaciofluvial deposits are overlain by a second till (for details, see Millward et al., 1987). These gravels are typically up to c. 10 m thick.

4.3.3 Glaciolacustrine deposits (Anglian) (GLLDUA)

Much of the buried valley running through the Upper Cam catchment is infilled with pale orange-brown silty fine sand or silt, locally interbedded with glacial till or gravel. The silts occur at the surface to the east and south of Newport, for example at [TL 516 336] where orange-brown clayey silt and very fine sand with a few sporadic flint chips can be proved by augering. A temporary exposure in a new housing estate on the south side of Newport [TL 5207 3298] exposed 2.5 m pale orange-brown silt and very fine sand, with occasional interbedded laminae of fine sand. Small-scale cross bedding indicates flow to the south (Figure 27). An old pit at Rickling Green [TL 5064 3023] proved 2-3 m of orange-brown silty-fine sandy silt and clay with occasional small flint chips. In the northern part of the buried valley north of Littlebury, the glacial silts are often buried beneath coarser sand and gravel, head or alluvium. Around Springwell Farm, a borehole drilled by Affinity Water proved over 51 m of fine sand and silt beneath the alluvium. Lake and Wilson (1990) document instances of glacial silt, notably

between Bonhunt and Newport, in Gamage's Wood near Audley End, and between Newport and London Jock Wood. Boreholes on the M11 proved up to 20 m of laminated clay and silt beneath a thin cover of till.



Figure 27. Cross-bedded silts and fine sands in a temporary exposure, Newport. Hammer is 0.3 m long.

Glacial silts are locally preserved in the buried channel between Bishop's Stortford and Harlow, for example, from boreholes around Sawbridgeworth (Figure 12 in Millward et al., 1987). However, these are too small and discontinuous to model.

4.4 POST ANGLIAN TERRACE DEPOSITS

The post Anglian sequence in the Chilterns is characterised by a series of fluvial terrace and alluvial deposits along the River Lea and their tributaries including the Beane, Mimram, Ash, Stort and Rib rivers, which are graded to the present drainage network. In the project area, two distinct terraces have been recognised, one 1-2.5 m above the alluvium and a second older terrace about 3-5 m above the alluvium.

4.4.1 Kempton Park Gravel Member (KPGR)

The lower terrace is the Kempton Park Gravel Member, which comprises sand and gravel, locally with lenses of silt, clay or peat, typically 2-5 m thick. The gravel forms a distinctive terrace along the River Lea a few metres above the present day river level. It occurs around Hertford, further south on the River Lea, extends up the Stort valley as far as Sawbridgeworth, and in the Rib catchment around Wadesmill. It has locally been quarried for gravel.

4.4.2 Taplow Gravel Member (TPGR)

The higher terrace is the Taplow Gravel Member, which comprises sand and gravel, locally with lenses of silt, clay or peat, typically 2-5 m thick. The gravel forms a distinctive terrace along the River Lea a few metres above the present river south of Hertford around Great Amwell and

Hoddesdon. It is locally present in the Stort catchment, although it is not always clear as to the relative levels of the various terrace deposits.

4.5 ALLUVIUM

In the study area, alluvium is associated with the present-day River Lee and its tributaries. It is composed mainly of clay, silt, sand and gravel, with localised lenses or beds of peat and peaty clay in the lower reaches. Gravel usually predominates in the lower part, with lenses and beds of sand, passing up into finer grained deposits.

Around 8-10 m of alluvium is present in the lower reaches of the River Stort close to the confluence with the River Lee, and 4-5 m where the A10 crosses the River Lee near Hertford. Elsewhere it is typically between 2-5 m thick, generally thinning further upstream.

4.6 PERIGLACIAL AND MASS-MOVEMENT DEPOSITS

Late Quaternary periglacial and mass-movement deposits are common in the Rib, Ash and Stort catchments. Two different units can be identified based on morphogenetic criteria: Head and Head 1. Their lithology is variable, depending on what material is being reworked, but often consists of sandy, silty flinty, gravelly clay or clayey gravel with many broken angular or subangular stained or bleached flint shards and Paleogene-derived well-rounded flint pebbles.

4.6.1 Head (HEAD)

Head is formed by the accumulation of material in the floor of a dry valley or at the base of a slope by a combination of periglacial processes including hill-wash (colluvium), solifluction and soil creep. Greater thicknesses are generally associated with the centre of valleys or accumulations on the lower parts of hillsides. Locally, thicker deposits can occur where Head deposits infill dissolution pipes or occur above very irregular rockhead. The composition of Head deposits is very variable, typically represented in the study area by clay, silt, sand and flinty gravel. Head is modelled in valley bottoms and hillsides across large parts of the study area. The assumption has been made for the model that Head may be concealed beneath alluvium or other superficial deposits.

Several exposures of Head were noted in deep stream gulleys where water flows off the glacial till onto the Chalk outcrop. These gulleys often cut through the Head deposits to reveal the underlying Chalk. Head deposits were noted in a deep stream gully in 'The Slade' north of Saffron Walden [TL 5386 3975] where 1-3 m of coarse flinty gravel is overlain by 1-3 m of orange-brown silty clay with flint chips. The sequence rests on an irregular pinnacled rockhead on soft destructured putty chalk. Similar coarse poorly sorted flinty gravel with an orange-brown silty clay matrix was observed in a stream gully in Wicken Bonhunt. At Deben Park Lake [TL 5442 3372] the dam spillway cuts a 2-4 m deep ravine where a 2-3 m high section reveals pale grey chalky till overlain by 1-2 m of Head comprising orange-brown silty clay with flint chips, occasionally laminated with thin stringers of chalky flinty fine gravel or sand and a gravelly bed at base, locally cross bedded.

Several sections of Head were seen in deep stream gulleys just south of Brent Pelham where the headwaters of the River Ash flow off the glacial till. At [TL 4334 2990] a 2.5-3 m deep stream gully is cut into orange-brown flinty crudely stratified gravelly head, with flinty gravel lenses interbedded with orange-brown gravelly clay and fine gravelly clay, fining up to silty orange-brown clay at the top. It rests on destructured weathered Chalk with a very irregular piped rock-head.

4.6.2 Head 1 (HEAD1)

Many of the valley sides in the Rib-Ash-Stort catchment area are covered in 1-3 m of poorly sorted, flinty, pebbly and gravelly orange-brown clay. These deposits, termed 'Head 1' are derived from solifluction of the Paleogene, river terraces, glacial deposits or the Clay-with-Flints Formation over the Chalk. The distribution of these solifluction deposits is influenced by solar insolation and aspect. Many of the Chalk valleys in the Chilterns, including those in the Rib-Ash-Stort catchment, are asymmetric with one gently sloping side covered in solifluction deposits

(typically east facing slopes), with bare chalk on the opposite side. Locally these deposits may contain an element of loessic silt. The base of the deposit is likely to be irregular, merging into weathered destructured Chalk. A 2-3 m section behind a barn at New Farm, Elmdon [TL 4799 3706] revealed 1.5 m pale grey-brown silty flinty chalky clay with nodular flints, flint chips and occasional chalk clasts resting on very weathered destructured, involuted soft putty chalk (Figure 28 and Figure 29). The deposit is disturbed by well-developed cryogenic flame and involution structures. A thin dark brown flinty clay soil caps the succession. Excavations for the A120 Little Hadham bypass revealed orange-brown silty loessic clay, gravelly clay and flinty gravel on east facing slopes west of Little Hadham.



Figure 28. Cryoturbated Head 1 deposits overlying destructured Chalk at New Farm, Elmdon [TL 4799 3706]. Auger is 1.2 m long.



Figure 29. Close up of Head 1 deposits overlying Chalk at New Farm, Elmdon [TL 4799 3706].

5 Geological structure and mass movement

Very few notable geological structures occur in the Rib-Ash-Stort catchment. A fault was identified running parallel with the A505 between Baldock and Odsey outside the project area. The bedrock dips gently to the southeast at generally less than 1° . There is some evidence that to the north of the catchment, the Chalk may start to dip very gently to the northwest. Minor faulting is probably ubiquitous throughout the project area. These faults are likely to have throws of less than 5 m and are too small to be resolved from field mapping, particularly given the poor exposure and extensive superficial deposits in the catchment. The best evidence for faulting comes from active quarries, where faulting can be observed directly, but few exposures occur in this area. A minor fault was observed in the Chalk at Newport Quarry but cannot be traced outside the quarry. Small faults with throws of <1 m can be seen in some of the old chalk pits, but these are too small to show on a map.

5.1 GLACIOTECTONICS.

The Chalk along the northern escarpment between Therfield, Barkway and Shaftenhoe End has been affected by glaciotectonics (Hopson, 1995), a result of the Anglian ice sheet impinging on the northern face of the Chalk escarpment. As the ice advanced across the chalk outcrop from the north, large, detached blocks of chalk, in particular the harder Chalk Rock were sheared from their original position and transported southwards. These rafts were often carried within the basal zone of the ice sheet or within deforming till layers and subsequently deposited as the ice impinged against the escarpment. In some cases, these blocks were emplaced tens to hundreds of metres from their original location and became embedded within glacial till, exhibiting signs of tilting, folding and faulting.

Aerial photographs combined with field mapping suggests an extensive suite of thrust Chalk Rock rafts separated by sheets of glacial till extending east-west between Therfield and Shaftenhoe End (Figure 30 & Figure 31), creating an imbricate thrust stack. The darker tills are clearly visible on the aerial photographs and mark the main thrusts, whereas the paler bedrock rafts, being harder, form topographical features.

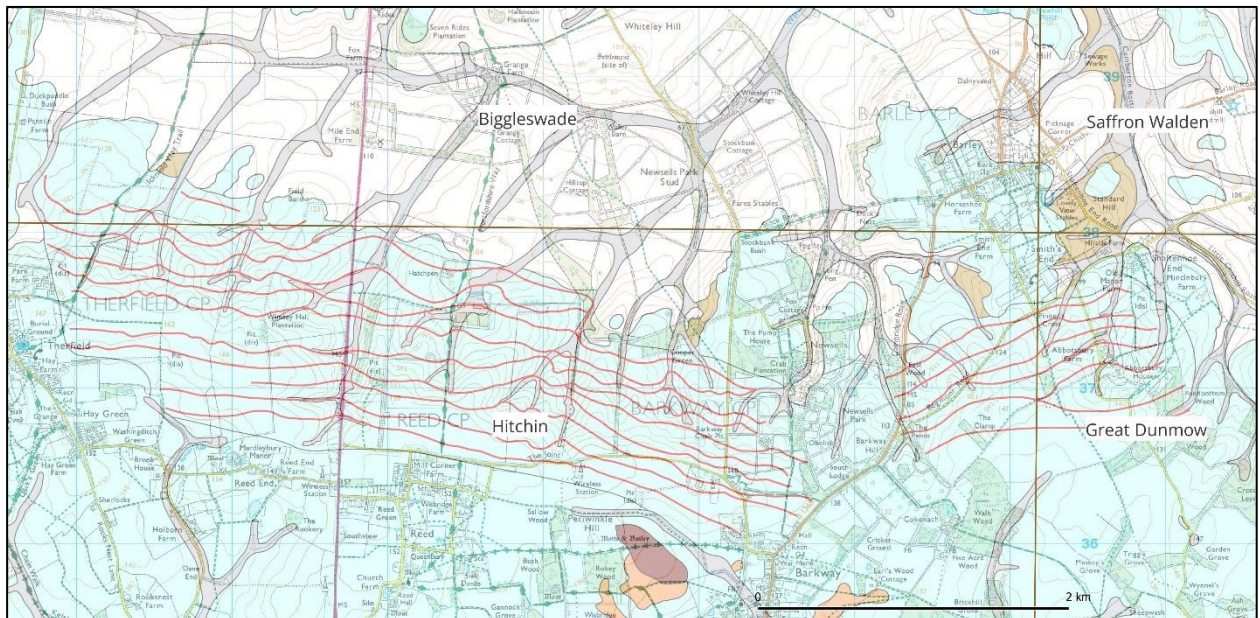


Figure 30. Map of glaciotectonic faulting in the Lowestoft Till between Therfield, Barkway and Shaftenhoe End. Blue is Lowestoft till; red are faults within the superficial till.

Two chalk pits on the north facing escarpment provide evidence for glaciotectonic activity. The first is Barkway Pit, a small disused chalk quarry [TL 3814 3663] 0.7 km north of Barkway and 4 km south of Royston. This pit exposes two inclined thrust rafts of Chalk Rock and the beds immediately above and below that have been ripped from the bedrock and transported a short distance by the ice before being deposited and preserved as an imbricated thrust stack within

the till. These are separated from each other by either a thrust fault or a bed of glacial till (Figure 31 and Figure 32). A second pit 1 km north of Reed [TL 3592 3705] contains sections that expose a single northward dipping 17.5 m thick raft of Chalk Rock and the beds immediately above and below.



Figure 31. Glaciotectonics in the Reed-Barkway area. A. Aerial photograph showing paler chalk rafts interleaved with darker till sheets marking imbricate thrusts within the till. B. Interpreted geological map showing thrust faults within the Lowestoft Till Member.



Figure 32. View of the Barkway pit looking west. The dipping sheet of glacial till marks the thrust contact between two chalk rafts, incorporating the Chalk Rock and the beds above and below.

5.2 LANDSLIPS

Two minor landslips occur in the catchment at Widford and at Hadham Cross. Both are on the east bank of the River Ash in the London Clay Formation, close to the contact with the underlying Lambeth Group (Figure 33).

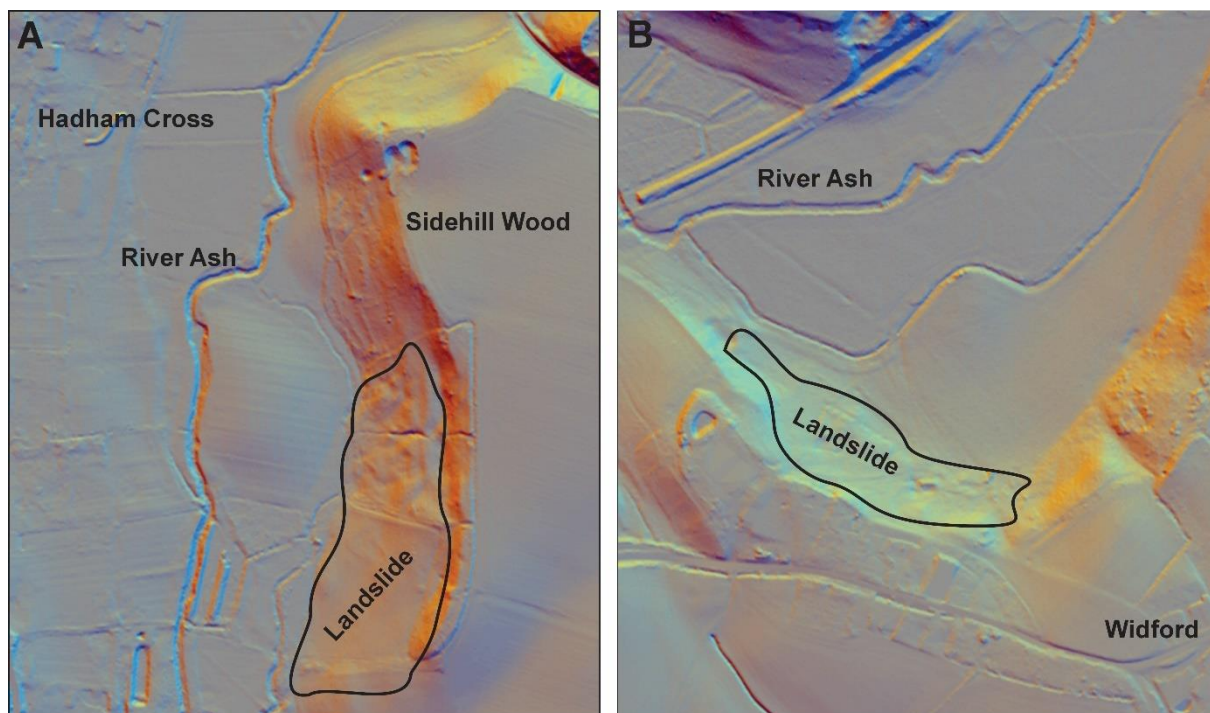


Figure 33. Landslides in the Rib-Ash-Stort project area. A. Just south of Hadham Cross, B west of Widford.

6 Karst Features

Karst features are present in the Rib-Ash-Stort catchment, including stream sinks, dolines and sediment-filled cavities (Whitaker, 1921; Farrant et al., 2017; Maurice et al., 2020;). The observations outlined here are a snapshot at the time of the survey and do not represent a systematic survey of the hydrogeology.

6.1 STREAM SINKS

Much of the catchment is covered by impermeable deposits, in particular glacial till which often caps the interfluvies between the major valleys, and in the south of the project area, the Lambeth Group and London Clay Formation. Where surface runoff from the impermeable deposits flows onto the Chalk, the streams often (but not always) sink underground. In the majority of cases, small streams draining the glacial till outcrop seep gradually into the Chalk over a diffuse stretch rather than in well-defined stream sinks. The point at which the stream channel becomes dry will vary with discharge, suggesting limited infiltration capacity and/or a variable thickness of superficial deposits in the valley floor. Under medium to high discharge conditions, surface flow often continues downstream to join the larger perennial rivers. These ephemeral stream channels are often vegetated in summer, especially the smaller ones. Larger stream channels often incise a deep gully into the underlying bedrock where they pass from the till outcrop onto the Chalk. It is likely that most streams draining the till outcrop lose at least some of their flow where they pass onto the Chalk.

A number of small stream sinks and dolines have been identified across the catchment. Many are concentrated around the Paleogene outliers at Collier's End and east of Standon. These are concentrated along the Chalk-Paleogene boundary where streams flowing off the Lambeth Group sink on reaching the Chalk. Many are small ephemeral sinks, but some can contribute significant flows, notably the Braughing Warren Bourne sink. In addition to those stream sinks around the Paleogene outliers, many of the streams flowing off the Lowestoft Till outcrop sink where they cross onto the Chalk. Sites where streams flowing off the Paleogene and glacial till deposits were observed to sink are shown in Figure 34 and Figure 35. Details of the stream sinks are given in Table 4.

The headwaters of the River Stort have been observed to sink at various places between Clavering and Manuden. The Environment Agency observed a two-metre-wide solution hole in the Chalk bedrock at Clavering [TL 4764 3175] where the river crosses from the till onto the Chalk outcrop (<http://www.geoessex.org.uk/uttlesford/>). It was noted to be choked with debris and is usually obscured by vegetation. The hole was not visible during the field survey and is likely to have been infilled with sediment. In October 2021 the River Stort was dry around Clavering, with a small discharge of 1-2 l/s entering the river from Clavering sewage treatment works. This flow sank 3.7 km further downstream where the Chalk is exposed in the river bed just north of Pinchpools [TL 4909 2854]. Sefton et al (2017) produced a series of flow duration vs distance plots for several rivers in Hertfordshire including the River Stort. This dataset suggests the 10 km stretch between 28 and 38 km upstream from the confluence with the River Lee is often dry when the headwaters are actively flowing. This corresponds to the stretch between Manuden and Clavering where the river flows over the Chalk.

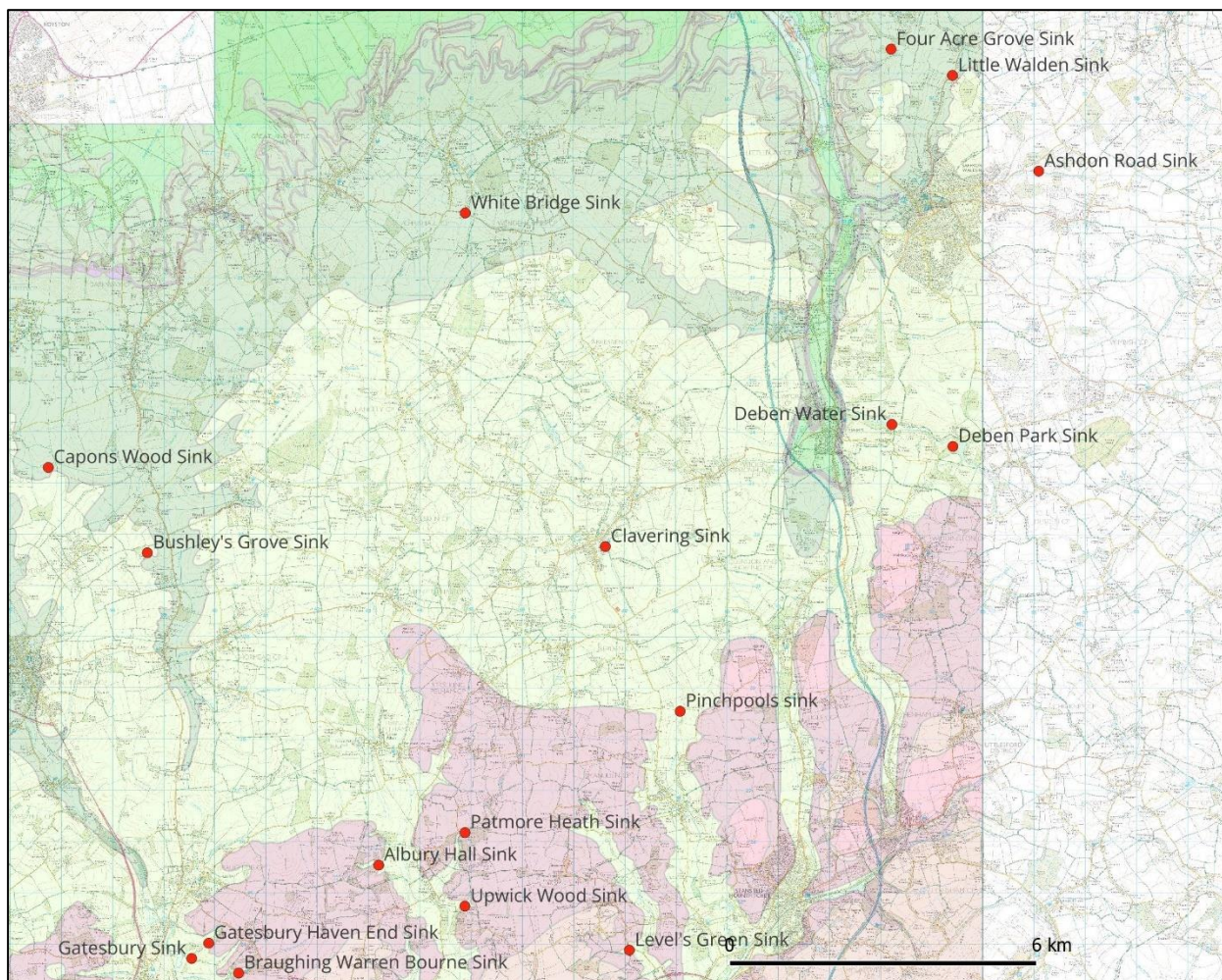


Figure 34. Stream sinks in the northern part of the Rib-Ash-Stort project area. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

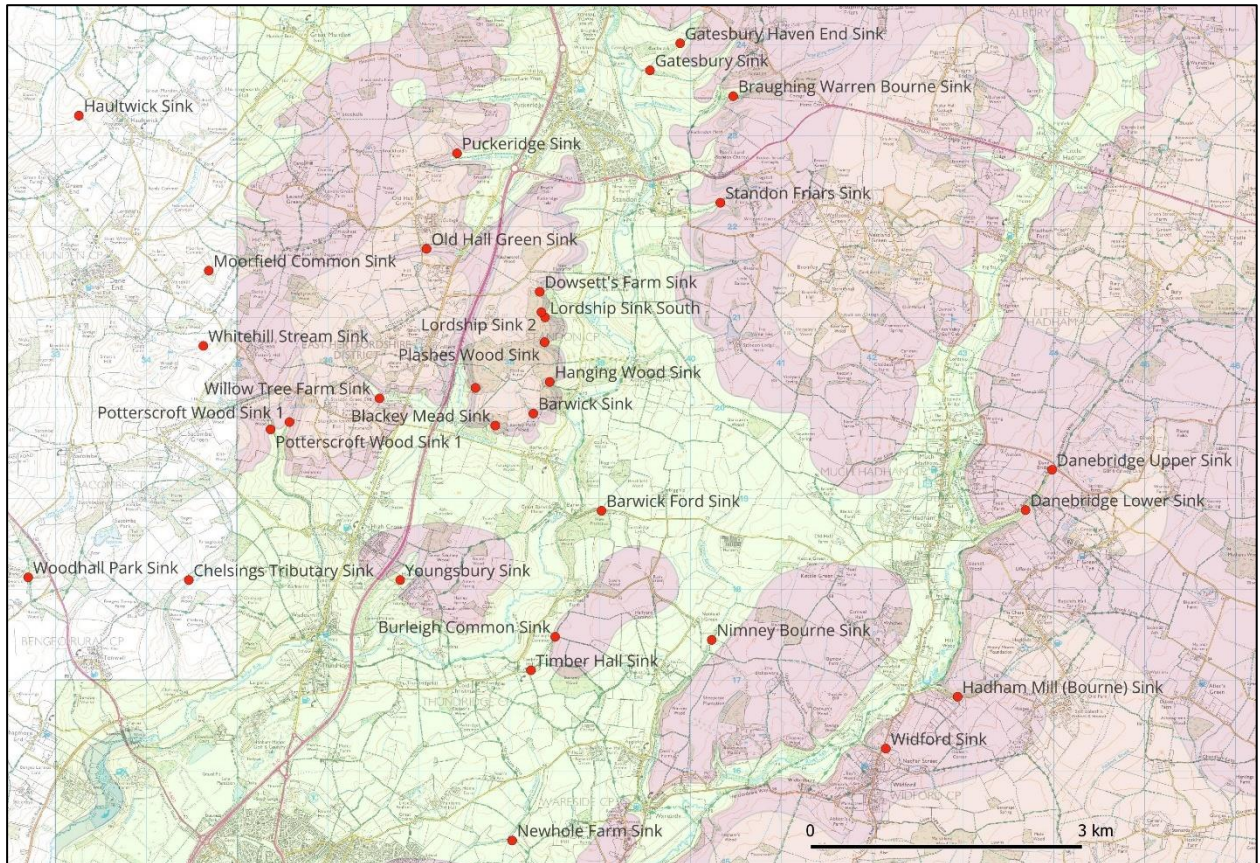


Figure 35. Stream sinks in the central part of the Rib-Ash-Stort project area. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

Table 4. Stream sinks in the Rib-Ash-Stort catchment.

Name	Easting	Northing	Size	Discharge	Notes
Barwick Ford Sink	539019	218863	Trickle	Intermittent	Stream draining till sinks into its bed in deep ravine, water flows on surface to River Rib in wet weather
Standon Friars Sink	540329	222258	Small	Intermittent	Stream draining till & Paleogene sinks into its bed in channel, water flows on surface to River Rib in wet weather
Braughing Warren Bourne Sink	540470	223433	Large	Perennial	Stream draining till & Paleogene sinks into its bed/diffuse boggy area in channel, water flows on surface to River Rib in wet weather
Gatesbury Sink	539553	223717	Medium	Intermittent	Stream draining till & Paleogene sinks into its bed in channel, water flows on surface to River Rib in wet weather
Gatesbury Haven End Sink	539886	224016	Small	Ephemeral	Stream draining till & Paleogene sinks into its bed in channel, water flows on surface to River Rib in wet weather
Burleigh Common Sink	538508	217474	Small	Ephemeral	Stream draining till & Paleogene sinks into a depression in fluvio-glacial gravel on chalk.
Timber Hall Sink	538242	217105	Small	Ephemeral	Stream draining till & Paleogene sinks into a depression in fluvio-glacial gravel on chalk.
Newhole Farm Sink	538034	215229	Small	Intermittent	Stream draining till & Paleogene sinks into its bed in channel, water flows on surface to River Rib in wet weather

Nimney Bourne Sink	540234	217440	Medium	Perennial	Stream draining till sinks into its bed in deep ravine, water flows on surface to River Ash in wet weather
Danebridge Lower Sink	543693	218871	Small	Perennial	Stream draining till (from tributary) sinks into its bed in stream bed, water probably sinks in many places, water flows on surface to River Ash in wet weather
Danebridge Upper Sink	543985	219315	Medium	Perennial	Stream draining till sinks into its bed in stream bed, water probably sinks in many places, water flows on surface to River Ash in wet weather
Hadham Mill (Bourne) Sink	542944	216814	Small	Perennial	Stream draining till sinks into its bed in deep ravine, water flows on surface to River Ash in wet weather
Widford Sink	542153	216242	Small	Perennial	Stream draining till sinks into its bed in deep ravine, water flows on surface to River Ash in wet weather. Also takes sewage effluent
Albury Hall Sink	543205	225539	Small	Intermittent	Stream in artificial channel sinks into old chalk pit, probably not the original sink.
Plashes Farm West Sink	537630	220218	Small	Intermittent	Stream draining Paleogene sinks in boggy sediment filled depression
Barwick Sink	538267	219935	Small	Intermittent	Stream draining Paleogene sinks in boggy depression, recently dug out, one of a series of ponds, larger depression downstream
Hanging Wood Sink	538448	220283	Small	Ephemeral	Small stream sink in ill-defined boggy area in valley floor, no discrete sink
Blackey Mead Sink	537848	219802	Trickle	Ephemeral	Small stream sink in ill-defined boggy area in valley floor, no discrete sink
Lordship Sink South	538397	220994	Small	Ephemeral	Small stream sink in ill-defined boggy area in valley floor, in woodland, no discrete sink
Lordship Sink 2	538356	221052	Small	Ephemeral	Small stream sink in ill-defined boggy area in valley floor, in woodland, no discrete sink
Dowsett's Farm Sink	538338	221276	Trickle	Ephemeral	Small stream sink in ill-defined boggy area in valley floor, no discrete sink
Plashes Wood Sink	538392	220721	Small	Intermittent	A small ephemeral stream draining the Palaeogene sinks in a shallow boggy nettle-filled depression, probably largely filled with sediment
Level's Green Sink	548100	223880	Small	Intermittent	Small stream appears to sink here but may be culverted beneath road.
Patmore Heath Sink	544890	226174	Small	Intermittent	Possible stream sink now bypassed by stream ditch, or possibly old Chalk pit? Not taking water at present.
Upwick Wood Sink	544888	224739	Small	Intermittent	Possible stream sink now bypassed by stream ditch, or possibly old Chalk pit? Not taking water at present.
Bushley's Grove Sink	538688	231634	Trickle	Ephemeral	Stream draining till sinks into its bed, water flows on surface to River Quinn in wet weather

Capons Wood Sink	536754	233299	Small	Ephemeral	Stream draining till sinks into its bed, water flows on surface to River Quinn in wet weather
Clavering Sink	547631	231756	Medium	Perennial	Two-metre-wide solution hole in the chalk bedrock of the river, now choked with sediment. Some water probably sinks hereabouts
Ashdon Road Sink	556093	239082	Small	Ephemeral	Stream disappears underground as it flows from the till onto the Chalk at a point adjacent to the public footpath midway between Martins Wood and the Ashdon Road.
Pinchpools sink	549090	228540	Medium	Perennial	Flow in river sinks into its bed about here in dry weather, includes flow from sewage works
Four Acre Grove Sink	553210	241462	Small	Intermittent	Stream draining till sinks into its bed in channel, water flows on surface to River Cam in wet weather
Deben Park Sink	554417	233709	Small	Intermittent	Stream draining till sinks into its bed in channel (overflow channel for dam), water flows on surface to River Cam in wet weather
Deben Water Sink	553227	234138	Small	Intermittent	Stream draining till sinks into its bed in channel (overflow channel for dam), water flows on surface to River Cam in wet weather
Little Walden Sink	554409	240950	Medium	Perennial	Flow in river sinks into its bed about here in dry weather (roughly between Little Walden and bridge south of Mead Hall)
White Bridge Sink	544895	238266	Medium	Perennial	Flow in river sinks into its bed about here in dry weather (roughly between White Bridge & Building End?)

6.2 DOLINES AND DISSOLUTION PIPES.

The top of the Chalk beneath the superficial deposits, particularly the river terrace deposits and Clay-with-Flints Formation, is likely to be highly weathered. The top Chalk surface may have an irregular rockhead punctuated by numerous dissolution pipes, especially where river terrace gravels directly overlie the Chalk. These pipes may be over 10 m deep (Gibbard et al., 1986), but recharge is likely to be diffuse. No other dolines were identified during the field survey; most dolines in the chalk are quickly infilled, ploughed in, or form so gradually that they do not form topographical features. Many surface depressions which may appear to be dolines are ploughed in chalk pits.

Dissolution features are exposed in the active Chalk quarry at Newport, where Whitaker et al., (1878) recorded two large gravel-filled pipes above a persistent tabular flint layer (now known to be the Seven Sisters Flint). At the same quarry Lake and Wilson (1990) noted several solution pipes, typically 1–2 m wide and 2–3 m deep, lined with a remanié deposit of dark brown, sandy clay and infilled with reworked Kesgrave material. The quarry was visited again in November 2021 and numerous dissolution pipes were observed in the eastern and southern quarry faces. Most are typically 1-2 wide and 2-3 m deep, but some extend to a depth of >5 m. They are typically infilled with ferruginous dark orange-brown sand and clay with pockets of very pebbly quartz rich gravel, representing a mixture of material derived from the Red Crag Formation and Kesgrave river terrace deposits (Figure 36). These are sometimes rimmed with dark brown

sandy clay containing unworn flint nodules. Some of these appear to be truncated by the Anglian glacial till, indicating a pre-Anglian age for the dissolution (Baker, 2019). In addition to the dissolution pipes, complex interdigitating of chalk and sediment filled fractures was noted on the eastern face, just below the overlying till. This may be the result of both dissolution and remobilisation of the periglacially weathered Chalk during the Anglian glaciation.



Figure 36. Dissolution pipes infilled with orange-brown sand and lined with darker brown flinty clay, Newport Chalk quarry. Hammer and spade c. 0.35 m high.

Baker (2019) reported buried sinkhole structures within the Kesgrave sand and gravel deposits at the now backfilled Hollow Road sand quarry, Widdington [TL 530 311]. These collapse features were formed by dissolution in the underlying Chalk and propagated upwards into the overlying sand units. Although the Chalk was not exposed at the Hollow Road quarry, it is present just below the former quarry floor at an elevation of 88–89 m OD, where it is pitted with a number of dissolutional pipes. Maximum observed pipe depths appear to be about 13 m (Baker, 2019). It is suggested that the features at Hollow Road, Widdington are dropout or suffosion features rather than collapse (caprock) sinkholes or cave infills. The planar nature of the till/sand interface indicates that no further subsidence occurred after the Anglian glaciation. Baker (2019) also observed three closely spaced sand filled dissolution pipes in a temporary ditch section at Shipton Bridge Farm [TL531322] in 1973. The pipes are around 1.5 m in diameter and in places >8 m deep.

Many of the deeply incised stream gulleys where streams flow off the till onto the Chalk expose a very irregular rockhead between the Chalk and the overlying till or Head deposits, or in some cases the Chalk-Paleogene contact. The rockhead surface is typically characterised by many small dissolution pipes up to several metres deep. Small dissolution pipes were also observed in the old chalk pit at Wicken Bonhunt [TL 4917 3368]. An old chalk pit near Furneaux Pelham [TL4404 2668] exposes a 2-3 m face of weathered Chalk with a dissolution pipe infilled with flinty grey clay and brown pebbly clay. An old chalk pit near the mouth of the Ash valley [TL 3737 13611] exposes a very irregular piped contact between the Chalk and Lambeth Group, as does the nearby Dairy Farm pit [TL 3831 1395]. An irregular piped contact between the Paleogene and underlying Chalk was noted in a small pit near Hadham Ford [TL 4343 2098].

Other than the dissolution pipes observed in quarries and chalk pits, no definitive dolines were identified during the field survey; most dolines in the Chalk are quickly infilled, ploughed in, or form so gradually that they do not form topographical surface features. Moreover, the evidence from the quarries suggests many are pre-Anglian in age and are buried beneath till. The occurrence of dissolution pipes in most of the currently exposed chalk pits suggest they are likely to be a ubiquitous feature across much of the Chalk outcrop, especially where there is a thin cover of sand-rich Kesgrave and Paleogene sediments but are less likely to occur at surface on the till outcrop.

6.3 SPRINGS

Several springs or groups of springs were identified during the survey, often in clusters suggesting localised areas of groundwater input into the major river valleys. Other springs are likely to be present. The largest springs in the area are the Chadwell and Amwell springs near Ware, just outside the model area. These springs supplied the New River and are the outlet of major karstic conduits fed by stream sinks in the Water End area near Hatfield (Cook, 2010; Maurice et al, 2020). The flow from the Chadwell springs varied from 25 l/s to 250 l/s (Whitaker 1921). The karstic conduits are also linked to springs around Great Amwell (Emma's Well, Rye House and Lynchmill springs). It is not known if these springs are also fed by groundwater from the north.

In the Ash valley near Widford, two small springs were observed issuing from the Chalk in Crackney Wood [TL 4124 1617 & TL 4114 1621]. Several boggy springs were also noted on the opposite side of the valley at Widfordbury. A group of significant springs occurs in Bingles Wood 400 m north of Ford Bridge, Braughing [TL 3898 2477], close to the confluence of the River Quin with the River Rib. Several springs with a flow of 1-2 l/s occur here, and also 270 m to the northwest. Former watercress beds are also present adjacent to Ford Bridge. Possible springs were noted in the River Ash between Much Hadham and Hadham Cross, and on the east bank a little further downstream at Sidehill Wood.

In the River Stort catchment, a significant group of springs occurs outside the project area at Bentfield Mill [TL 500 247] to the southeast of Stansted Mountfitchet. Some of these contribute several l/s to old watercress beds, and other springs and boggy areas are present in the woods northwest of the old watercress beds. The catchment area for these springs may include parts of the Upper Cam area. Other springs may occur in the reach between Manuden Lodge and Blythe Farm.

Some springs also occur at the base of the river terrace deposits where they overlie the Palaeogene, for example a set of boggy springs in Bogs Wood, Patmore Heath, where water in the Westland Green terrace gravels emerges over the Lambeth Group [TL 4520 2541]. A strong spring was noted on old field slips at the base of the till overlying London Clay Formation near Roydon Park [TL 3982 0939].

6.3.1 Upper Cam valley

Several springs or groups of springs were identified in the Upper Cam catchment. Springs often occur in the lower reaches of these tributary valleys along the margin of the buried valley that runs north-south through the Upper Cam valley. These are typically characterised by numerous small springs and seepages that collectively add up to flows of 1-10 l/s.

Areas of significant groundwater discharge were observed in the Wicken Water valley west of Newport around St Helen's Chapel and Bonhunt Water, close to where the M11 crosses the valley [TL 512 335]. In the Wendens Ambo area, the head of the Wenden stream was observed to be 380 m upstream from the M11 bridge [TL 5042 3623] and augmented by numerous small springs and seepages between the M11 and the railway line [TL 510 362], particularly upstream of Wenden Hall. In the Deben Water east of Newport, the zone of groundwater recharge appears to be between the confluence with the River Cam and the footpath at the Chalkpit plantation [TL 532 341].

Another significant group of springs occurs c. 800 m south of Audley End around [TL 524 373] where many small springs and seepages issue over a 300 m stretch along the eastern margin of the Upper Cam floodplain, close to Wenden Road. The springs issue from flinty gravel at or close to the Chalk outcrop and about 6-8 m below the boundary between the Lewes Nodular Chalk and the Seaford Chalk formations and merge to flow into a single tributary of the River Cam with an estimated flow of c. 10-20 l/s. These springs lie c. 1-2 m above the level of the River Cam. Very little water was observed flowing directly into the River Cam from the alluvial gravels exposed along the bank in this area, suggesting the springs are fed by discrete inflows from the Chalk, rather than groundwater rising up through the superficial deposits that infill the buried valley.

A similar group of springs occurs on the east side of the River Cam, 800 m northeast of Littlebury Church. Again, a series of small discrete springs and seepages emerges over a 250 m stretch along the margin of the Upper Cam floodplain and close to the edge of the buried valley. The water issues from flinty gravel, probably Head deposits overlying chalk at the foot of a dry valley. Again, the springs are slightly topographically higher than the adjacent floodplain, with an estimated discharge of around 20 l/s. The springs are located about 8-10 m below the Chalk Rock, which crops out on the east side of the B184.

7 Passive Seismic Surveys

To constrain the geometry of the buried valley deposits in the Rib-Ash-Stort catchment, additional geophysical data was acquired. Geophysical transects (Figure 37) were carried out at various points along the buried valley between Harlow and Bishops Stortford, in the Stort valley, and on the interfluvial areas across the area using a passive seismic detector (Tromino).

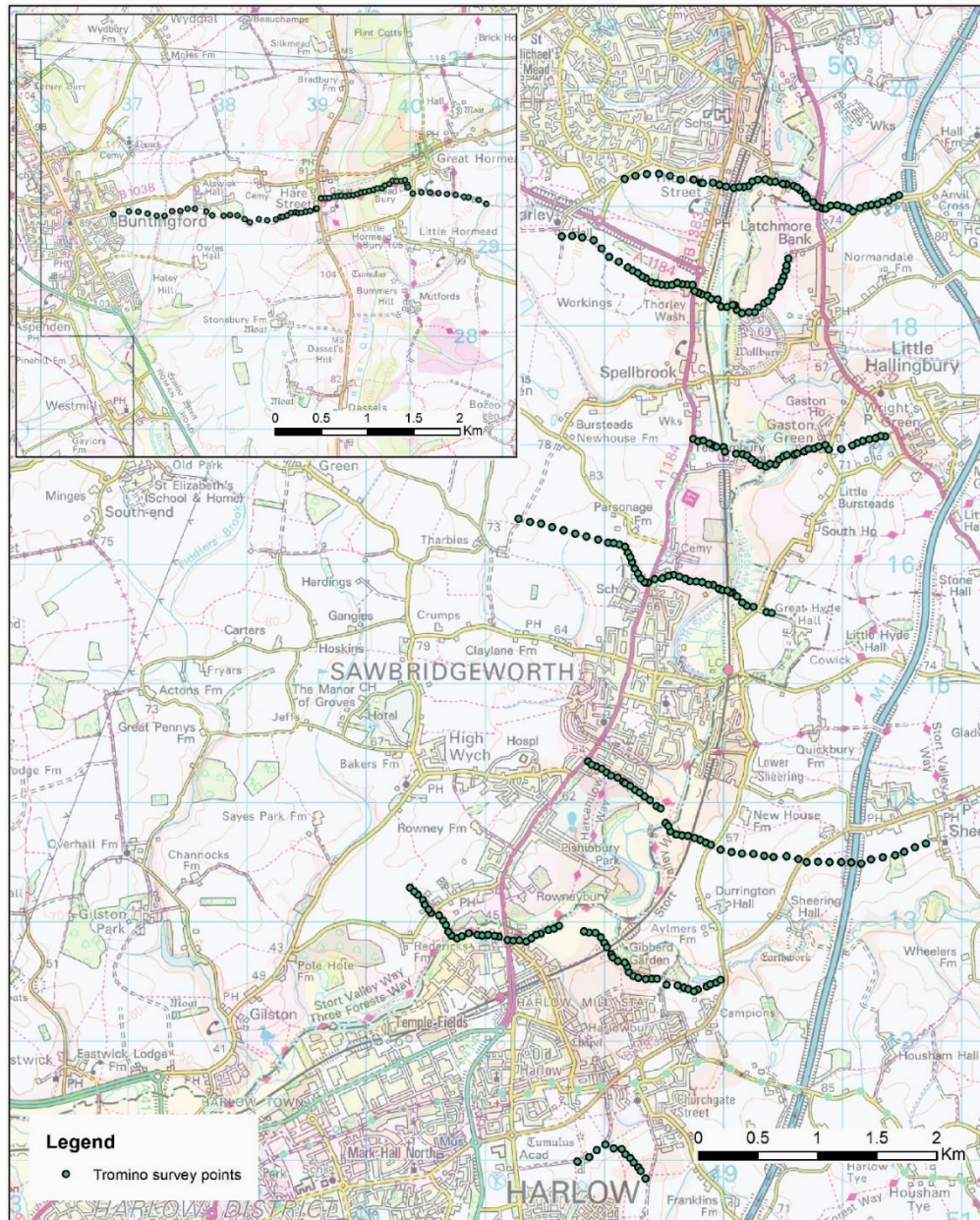


Figure 37. Location of the geophysical transects in the Harlow-Bishop's Stortford and Buntingford areas. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

Tromino uses background seismic energy to create seismic profiles and the data was used to constrain the geometry and depth of the superficial deposits. Given uncertainties in the seismic velocity profiles of the various deposits, the sections should not be used as an indicator of the absolute depth to rockhead but can be used to constrain the geometry of the superficial deposits. The profiles are documented in Appendix 1. Previous geophysical surveys across the Hitchin buried valley focused on the area to the north-west (Raines and Chacksfield, 1991; Chacksfield and Raines, 1992).

7.1 THE PASSIVE SEISMIC METHOD

The H/V ambient noise seismic method is a novel, non-invasive technique that was initially developed for earthquake microzonation studies. However, it is increasingly being used to estimate the structure and depth of the bedrock beneath superficial deposits (Chandler and Lively, 2014). The energetically dominant part of seismic ‘noise’ which consists mainly of surface waves, is traditionally regarded as a nuisance by seismologists, but is rich in information, especially in the structure of the near-surface. As this noise is ever-present and ubiquitous, it has become a convenient exploration tool (Castellaro et al., 2005).

One way of analysing seismic noise is the horizontal-to-vertical spectral ratio method, which computes the ratio between the horizontal and vertical (H/V) components of seismic noise measurements at a single station. The underlying assumption is that ambient noise consists mainly of surface waves (Rayleigh and Love) and/or body shear waves reflected and refracted inside shallow layers characterised by a strong impedance (velocity x density) contrast. Because seismic noise varies largely in amplitude as a function of the noise “strength”, the spectral ratio remains essentially unaffected and is tied to local subsoil structure.

The H/V method uses a single, broad-band three-component seismometer, in this case a Tromino Zero and a Tromino 3G, to record low-amplitude ambient vibrations of the ground. These vibrations are produced by local surface sources such as traffic and other industrial/human activities, normally at frequencies > 1 Hz, or from far-distance sources such as oceanic waves, winds and other meteorological sources below 0.3 Hz (Bonnefoy-Claudet et al., 2006 and Acerra et. al., 2004). The instrument itself is a small, portable device approximately 140 x 100 x 80 mm in size, powered by two AA batteries (the small red box in the foreground of the photo, Figure 38). It sits directly on the ground surface, and measures the natural, ambient vibrations in the ground. Each measurement usually takes between 10 and 30 minutes.



Figure 38: Tromino passive seismic instrument in operation next to an observation borehole.

Processing of the passive seismic data was undertaken in three stages:

- (i) initial screening to ensure that the data were valid
- (ii) filtering of artificial noise from the data, and
- (iii) the depth of the frequency peaks was determined from the assumed bulk shear wave velocity for the profile, using:

$$h = V_s/4f \quad \text{[Equation 1]}$$

Where h = depth; V_s = shear wave velocity, and f = frequency (Hz)

The greatest area of uncertainty in the interpretation of the data comes from the requirement to assess the shear wave velocity of the near surface strata for modelling, as the Grilla Software is designed to model from the surface shear wave velocity. Whenever possible shear wave velocity profiles are validated against measurements of shear wave velocity using such techniques as Multi-Channel Analysis of Surface Waves (MASW); or calibrating the results using borehole data. In the absence of ground-truthed data the approach is to select appropriate shear wave velocities from published literature.

7.2 SURVEY

The survey was carried out in two phases in 2023 by taking measurements at c. 50-100 m intervals along selected transects, principally across the buried valleys or where there are significant superficial deposits. Additional readings were taken close to boreholes to provide some constraint on the seismic velocity profiles. The locations of the measurement points were recorded using a hand-held GPS which generally had a precision of about +/-10 m.

7.3 PROCESSING

The Tromino and SoilSpy data were processed using Grilla software, a propriety package designed specifically for these instruments. Colour contour plots of the horizontal to vertical ratio (H/V) values were generated in Surfer. An example shown in Figure 39, and the full set of plots is given in Appendix 1. The higher values of H/V ratios, in yellow, orange and red colours represent zones of high acoustic impedance contrast (i.e. a transition from weaker to more competent rocks). The zone of high H/V values has been interpreted as the base of superficial deposits/top of Chalk or the top of unweathered Chalk.

The processing relies on representative values for the shear-wave velocity and its rate of increase with depth. This can be verified by MASW surveys, taking Tromino measurements over known geology (e.g. borehole location), or using typical values from literature.

It should be noted that there are lateral changes in mapped surface geology along many of the profiles. The SoilSpy MASW data shows that the shear wave velocity (V_s) profile also varies, so the parameters used in processing the Tromino data used averaged values which were assumed to be reasonable given the composition of the underlying strata. Should other data prove the values to be incorrect, the depths of the profiles are adjusted accordingly. An increase in the V_s or exponent values used in processing would result in an increase in the interpreted depths of strata. The processing algorithm assumes a smooth increase in velocity with depth, so does not consider step-changes in velocity, as might be expected at the top of unweathered (competent) Chalk.

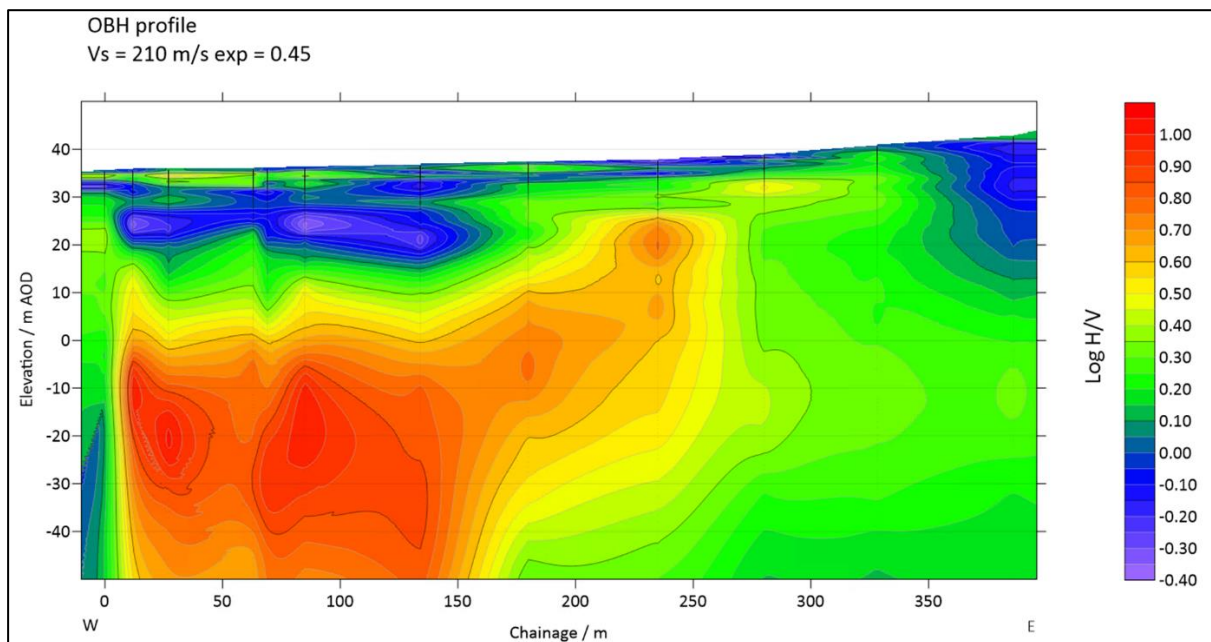


Figure 39. Example of the colour contour plot generated in Surfer. The red and orange colours show zones of high acoustic impedance contrast.

8 3D Geological Modelling

This geological model encompasses the Rib-Ash-Stort catchments as outlined in Figure 1. The purpose of the model is to demonstrate the distribution of geological units within the three catchments, including the Upper Cam area, in order to inform the work of the Environment Agency about the management of water resources in the area. The geology is dominated by Palaeogene and Cretaceous strata, together with superficial deposits including glacial deposits, river terraces of the pre- and post-diversionary River Thames, alluvium and periglacial mass-movement deposits. The model is suitable for use at scales between 1:100 000-1:10 000 down to the base of the Chalk Group. The model includes 10 bedrock units and 19 superficial units.

8.1 MODELLED SURFACES/VOLUMES

Both bedrock and superficial deposits were mapped and modelled as part of this project. Each of the modelled units and the list of BGS Lexicon codes (LEX-RCS codes) used in this model is given in Table 1 and Table 3. These tables should be used as a legend when viewing images of the model.

8.2 MODELLED FAULTS

No faults were mapped within the model area. Nearly all the faults observed in the catchment (usually in old pits) are minor (displacements of less than 5 m) and therefore were not modelled as these were beyond the resolution of the model. Additionally, it is hard to prove displacement in the subsurface without direct evidence, usually best seen in outcrop. It is likely that there are many more minor faults present than shown in the model (Aldiss, 2013). In areas away from primary data control, the absence of faults should not be assumed.

It is important to understand the nature of geological faults, and the uncertainties that attend their mapped position at the surface. Faults are planes of movement along which adjacent blocks of rock strata have moved relative to each other. Larger faults commonly consist of zones, perhaps up to several tens of metres wide, containing several to many fractures. The portrayal of such faults as a single line on the geological map may therefore be a generalisation.

8.3 MODEL OUTLINE AND DIGITAL TERRAIN MODEL (DTM)

The model outline is shown in Figure 1. The model used the Ordnance Survey (OS) Terrain Digital Terrain Model (DTM) which has a 50 m resolution and is free to use and available to all with no copyright issues.

8.4 BOREHOLE DATA

Borehole records (Figure 5) used for the model fall into two categories, based on the information the borehole provides. These are lithological boreholes and geophysical boreholes. Both are detailed below. Start heights were honoured where present; where no start height was recorded or was obviously erroneous then these were hung from the DTM. Particular clusters of boreholes are associated with urban infrastructure around Harlow and along road schemes (M11, A120 and A10) and mineral assessment boreholes around Hertford (Figure 42).

8.4.1 Lithological boreholes

Lithological, stratigraphical and other significant details from selected boreholes were entered into the corporate borehole database (the BGS Borehole Geology data entry application). Not all boreholes in closely clustered sets were coded, but the deepest and most representative were included; any significant local variation in sequence was also recorded by coding. A selection of the most suitable boreholes was considered in the model, where possible ensuring an even spread of borehole data across the model area. Priority was given to boreholes that have good quality stratigraphical logs, particularly those with geophysical logs, and those that reach a depth of 20 m or more below ground level. Many of these were mineral exploration boreholes drilled by the BGS Industrial Minerals Assessment Unit (IMAU) in the 1970s & 1980s.

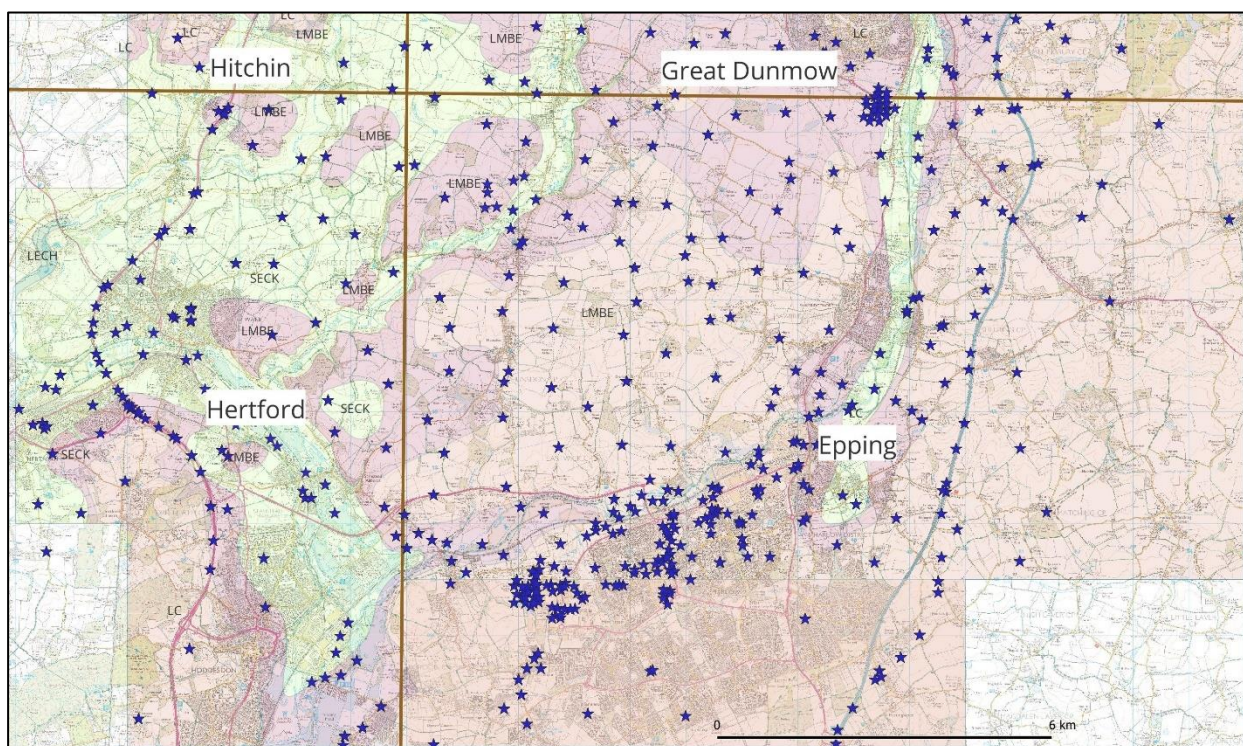


Figure 40 Locations of coded boreholes in the southern part of the project area, with bedrock geology and 1:50K sheet boundaries. Contains Ordnance Survey data © Crown Copyright and database rights [2022]. Ordnance Survey Licence no. 100021290.

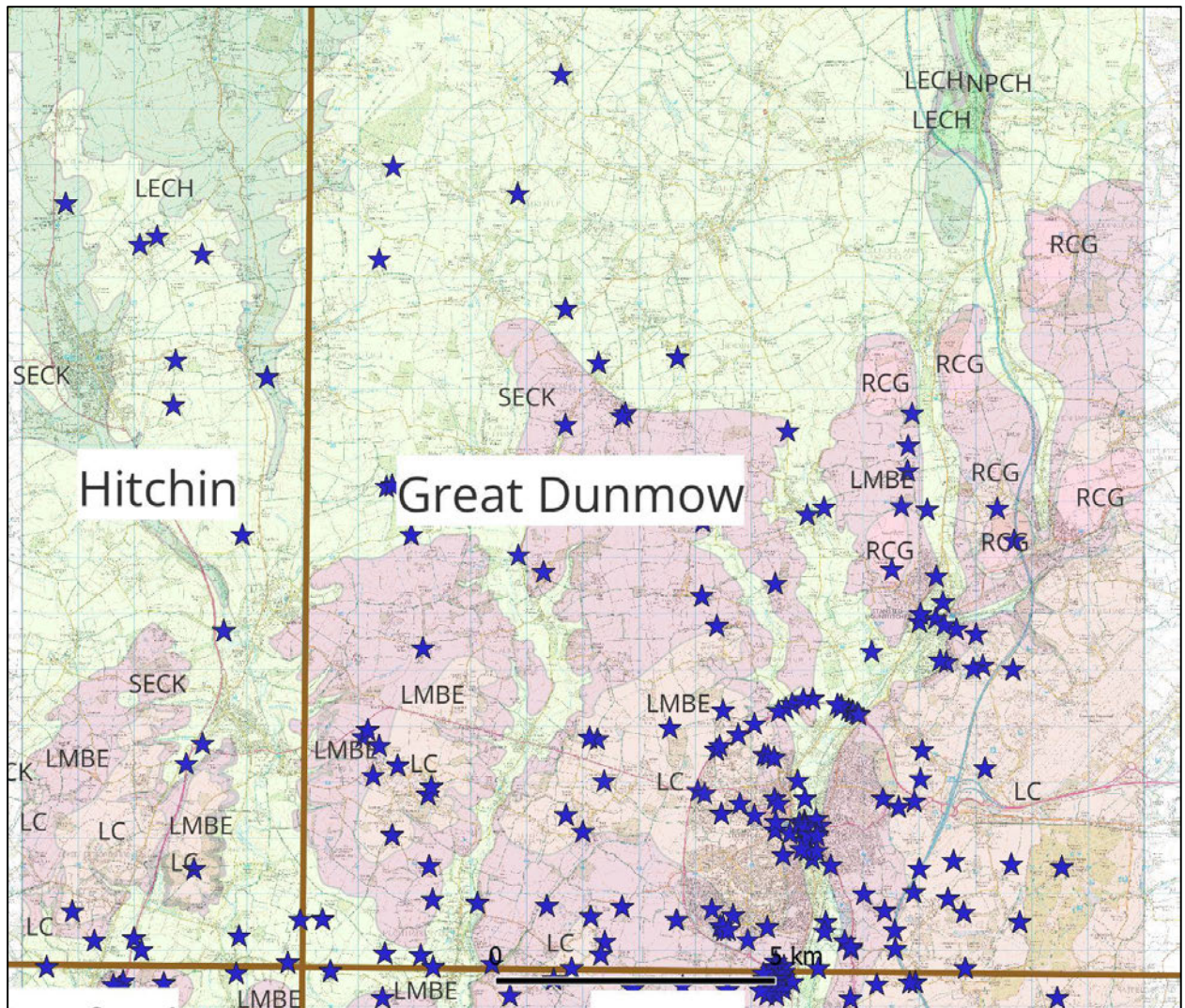


Figure 41. Locations of coded boreholes in the northern part of the project area, with bedrock geology and 1:50K sheet boundaries. Contains Ordnance Survey data © Crown Copyright and database rights [2022]. Ordnance Survey Licence no. 100021290.

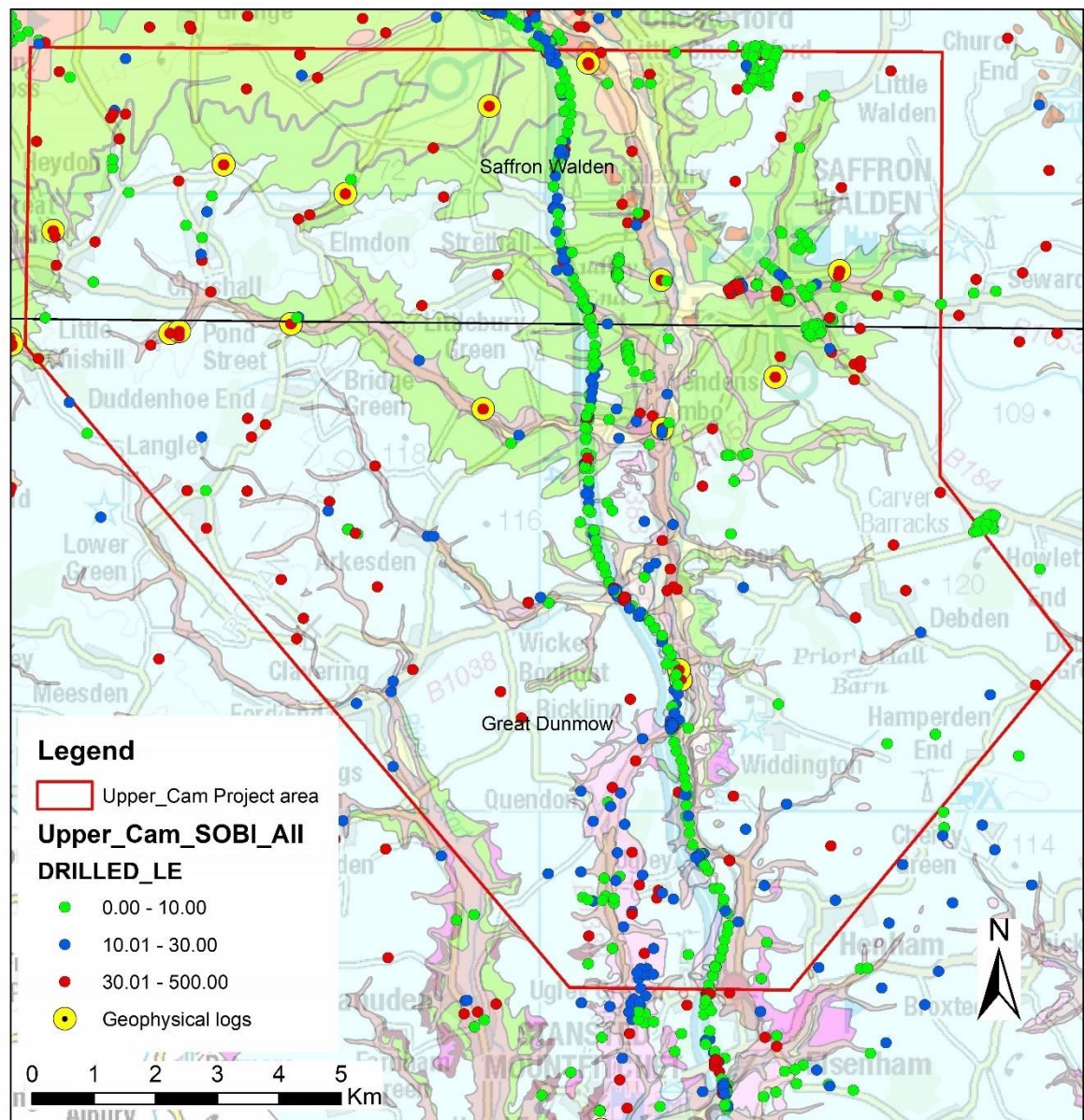


Figure 42. Map showing locations of boreholes (coloured by depth) and cross sections (dark blue) in the Upper Cam catchment. Contains Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

8.4.2 Geophysical boreholes

Geophysical logs (Figure 6 and Figure 7) are the most useful for determining the lithostratigraphy of the Chalk Group. Fifteen resistivity and gamma logs were interpreted and entered into the corporate Borehole Geology (BoGe) database. Geophysical logs were included in cross-section correlations that were outside, but close to, the model area, to help better constrain the Chalk formations, as there were only a limited number of geophysical borehole logs available in the model area.

8.4.3 Borehole Download

Boreholes were downloaded from the BGS borehole database (BoGe) using Groundhog borehole management software (Wood et al., 2015). Start heights absent from BoGe were populated by the OS50m DTM.

8.5 CROSS SECTION LOCATION AND SPACING

Cross sections were compiled using Groundhog software and were distributed to make best use of borehole information, and to provide optimal coverage for the model calculation. The cross

sections were orientated approximately parallel and perpendicular to the general dip of the bedrock geology, with many additional ‘helper’ sections to aid the correlation of specific units or in areas where there is significant geological complexity. Sections were constructed along the line of the passive seismic transects and the interpreted seismic images dropped onto the cross section so the data could be used in interpreting the geology. A denser network of sections was created to model the river terrace and glacial deposits in the buried valleys, around Harlow and where the palaeo-Thames terraces are present beneath the till in the south of the project area. Sections were edited during the modelling process in Groundhog where required. The sections are shown in Figure 43.

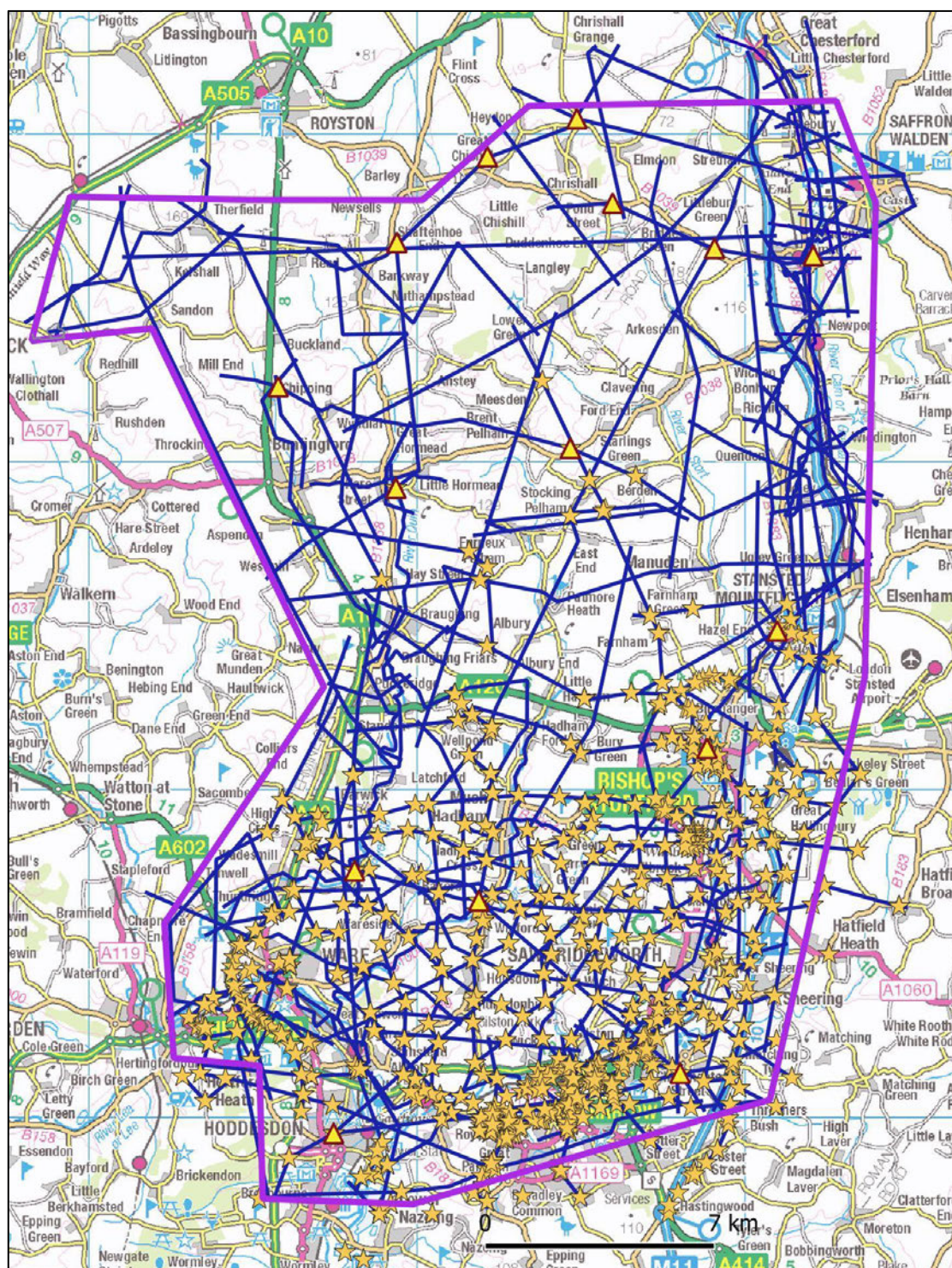


Figure 43. Location of all cross-sections (main sections and helper sections) used in the model, and coded boreholes (stars) and geophysical logs (triangles). Contains Ordnance Survey data © Crown Copyright and database rights [2022]. Ordnance Survey Licence no. 100021290.

8.6 MODEL WORKFLOW

The model was built and edited in Groundhog software using a standard methodology (Wood et al, 2015). The model is based on cross-sections, boreholes, structure contours and map data. Geological linework from the mapping was brought into the modelling software, along with borehole data and the passive seismic interpretations. The modelling used the available data to create gridded surfaces for each unit at 15 m resolution. Several geological units were modelled not by correlating cross sections, but by using an assumed thickness. An assumed thickness of 25 m was used to model each of the lowest two bedrock units, the Zigzag Chalk Formation and West Melbury Marly Chalk Formation respectively. This was done as the lack of borehole and outcrop data at depth prevented a modelled surface to be generated. The modelled thicknesses of each unit are given in Appendix 2.

8.6.1 Model assumption and rules

Several assumptions were made in the construction of this model:

- River Terrace Deposits adjacent to alluvium tracts were assumed to extend beneath them.
- Head 1 deposits were assumed to extend beneath valley bottom Head deposits.
- The geological line-work honours the Ordnance Survey topography represented by the 1:25 000 scale topographic contours. Where the model DTM differs from the OS contour data, it may cause anomalies in the geological model, for example, where valley bottom Head deposits crop-out on valley sides. It is assumed that the DTM is inaccurate due to trees or artificial made ground, which creates some thickness anomalies on steep wooded hillslopes, and on steep slopes in areas of made ground.
- In the model we assume that Chalk formation thicknesses remain relatively constant over the scale of the model. The data from boreholes and outcrops are not sufficient to delimit intra-formational facies and thickness variations that may exist in the Chalk Group away from the scarp edge and key boreholes. This is particularly the case for the lower Chalk Group units on the dip slope where there is no outcrop data and very few deep boreholes.
- Faults have not been modelled. There is no specific evidence for displacement of strata. The spacing of the boreholes and observations is often not dense enough to determine minor faulting.
- Areas of Made Ground were not modelled. Some superficial and bedrock units modelled beneath these areas may show on the model as being anomalously thick, for example around the old sand and gravel pits north of Hertford.
- In the Beane catchment, the Chalk Rock, Kenworth Member and the Top Rock were modelled as separate entities. In this area the Chalk Rock and the Top Rock were not modelled as separate entities.

8.6.2 Generic Groundhog model limitations

- Geological interpretations are made according to the prevailing understanding of the geology at the time. The quality of such interpretations may be affected by the availability of new data, by subsequent advances in geological knowledge, improved methods of interpretation, improved databases and modelling software, and better access to sampling locations. Therefore, geological modelling is an empirical approach.
- It is important to note that this 3D geological model represents an individual interpretation of the data available; other interpretations may be valid. The full complexity of the geology may not be represented by the model due to the spatial distribution of the data at the time of model construction and other limitations including those set out elsewhere in this report.
- Best endeavours (detailed quality checking procedures) are employed to minimise data entry errors but given the diversity and volume of data used, it is anticipated that occasional erroneous entries will still be present (e.g. borehole locations, elevations etc.) Any raw data considered when building geological models might have been transcribed from analogue to digital format. Such processes are subjected to quality control to

ensure reliability; however, undetected errors may exist. Borehole locations are obtained from borehole records or site plans.

- Digital elevation models (DEMs) are sourced externally by BGS and are used to cap geological models. DEMs may have been processed to remove surface features including vegetation and buildings. However, some surface features or artefacts may remain, particularly those associated with hillside forests. The Digital Terrain Model (DTM) may be sub-sampled to reduce its resolution and file size; therefore, some topographical detail may be lost. On steep wooded slopes, such as the main Chiltern Hills escarpment and some of the steeper valley sides, the DTM used in the model may be significantly different from the OS contour data. The difference in derived surface elevation impacts on the model in these areas and some of the modelled thickness variations in the Chalk formations along steeper slopes may be artefacts of the modelling, rather than true thickness variations. In some of the dry valleys, the DTM does not accurately reflect the Ordnance Survey contour profiles upon which the geological line work is based. Thus, in some instances, the valley bottom Head deposits or Alluvium appear in the model to occur on the valley sides rather than sit in the valley bottom. This is an artefact of the DTM used, which includes trees, and therefore does not match OS contour data.
- The geological map linework in the model files may be modified during the modelling process to remove detail or modify the interpretation where new data is available. Hence, in some cases, faults or geological units that are shown in the BGS approved digital geological map data may not appear in the geological model or vice versa. Modelled units may be coloured differently to the equivalent units in the published geological maps.
- Borehole start heights are obtained from the original records, Ordnance Survey mapping or a DTM. Where borehole start heights look unreasonable, they are checked and amended, if necessary, in the index file. In some cases, the borehole start height may be different from the ground surface, if for example, the ground surface has been raised or lowered since the borehole was drilled. This is commonly the case for site investigation boreholes on road and rail schemes, and for mineral assessment boreholes in gravel quarries, or if the borehole was not originally drilled at the ground surface.
- Borehole coding (including observations and interpretations) was captured in a corporate database before the commencement of modelling and any lithostratigraphical interpretations may have been re-interpreted in the context of other evidence during cross-section drawing and modelling, resulting in a mismatch between BGS databases and modelled interpretations.

8.6.3 Model specific limitations

- Along the edges of the model, some units may show anomalous thicknesses. These are edge effects created by the way the surfaces are generated in the modelling software.
- Faults were not modelled as none were identified in the project area. There will be many minor faults (throw of less than 10 m) running through the entire model area.
- In some areas, the subsurface data is based on very limited borehole data and not supported by other geophysical data. In these areas, the confidence of the model is low and the data should be viewed with caution. This is particularly the case where the Chalk Group outcrop is buried beneath superficial deposits, and few borehole logs exist. Consequently, most of the Chalk formation surfaces are derived from the new geological mapping and are not well constrained by borehole data except close to geophysical boreholes. Therefore, Chalk units not at outcrop and lower down in the Chalk stratigraphy are interpolated by estimated thicknesses.
- The region is cut by several buried valleys, the geometries of which are very poorly constrained with few boreholes. The lithology and thickness of the glaciogenic deposits infilling these buried valleys is likely to be highly variable with rapid lateral and vertical changes in the spatial distribution of the dominant lithologies. The margins of the buried valleys are known to be very steep, and the basal long profile is likely to be highly irregular with some areas cutting down deeply into the underlying bedrock.
- The rockhead surface on the Chalk Group outcrop is likely to be highly irregular beneath the Clay-with-Flints Formation, river terrace deposits and any remnant Palaeogene

deposits due to the presence of dissolution pipes. Borehole data elsewhere suggests these may extend up to 20 m into the underlying Chalk Group. Thus, borehole records of the superficial deposit thickness may be unreliable and are only relevant to spot locations and cannot be used to extrapolate the rockhead surface with certainty. The modelled base Clay-with-Flints Formation surface is a smoothed approximation of the average rockhead surface, rather than presenting a realistic actual rockhead. Several infilled dissolution pipes have been modelled, but only where they are indicated by borehole data; it is expected that many more dissolution pipes may exist elsewhere within the model area.

- The Head deposits (Head and Head 1) were modelled by correlating cross sections. The relationship between the Head deposits and the Head 1 deposits on the valley sides is likely to be complex and is not modelled accurately. In reality, these deposits merge into each other. Similarly, Head 1 deposits may interdigitate with alluvium deposits.
- The base of the glacial till in many areas is reworked underlying material, so the base of the glacial till can be difficult to map/model precisely.
- Periglacial weathering and mass-movement means that the river terrace and till deposits capping many of the hills and interfluvies may grade downslope into solifluction deposits (Head 1). The boundary between these units is likely to be gradational.
- Artificial deposits, including made, worked and artificial ground are not modelled. Mass movement deposits are also not modelled.
- Many of the borehole logs are based on drillers logs, rather than being interpreted by a geologist. This can lead to errors in interpretation.

8.6.4 Model uncertainty

As with any geological model, significant uncertainties are associated with the Rib-Ash-Stort catchment model. The biggest uncertainty stems from the lack of good quality deep boreholes with down-hole geophysical logs across much of the catchment. Consequently, there is little or no control on the thickness of the lower Chalk Group units, particularly below the New Pit Chalk Formation away from the Chiltern Hills escarpment. For the purposes of modelling, a uniform thickness for the West Melbury Marly Chalk and Zig Zag Chalk formations had to be assumed based on the limited available borehole and outcrop data. In addition, the extent of the superficial cover means that there is very little chalk exposed at surface across much of the catchment.

In addition, there may be significant intra-formational variation within some of the units, particularly the Lewes Nodular Chalk Formation and within the Grey Chalk Sub-group. Given the paucity of spatial and borehole data, it is not possible to identify or model significant facies or thickness changes within individual formations, such as those that may be associated with the Chalk Rock and Top Rock.

Whilst few faults have been identified in the catchment, observations in Kensworth Quarry in the Ver catchment and in the chalk quarry at Newport suggest that the project area may be cut by many small faults with throws less than 5 m. It has not been possible to model these.

The thicknesses of the superficial deposits are poorly constrained. This is particularly the case with the Clay-with-Flints Formation and Lowestoft Till Member, which are likely to be highly variable in thickness, in part due to the effects of dissolution and an irregular topographical surface upon which they were deposited. Many of the river terrace gravels are degraded and partially covered by solifluction deposits, which make mapping their outcrops difficult. Their outcrops are based on interpretation of the Digital Terrain Model, information from Gibbard (1977, 1985) and others, geological mapping and borehole data where available. Local dissolution pipes have been modelled where there is borehole evidence for them, but in reality, the base of the Clay-with-Flints Formation and the river terraces are likely to be more irregular than shown.

Many of the paleo-Thames terraces are only known from boreholes, being largely covered by till. Consequently, their spatial distribution is poorly known and constrained only by borehole data.

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British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: <https://of-ukrinerc.olib.oclc.org/folio/>.

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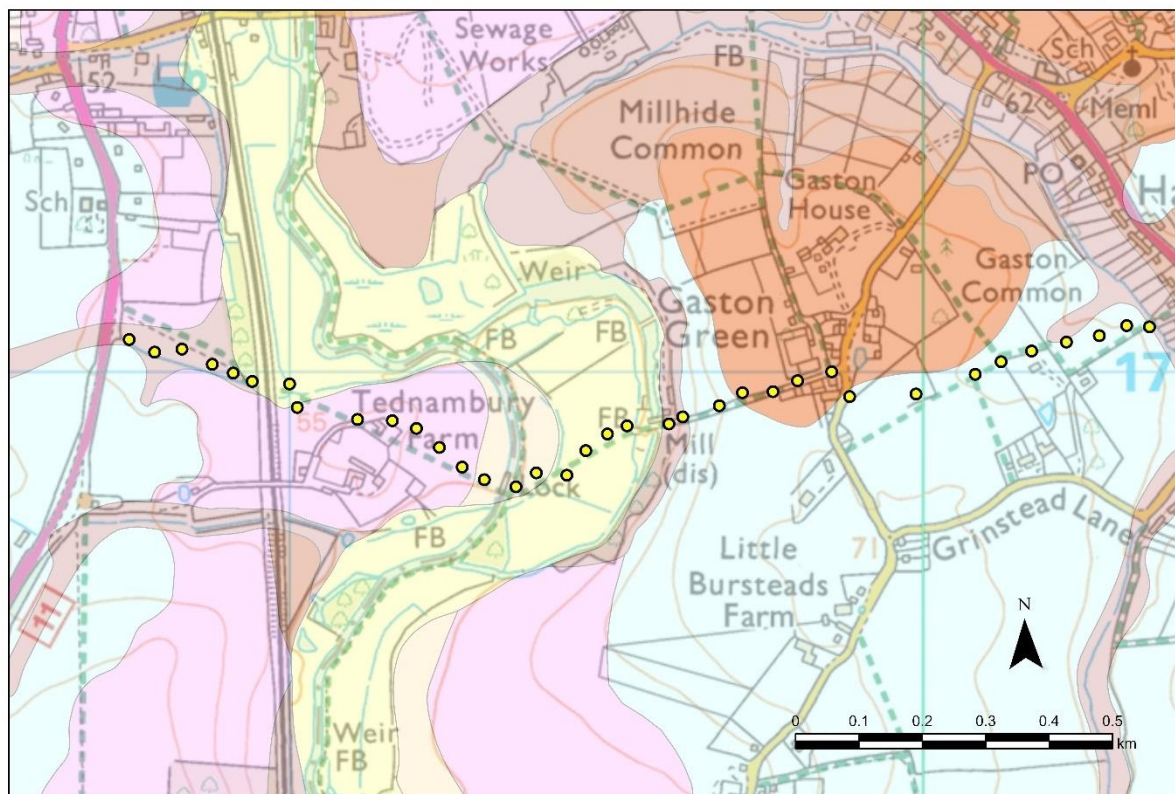
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Appendix 1 Passive Seismic sections.

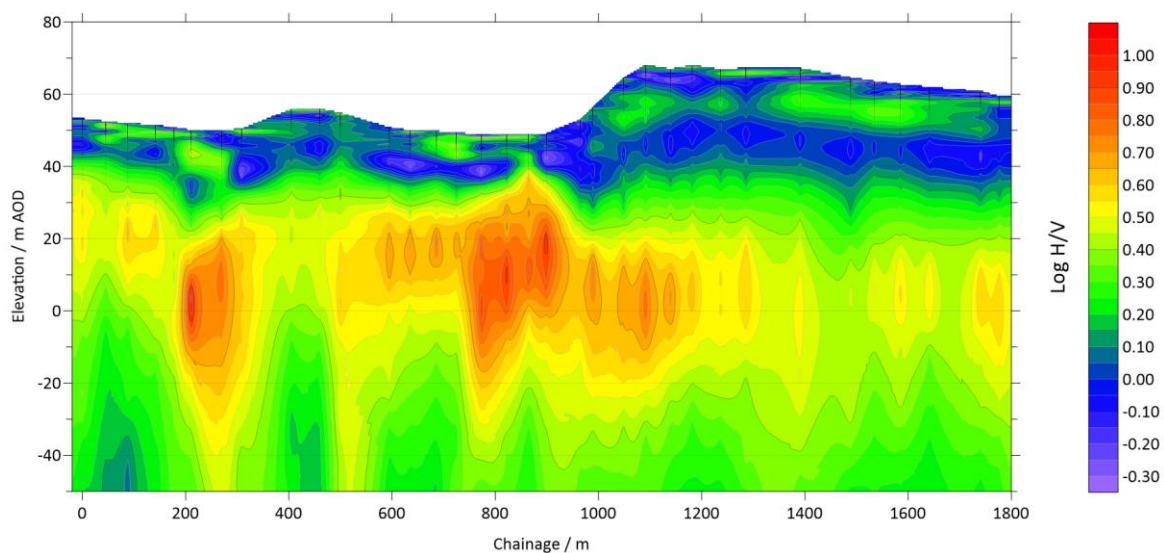
The data from is 15 passive seismic sections given below. The interpretations are done on the data processed with $V_s = 150$ m/s and exponent = 0.35, as these seemed to be a reasonable average value based on the SoilSpy data. Most of the profiles have a seismic contrast at shallow depth, following a very subtle H/V peak, which may be a boundary between loose and consolidated superficial deposits, or base of superficial deposits. A stronger seismic reflector follows a stronger H/V peak, commonly 10 m – 30 m deep, which may represent rock-head in some sections. All map extracts contain Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

SECTION 1. GASTON GREEN

Gaston Green, north of Sawbridgeworth in the Stort valley.

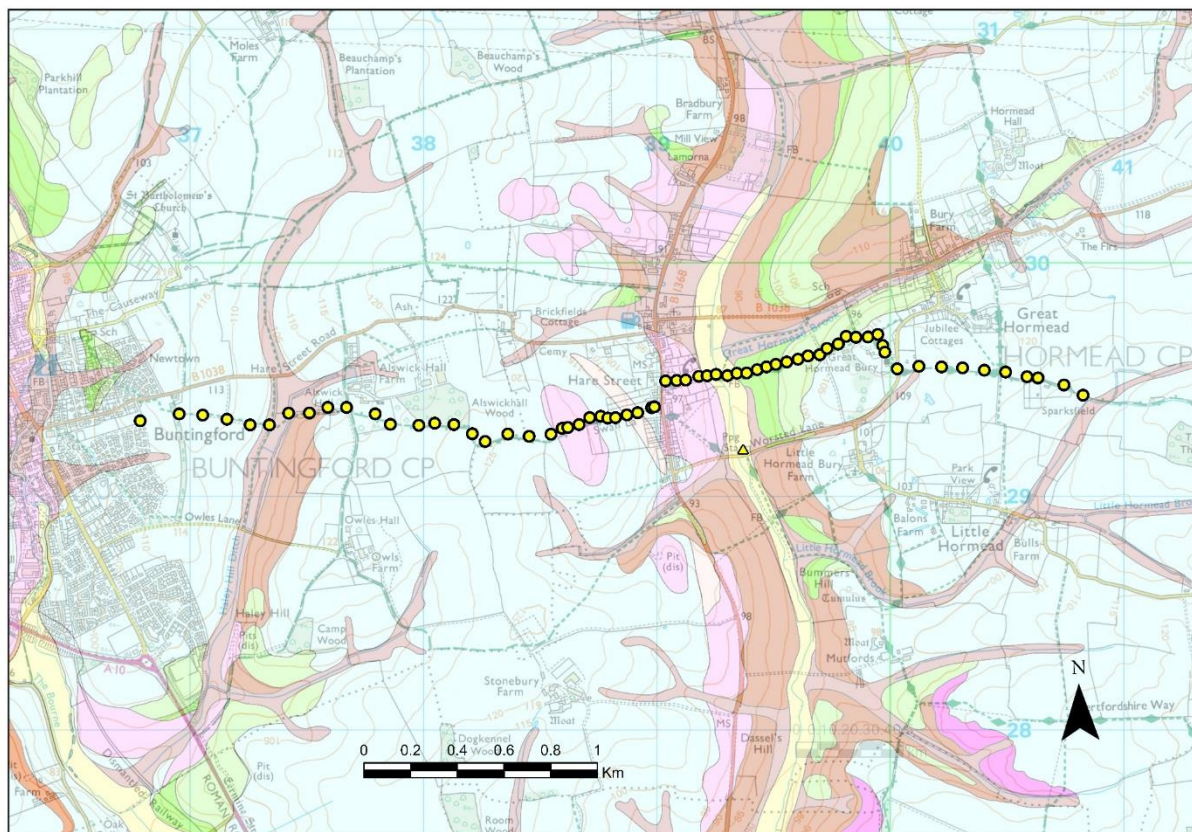


Gaston Green
Tromino Profile
 $V_s = 150$ m/s exp = 0.35

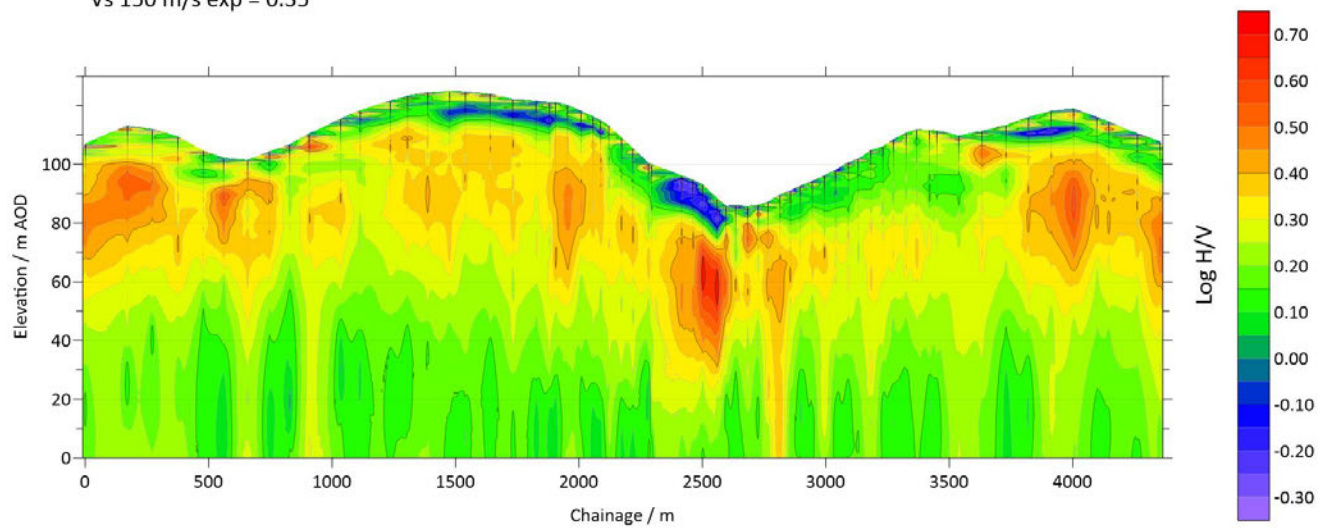


SECTION 2. HARE STREET

East-west traverse across the Ash Valley east of Buntingford.

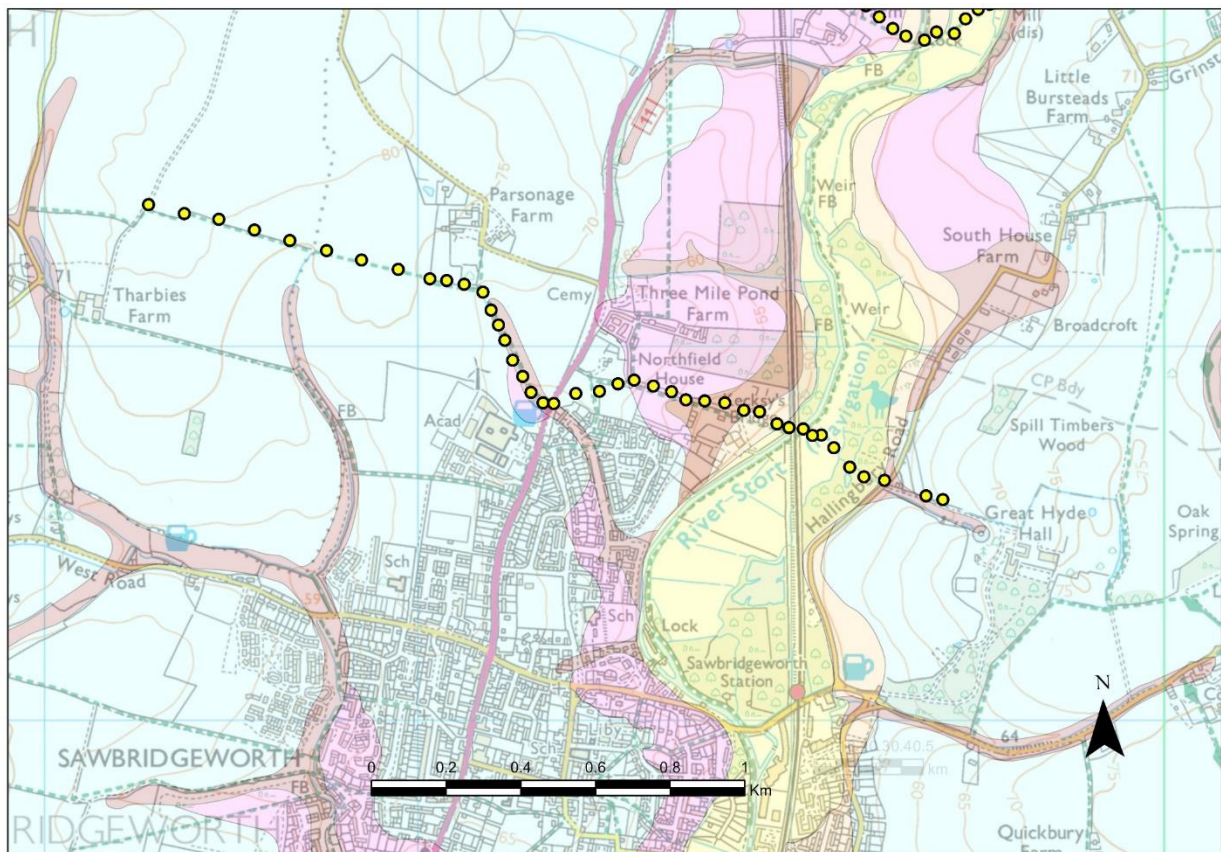


Hare Street
Tromino Profile
Vs 150 m/s exp = 0.35

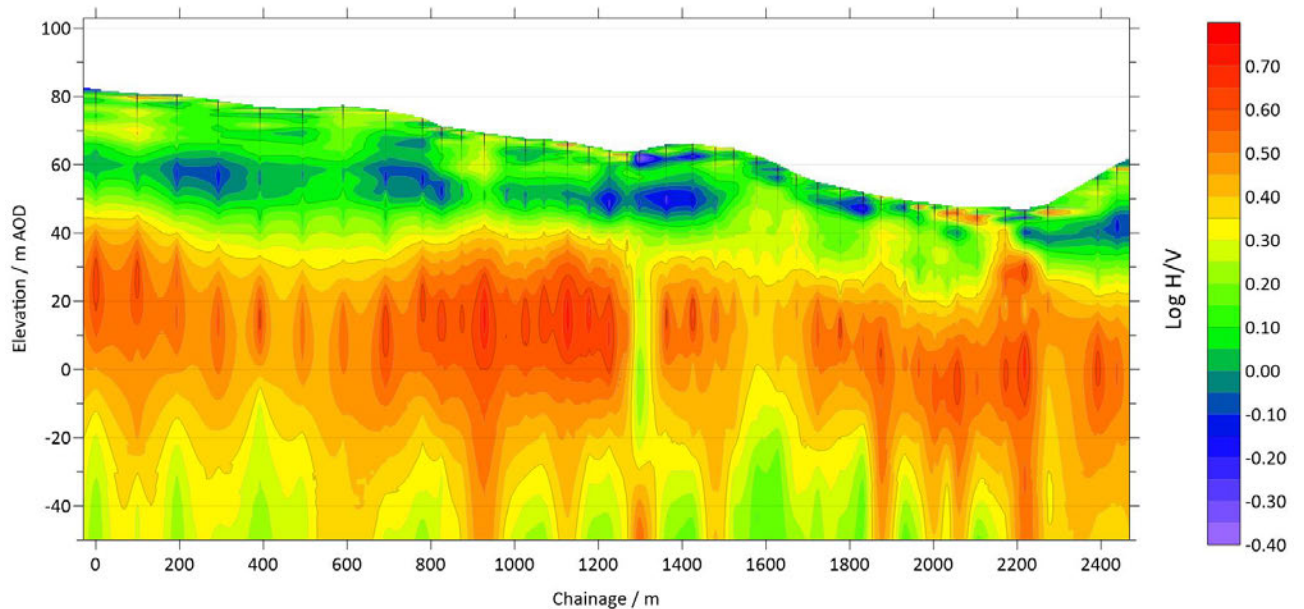


SECTION 3. KECKSY'S BRIDGE

North of Sawbridgeworth in the Stort valley. Partly across the buried valley.

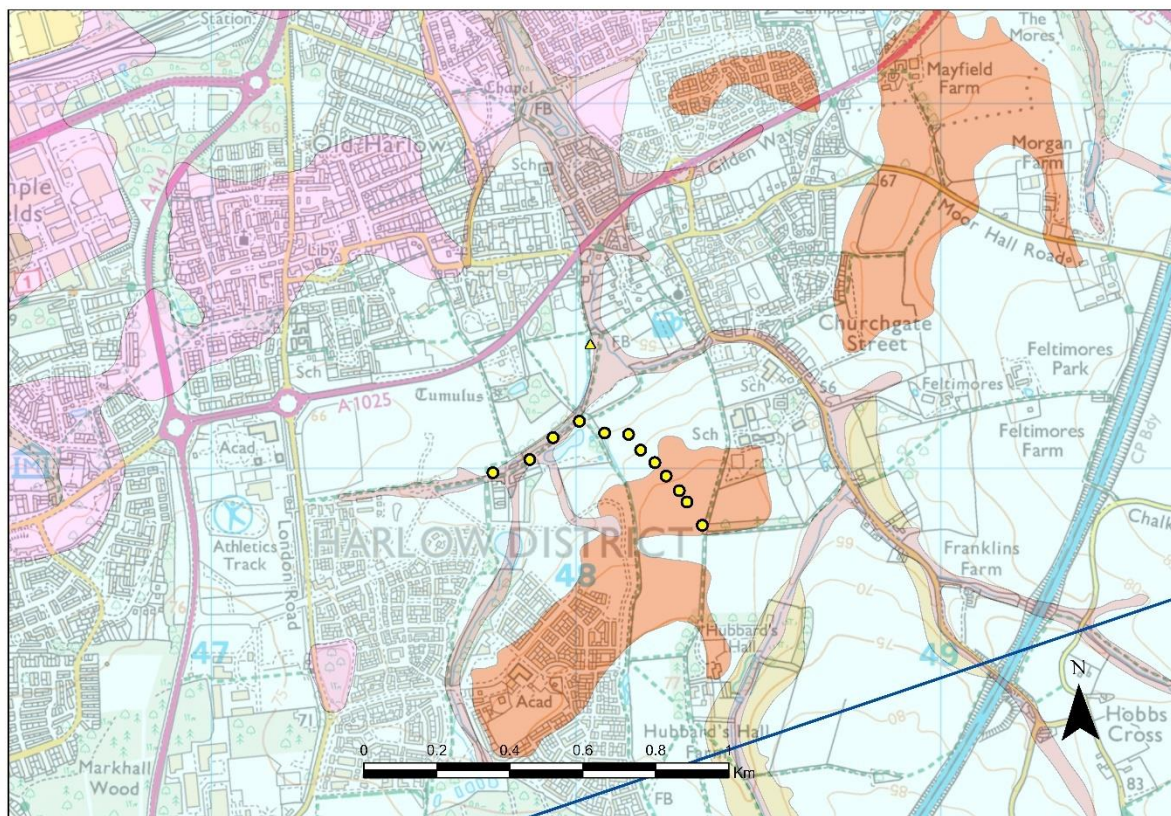


Kecksy's Bridge
Tromino Profile
Vs 150 m/s exp = 0.35

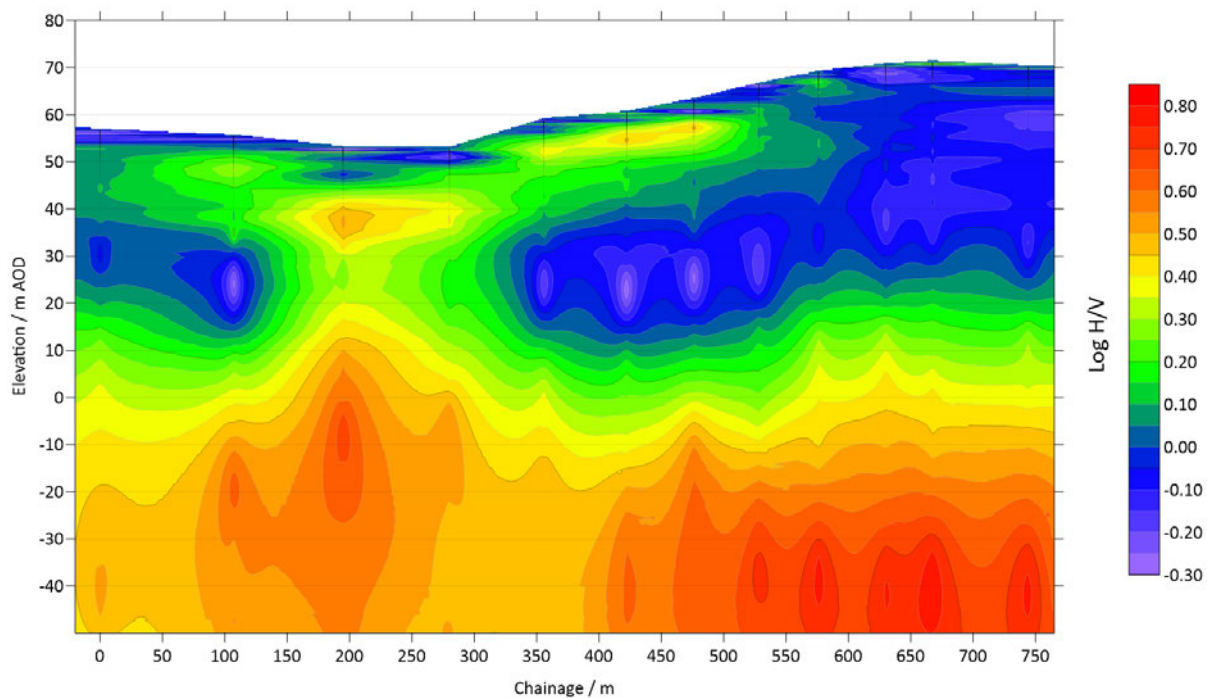


SECTION 4. MARK HALL

Mark Hall, on the eastern edge of Harlow, at the southern end of the Stort buried valley.

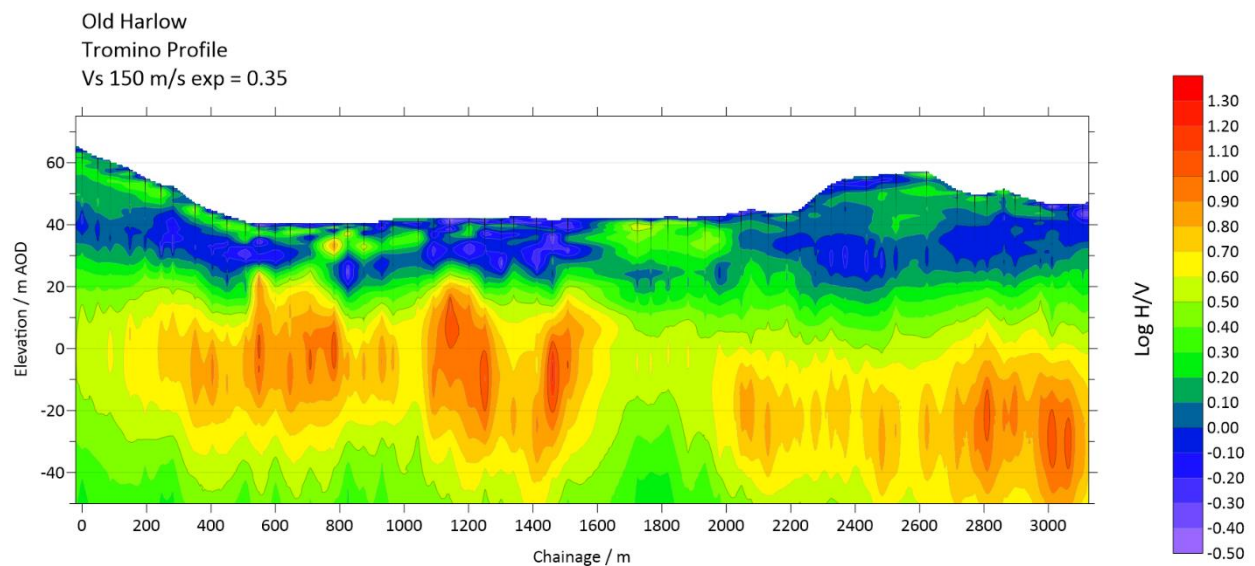
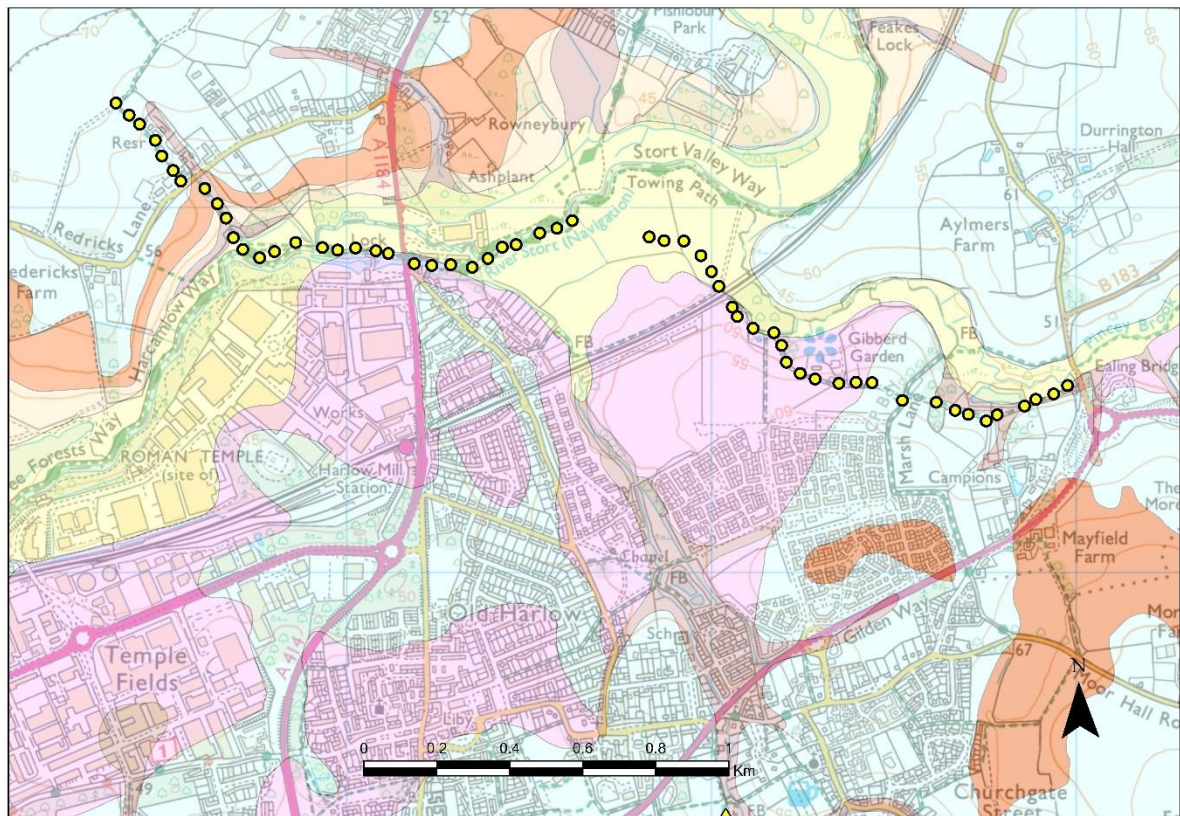


Mark Hall
Tromino Profile
Vs 150 m/s exp = 0.35



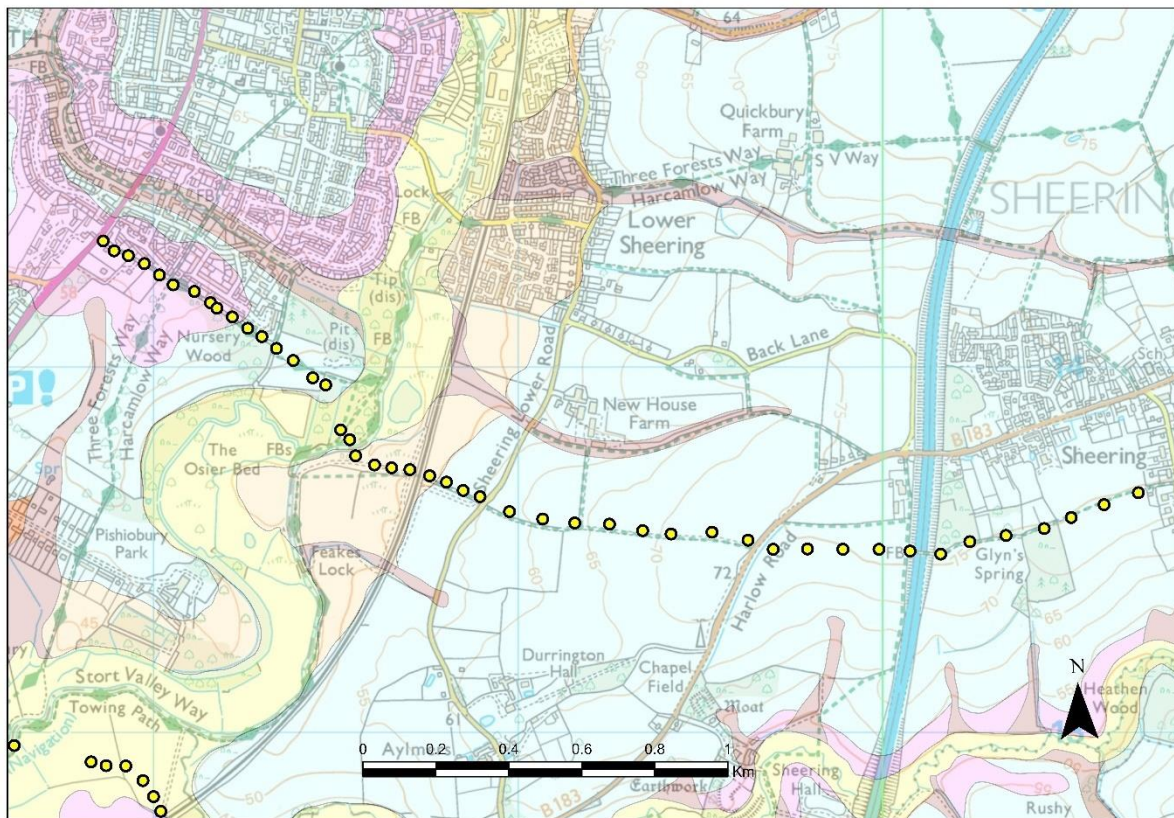
SECTION 5. OLD HARLOW

Northeast of Harlow, trending NW-SE across the lower Stort valley at the southern end of the buried valley.

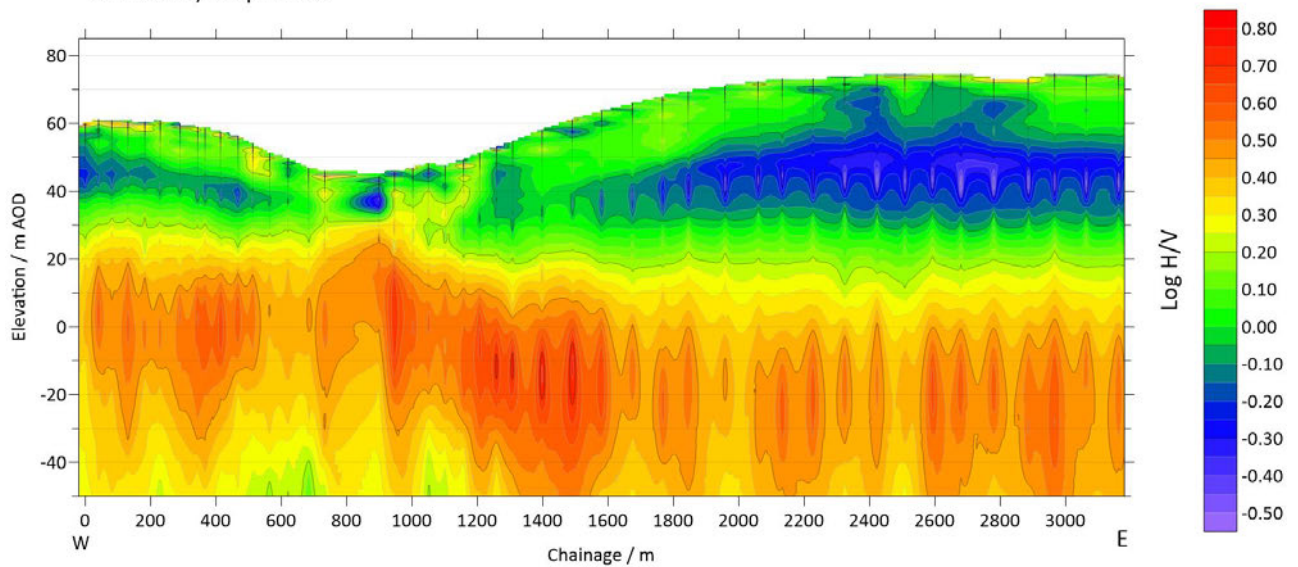


SECTION 6. SAWBRIDGEWORTH

South side of Sawbridgeworth, crossing east-west across the Stort buried valley.

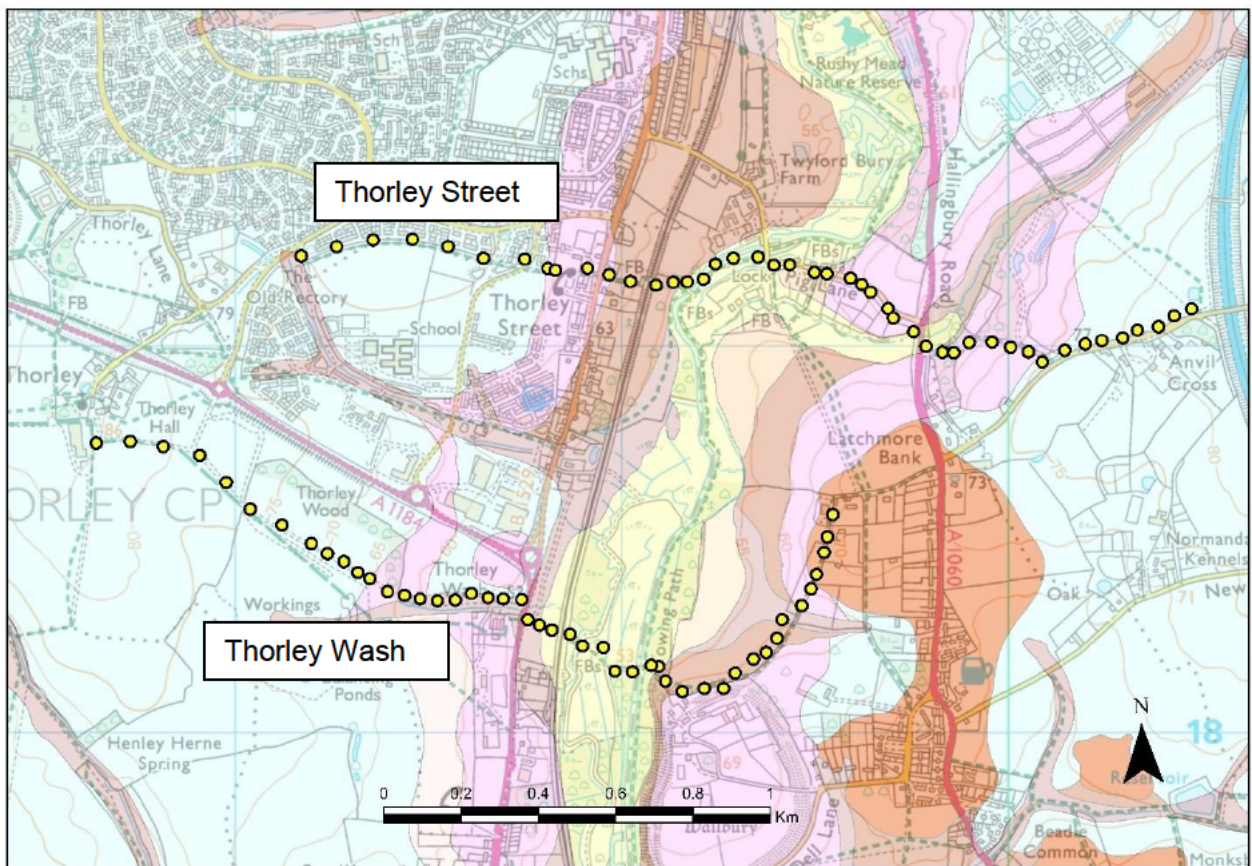


Sawbridgeworth
Tromino Profile
 $V_s = 150 \text{ m/s exp} = 0.35$

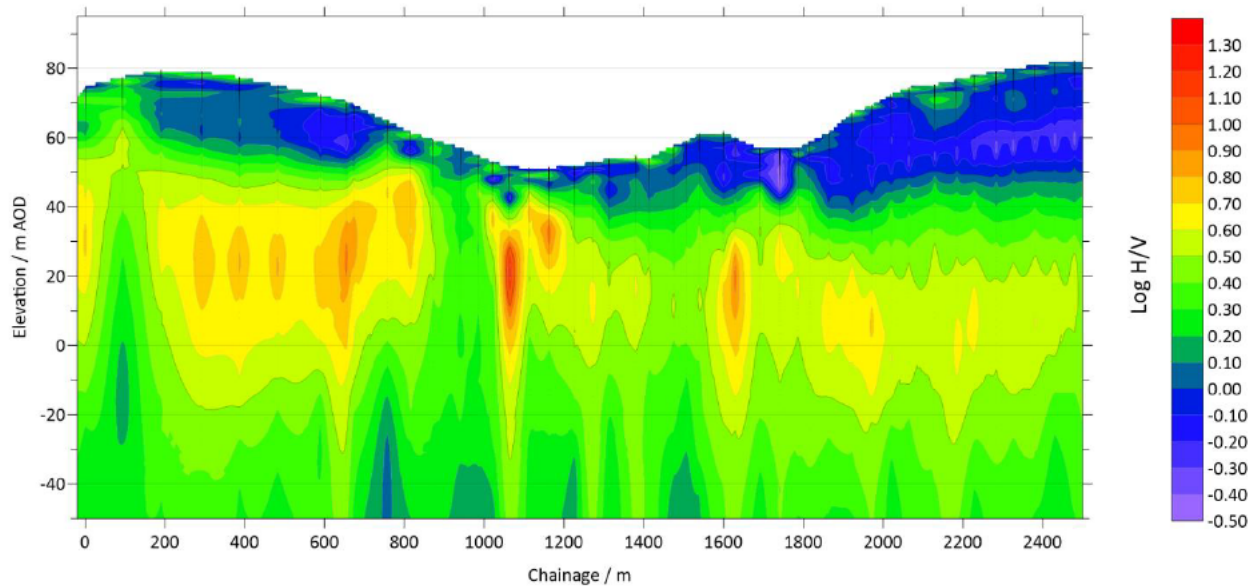


SECTION 7. THORLEY STREET

Section trending east-west across the Stort buried valley to the south of Bishop's Stortford.

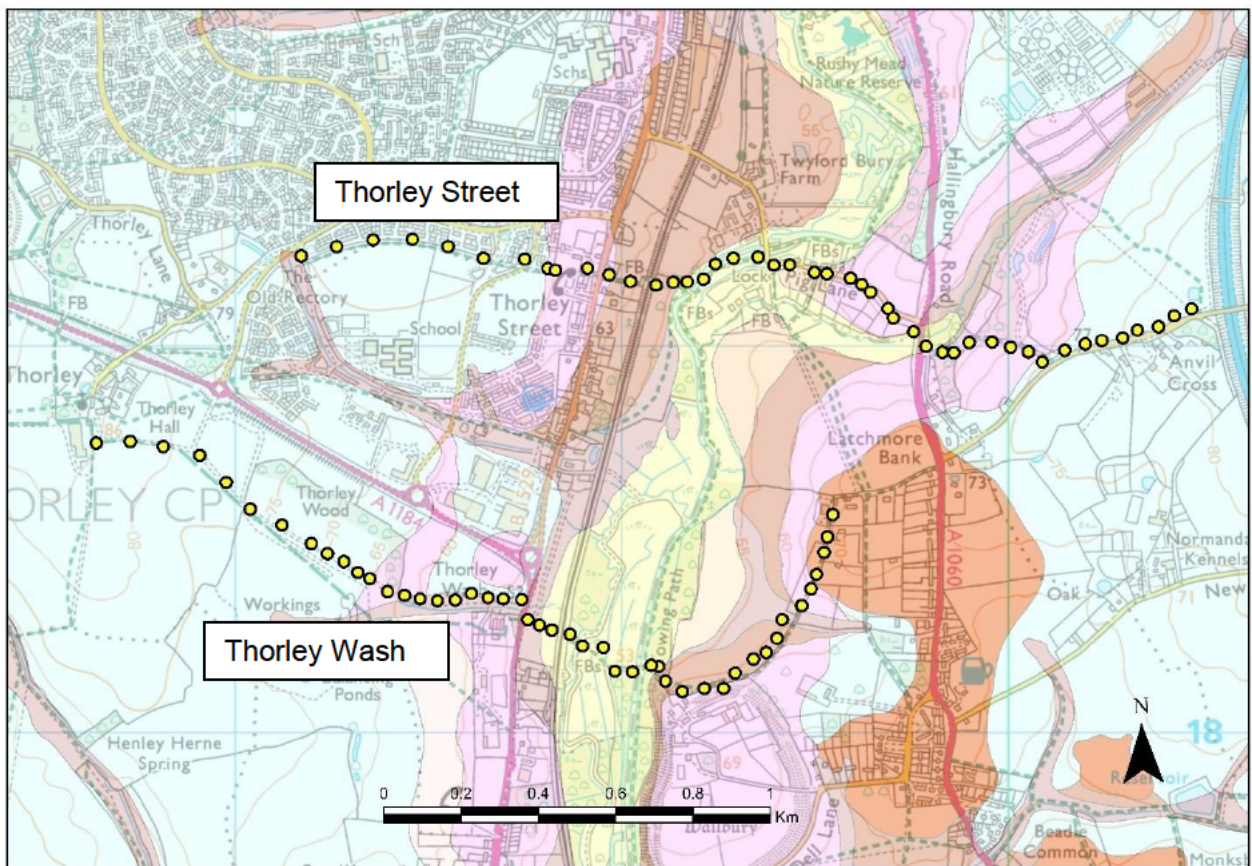


Thorley Street
Tromino Profile
 $V_s = 150 \text{ m/s}$ $\exp = 0.35$

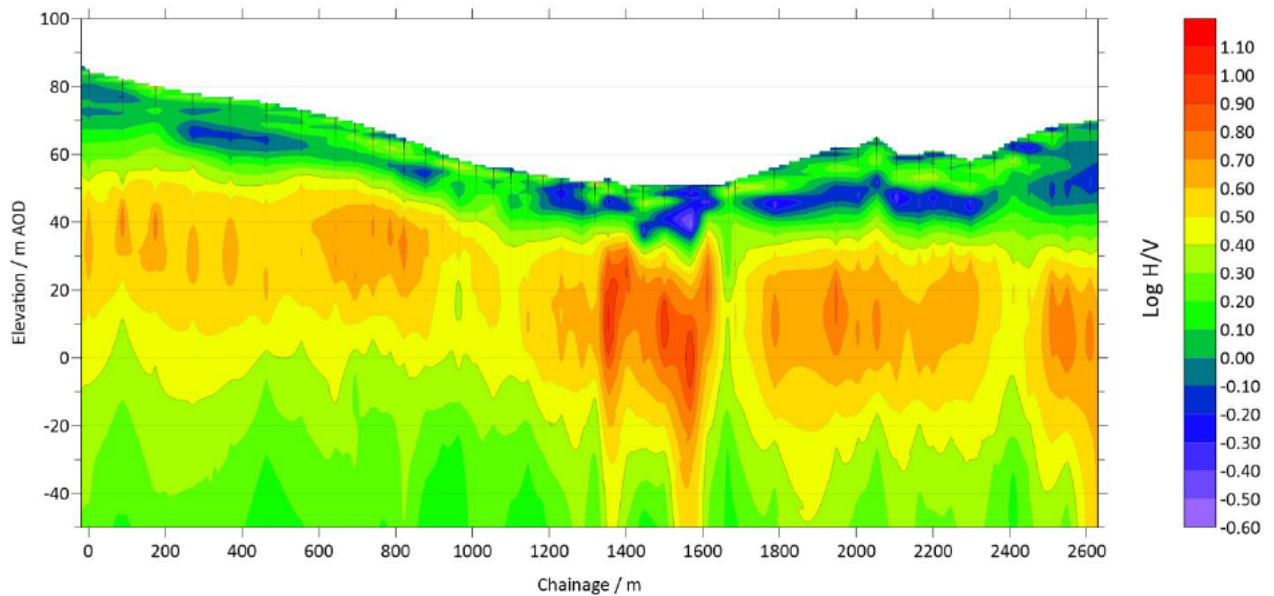


SECTION 8. THORLEY WASH

Section trending east-west across the Stort buried valley to the south of Bishop's Stortford.

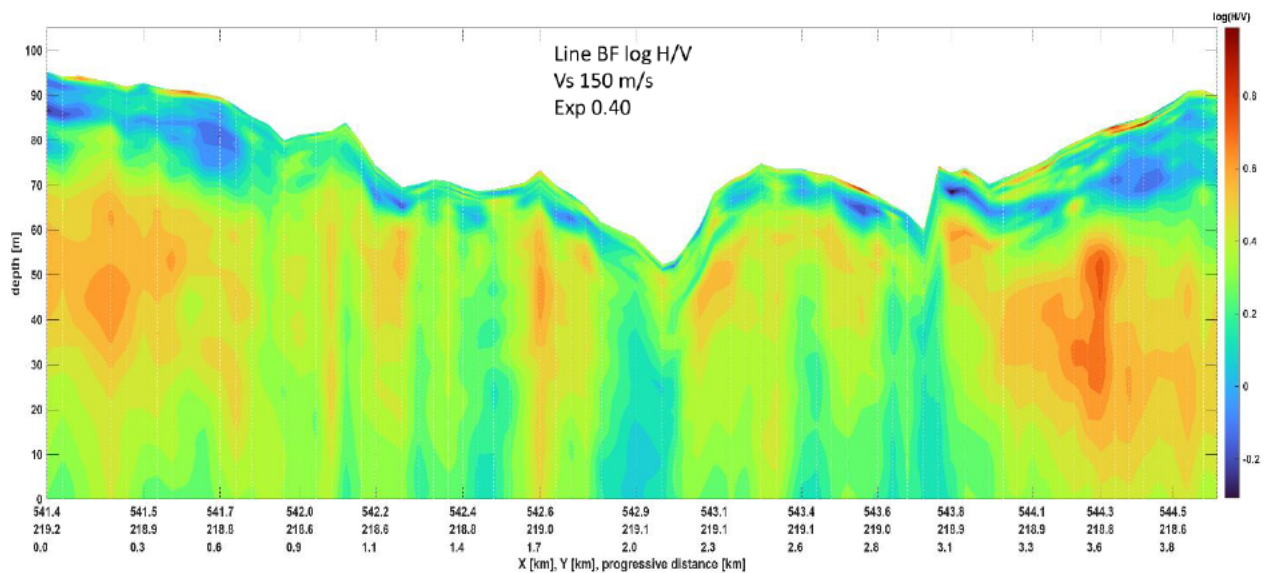
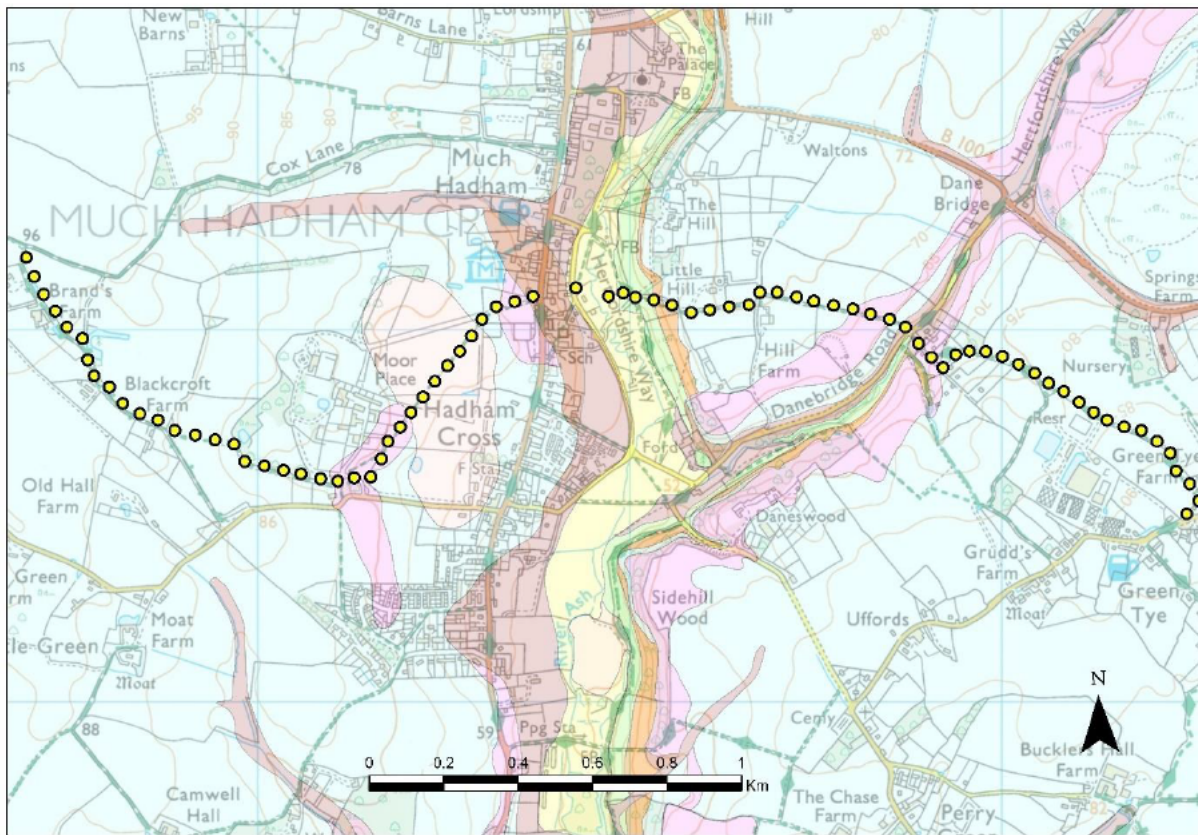


Thorley Wash
Tromino Profile
 $V_s = 150 \text{ m/s}$ $\exp = 0.35$



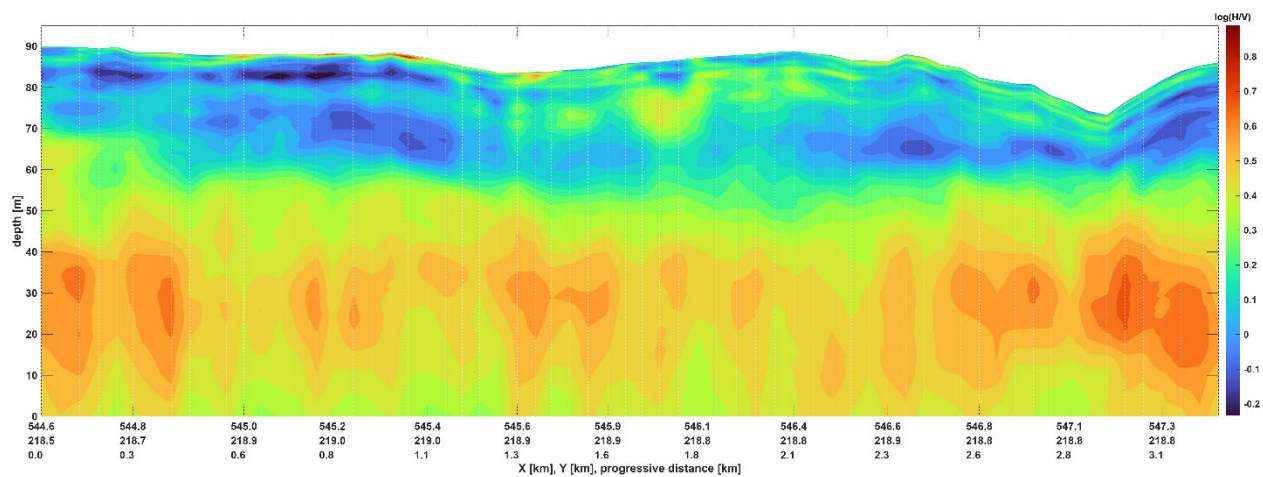
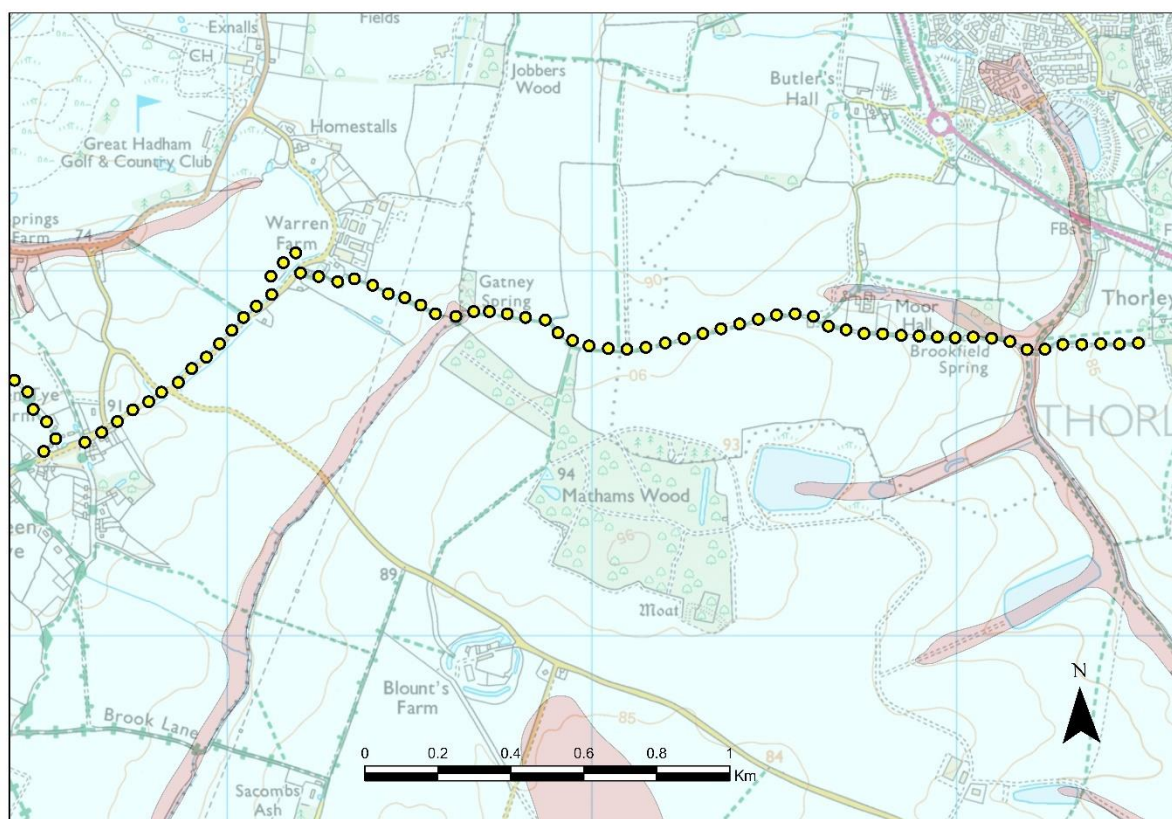
SECTION 9. MUCH HADHAM

Section trending east-west across the River Ash valley at Much Hadham.



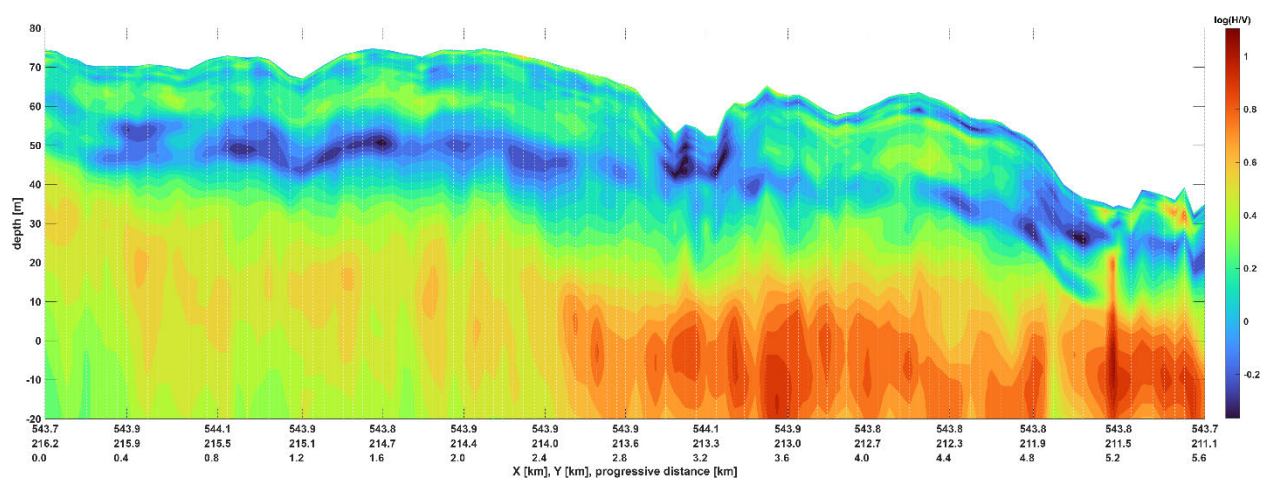
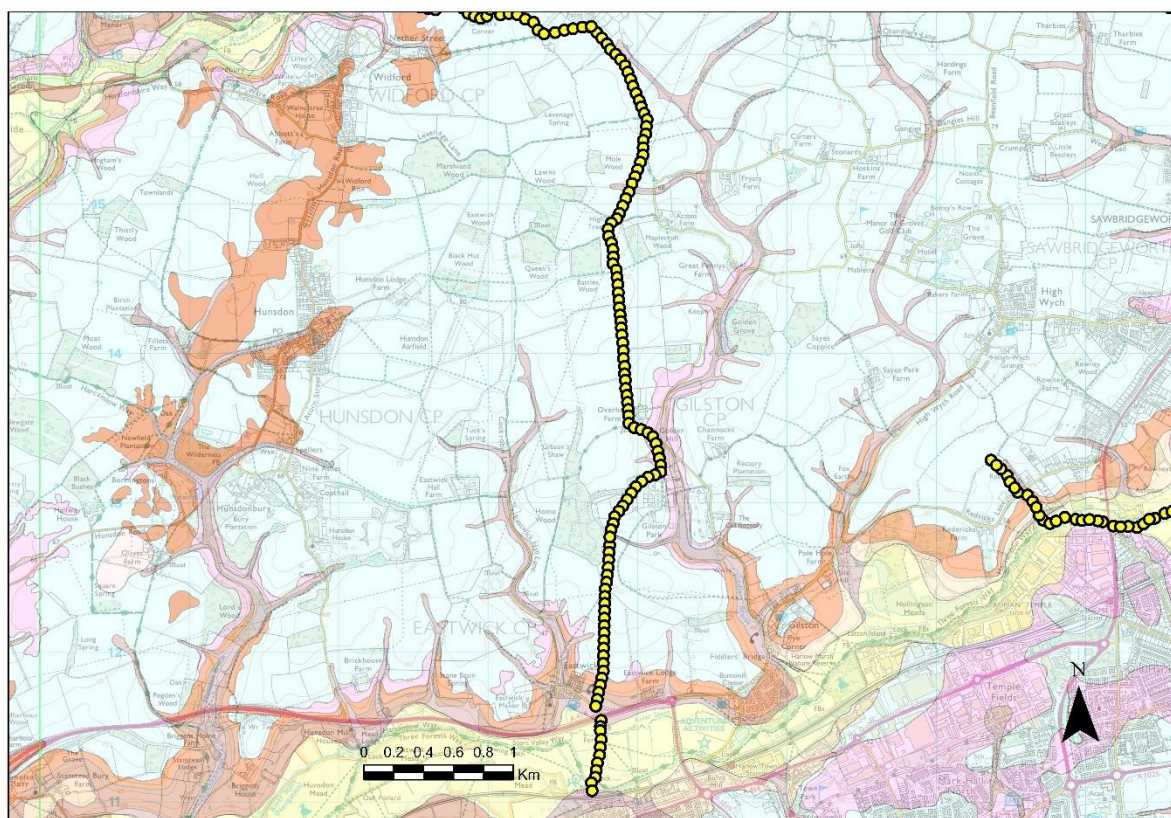
SECTION 10. MUCH HADHAM TO THORLEY

Section trending east-west over the interfluvium between the River Ash valley at Much Hadham and the River Stort at Thorley.



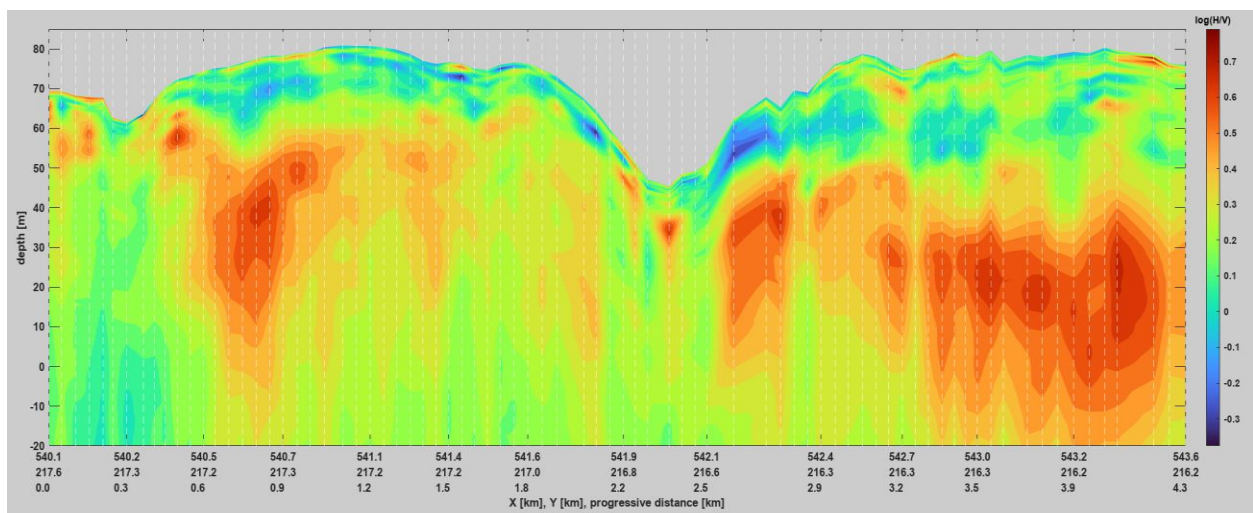
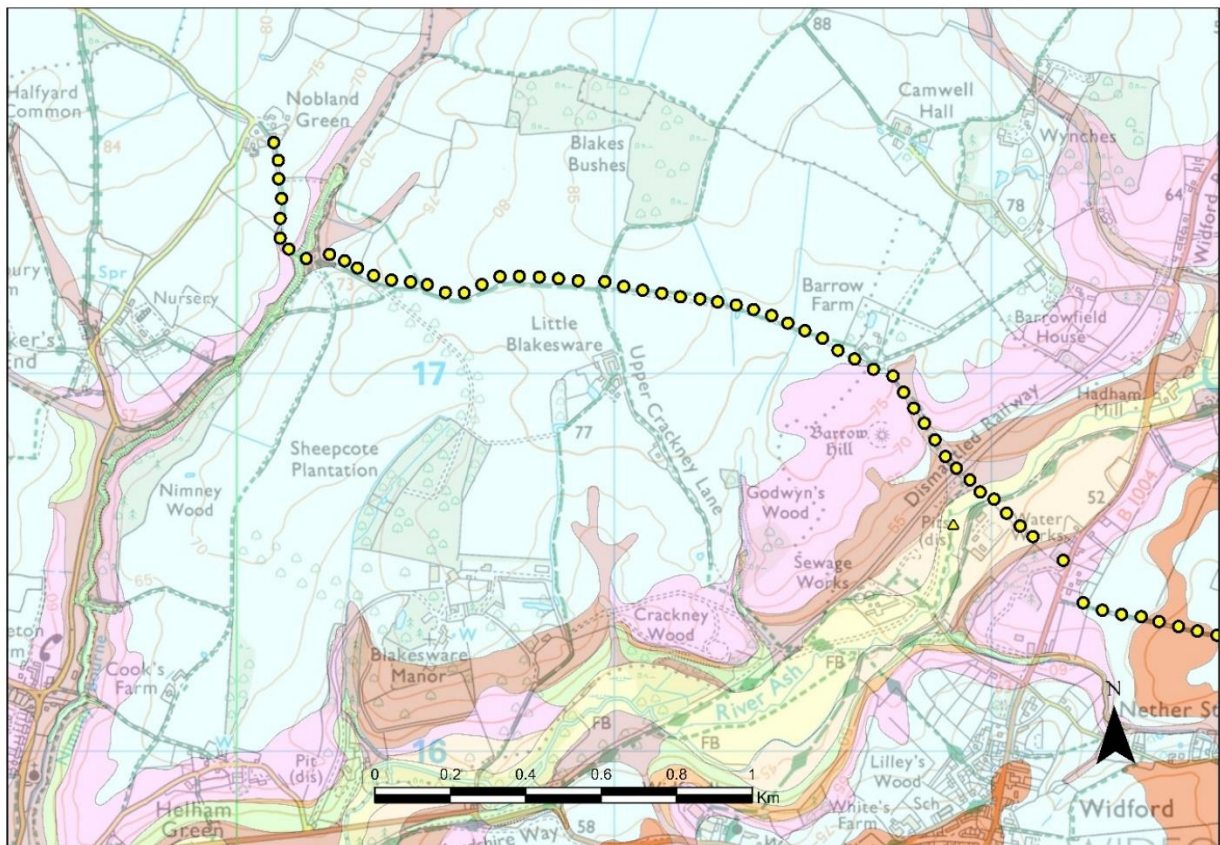
SECTION 11. WIDFORD TO HARLOW

North south traverse from Widford to the Stort valley north of Harlow.



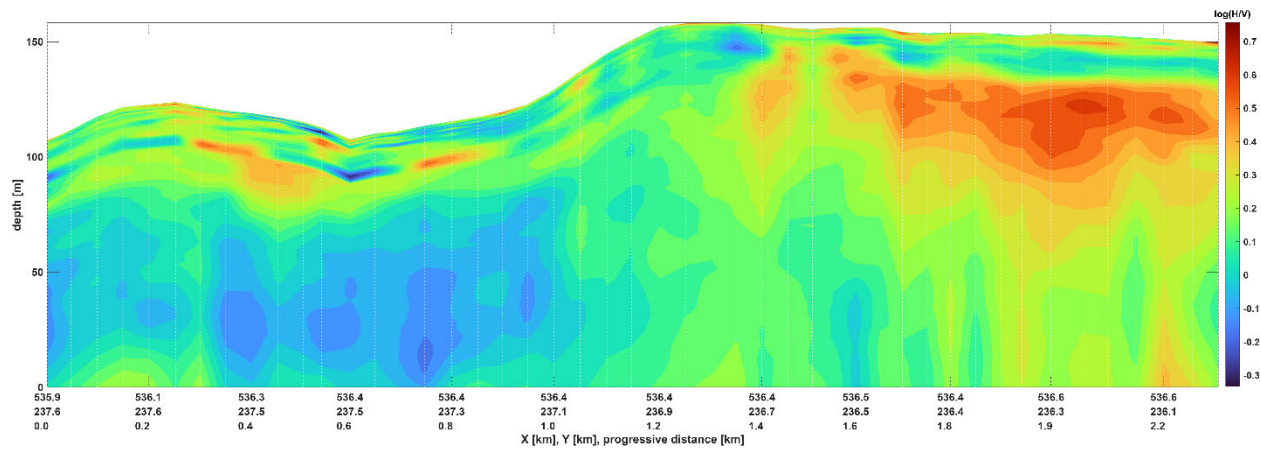
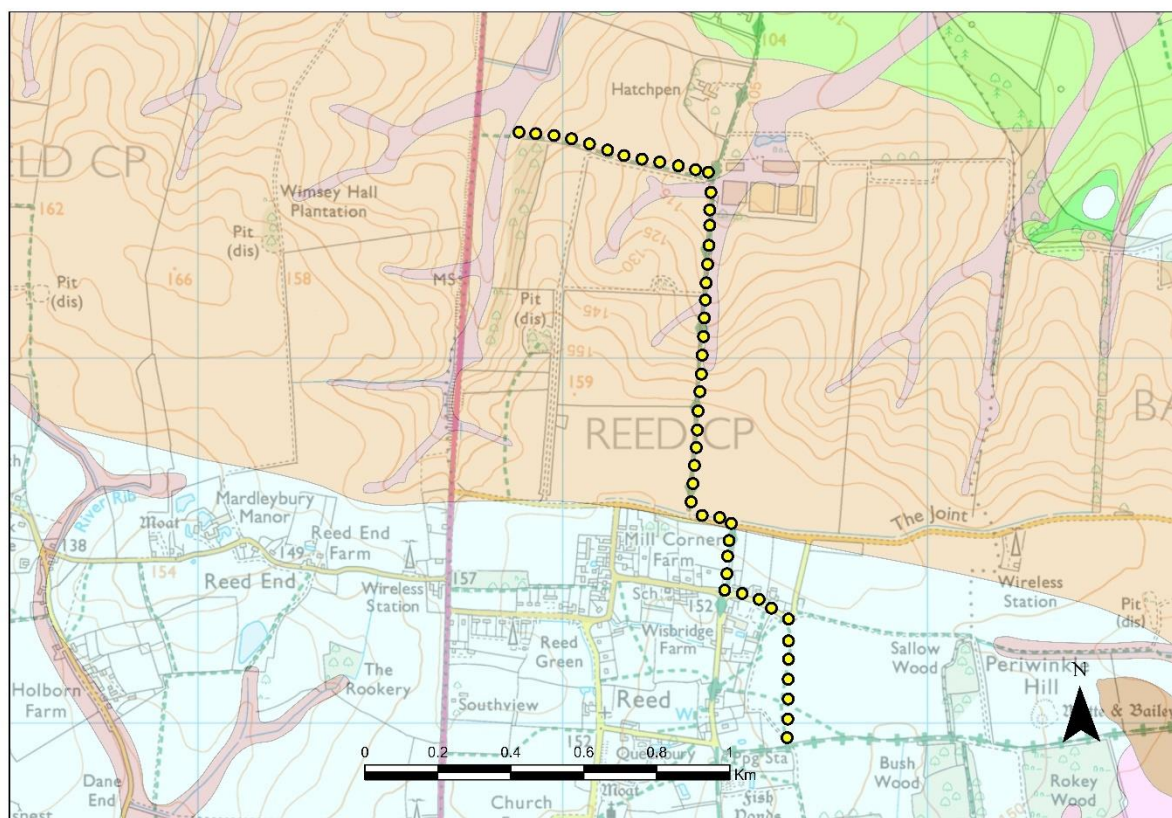
SECTION 12. NOBLAND GREEN TO WIDFORD

Northwest to southeast traverse from Nobland Green to Widford.



SECTION 13. REED

North south section across the thrustured till deposits at Reed, south of Royston.

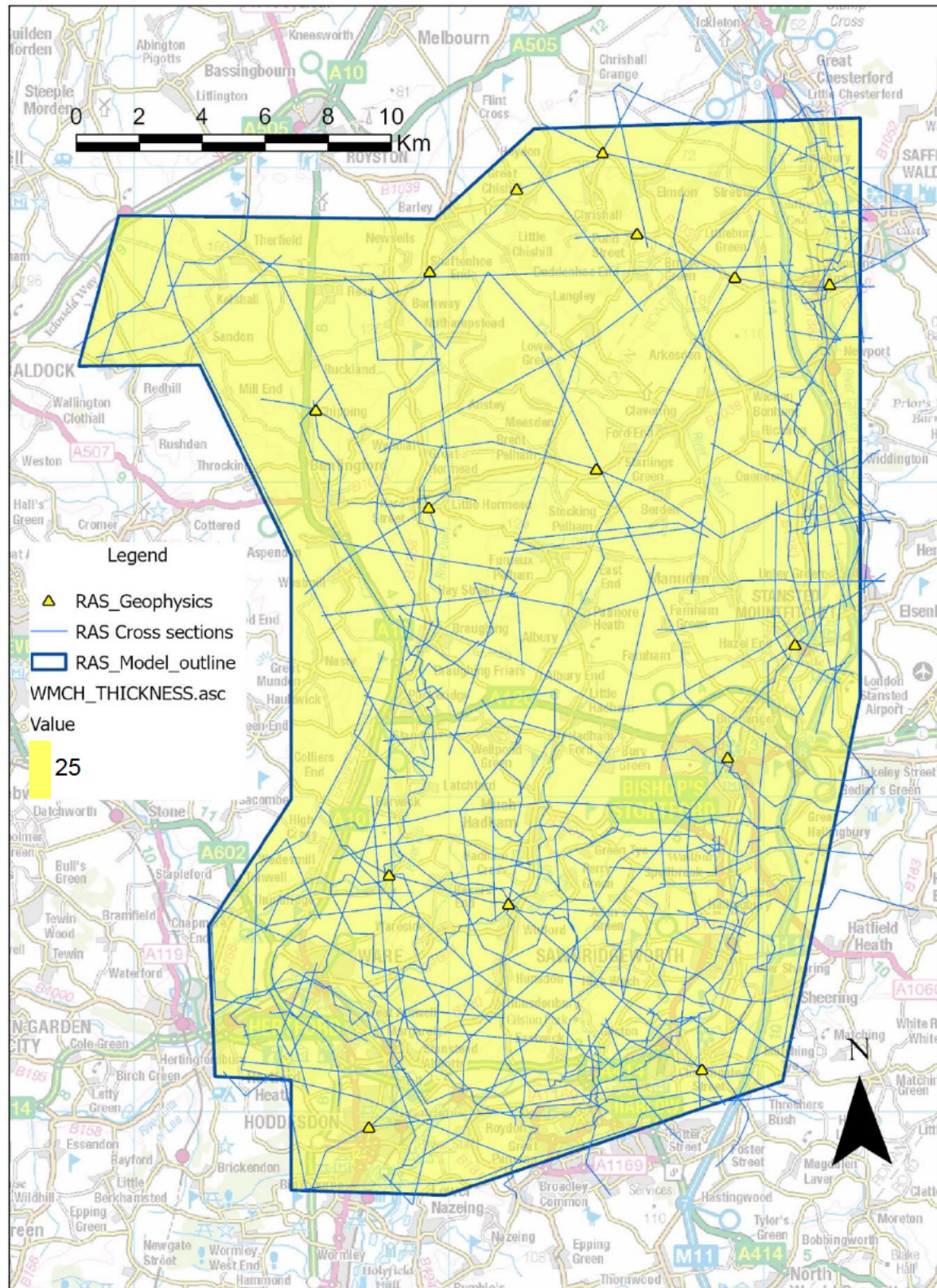


Appendix 2 Thickness Maps

Thickness maps for each modelled unit were generated as part of the modelling process. These are reproduced in this appendix. All map extracts contain Ordnance Survey data © Crown Copyright and database rights [2025]. Ordnance Survey Licence no. 100021290.

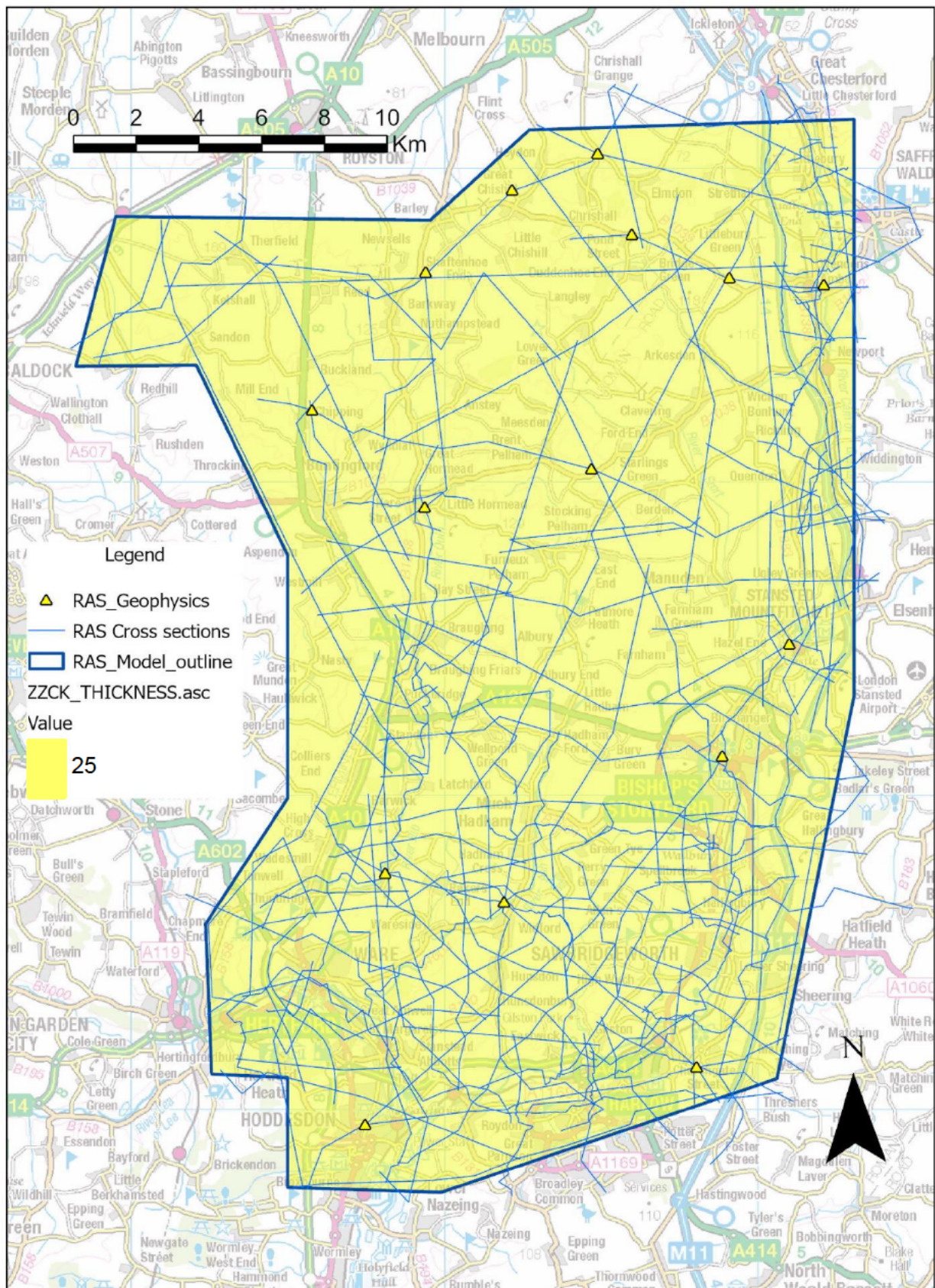
WEST MELBURY MARLY CHALK FORMATION

(uniform modelled thickness of 25 m)

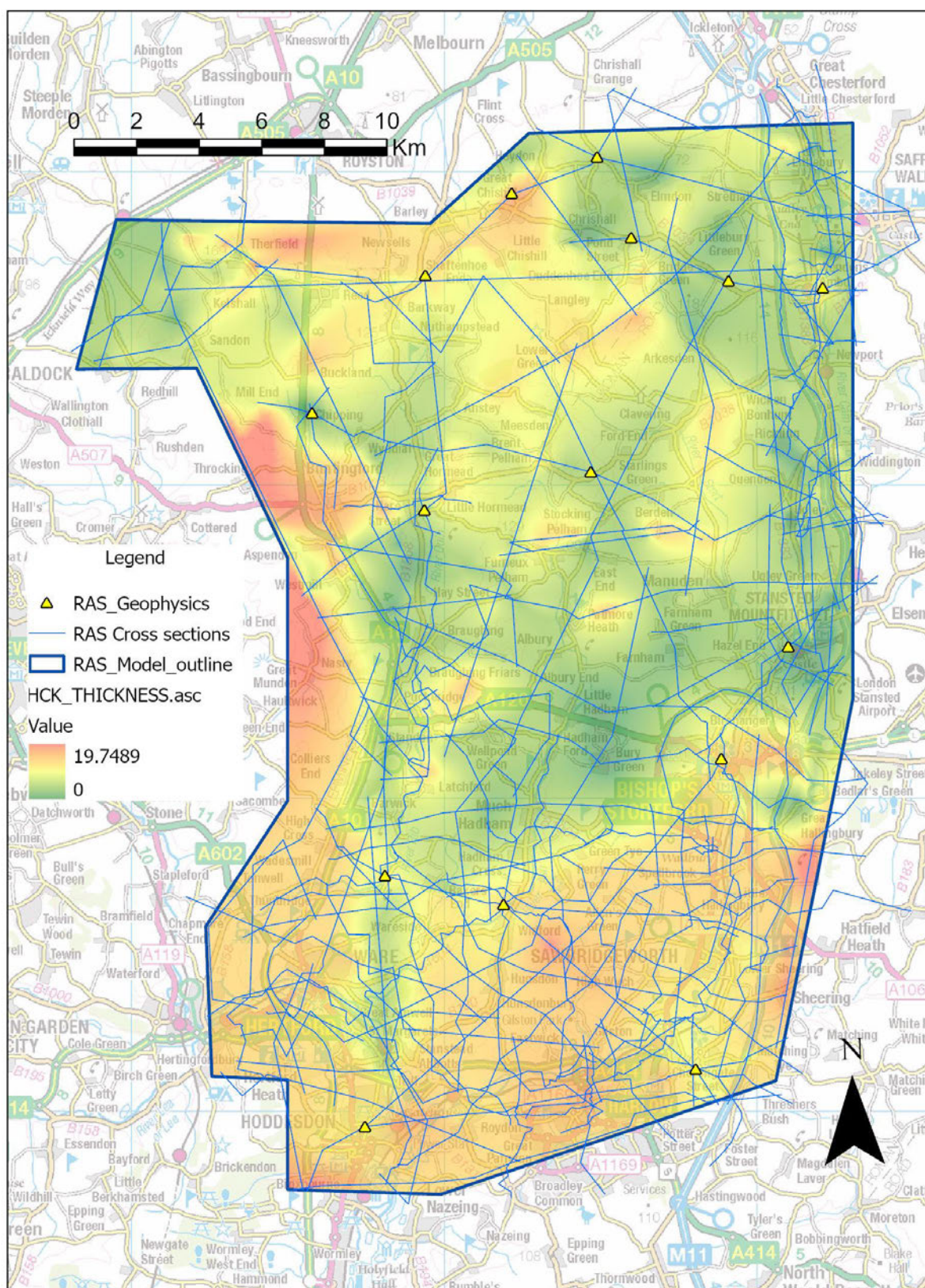


ZIG ZAG CHALK FORMATION

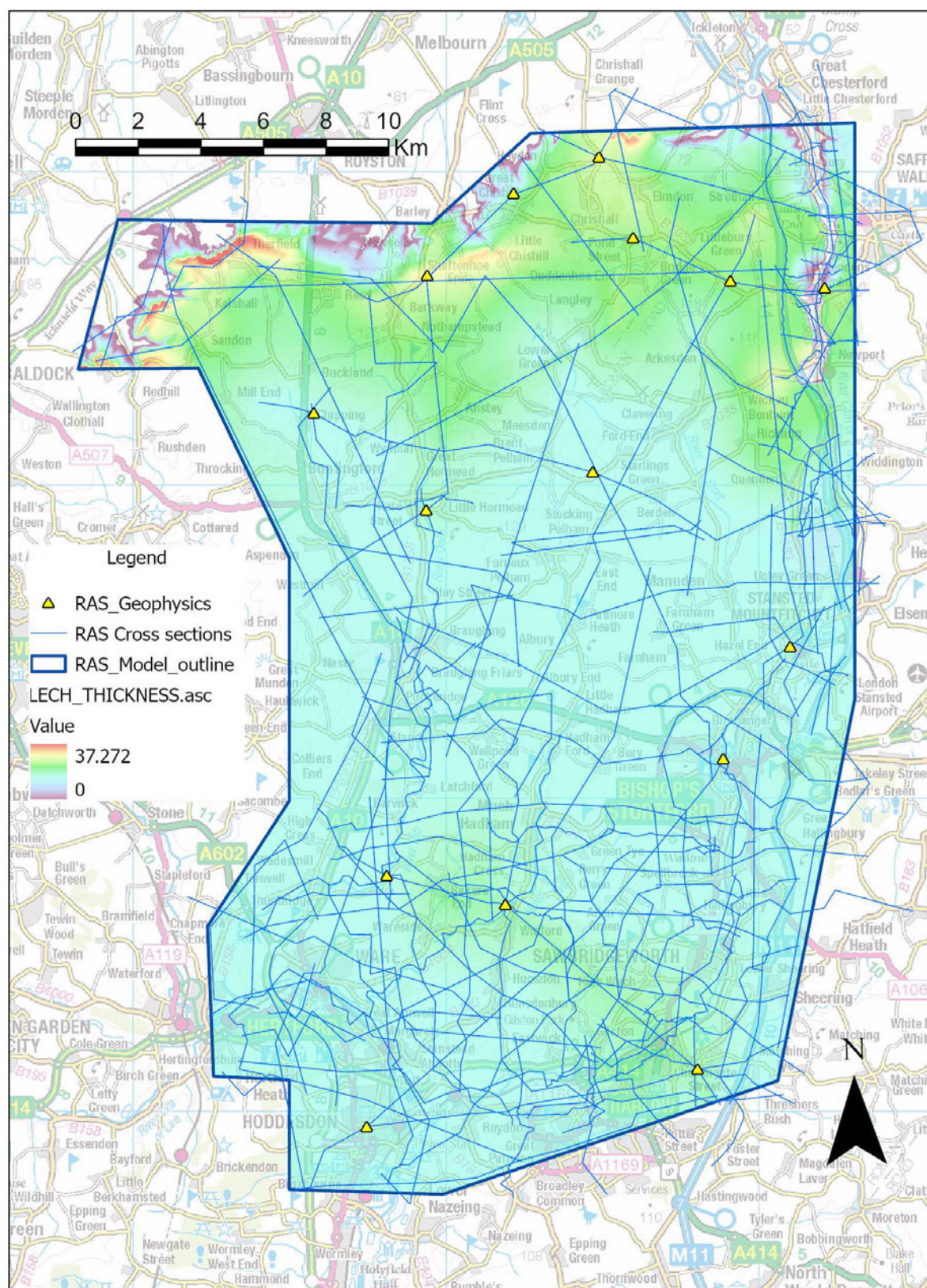
(uniform modelled thickness of 25 m)



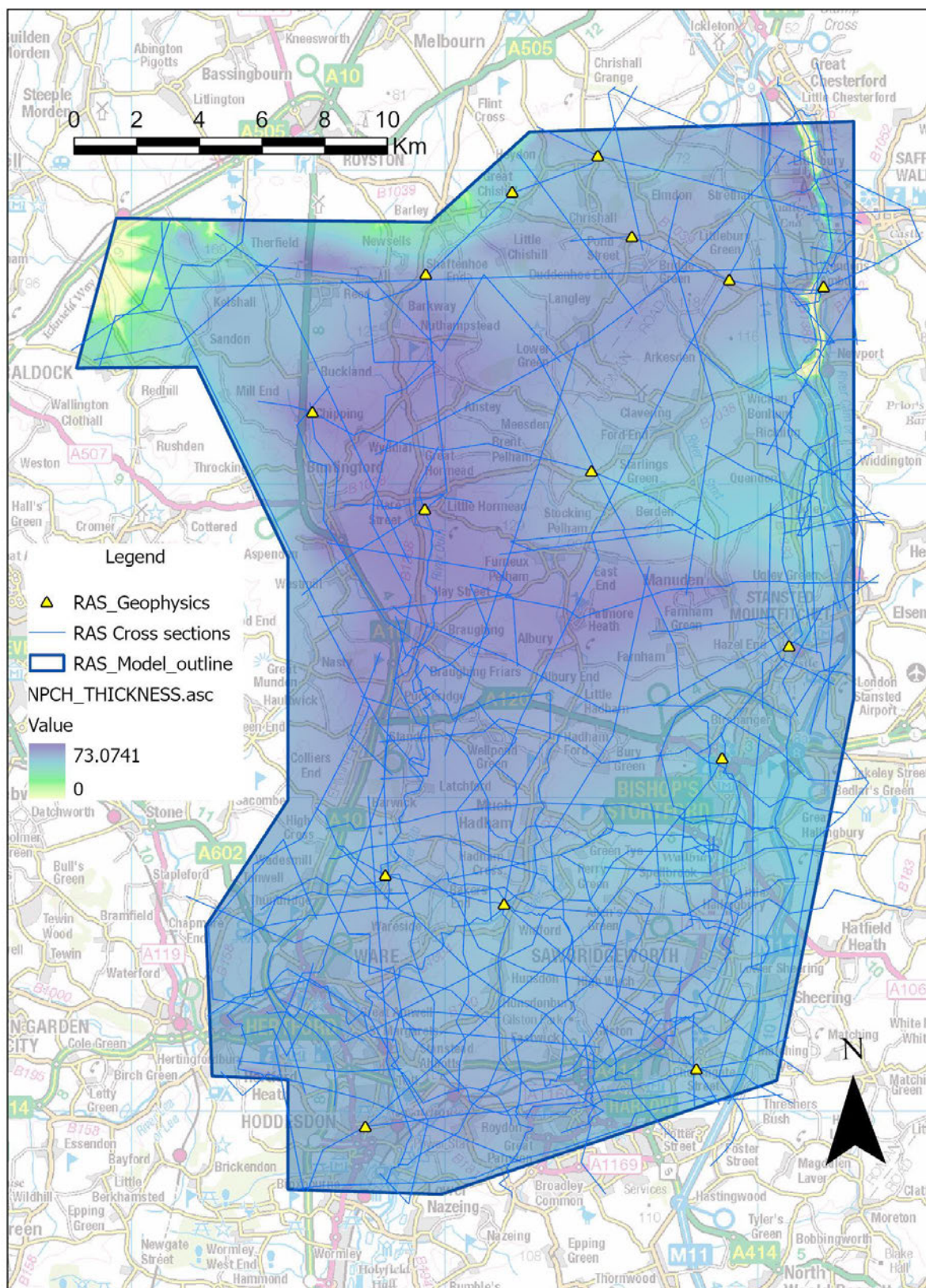
HOLYWELL NODULAR CHALK FORMATION



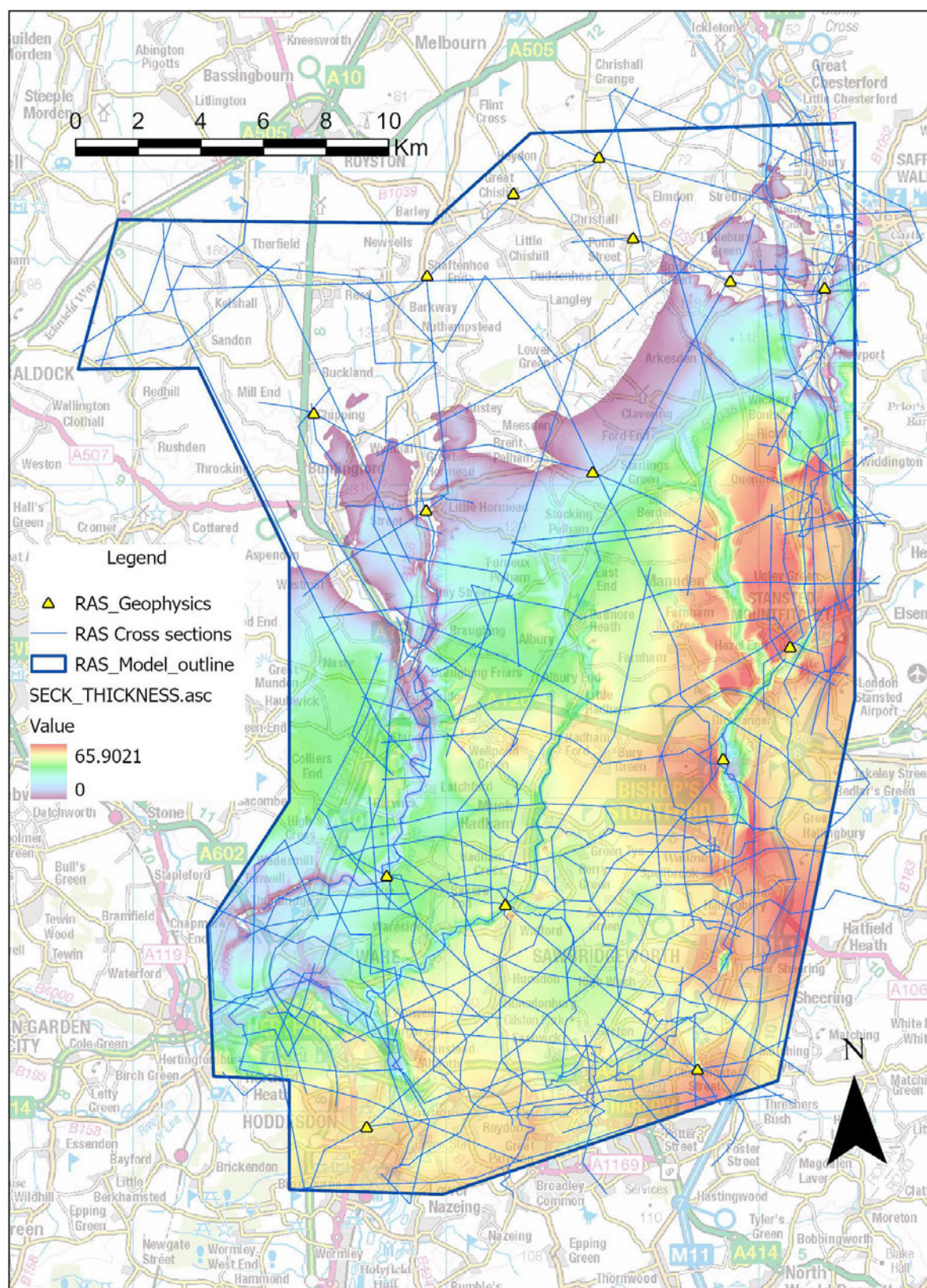
NEW PIT CHALK FORMATION



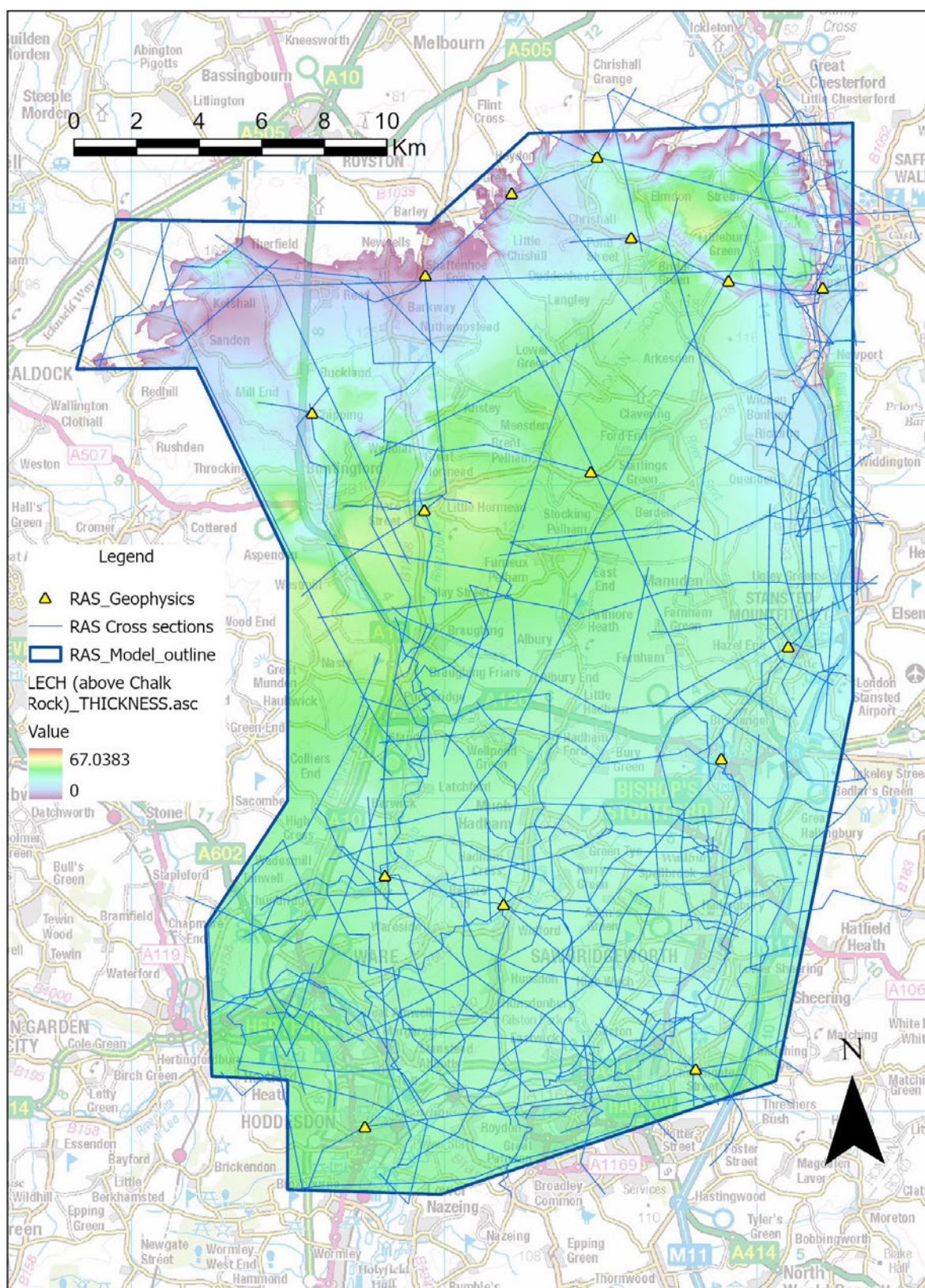
LEWES NODULAR CHALK FORMATION CHALK FORMATION (BELOW CHALK ROCK)



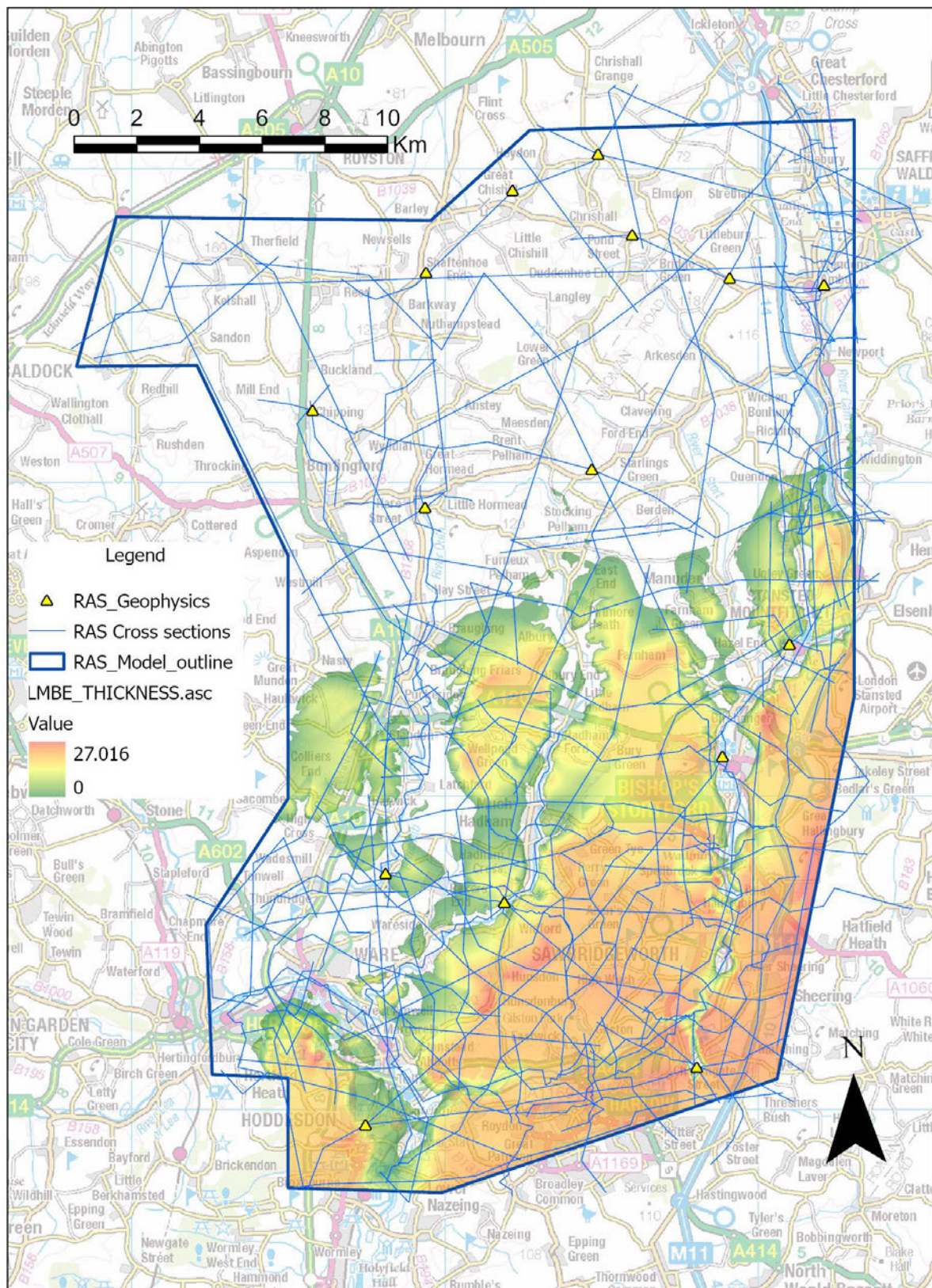
LEWES NODULAR CHALK FORMATION CHALK FORMATION (ABOVE CHALK ROCK)



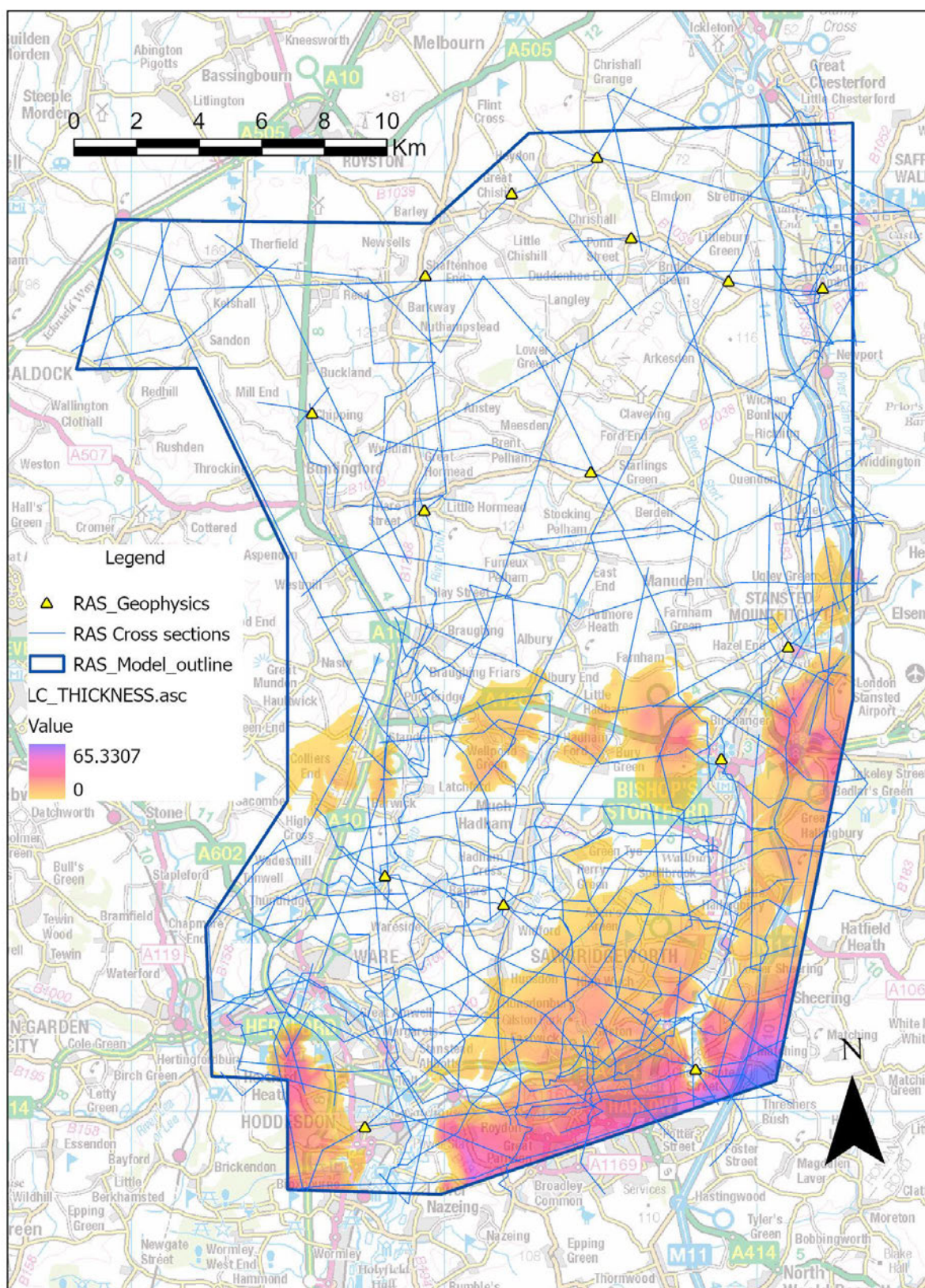
SEAFORD CHALK FORMATION



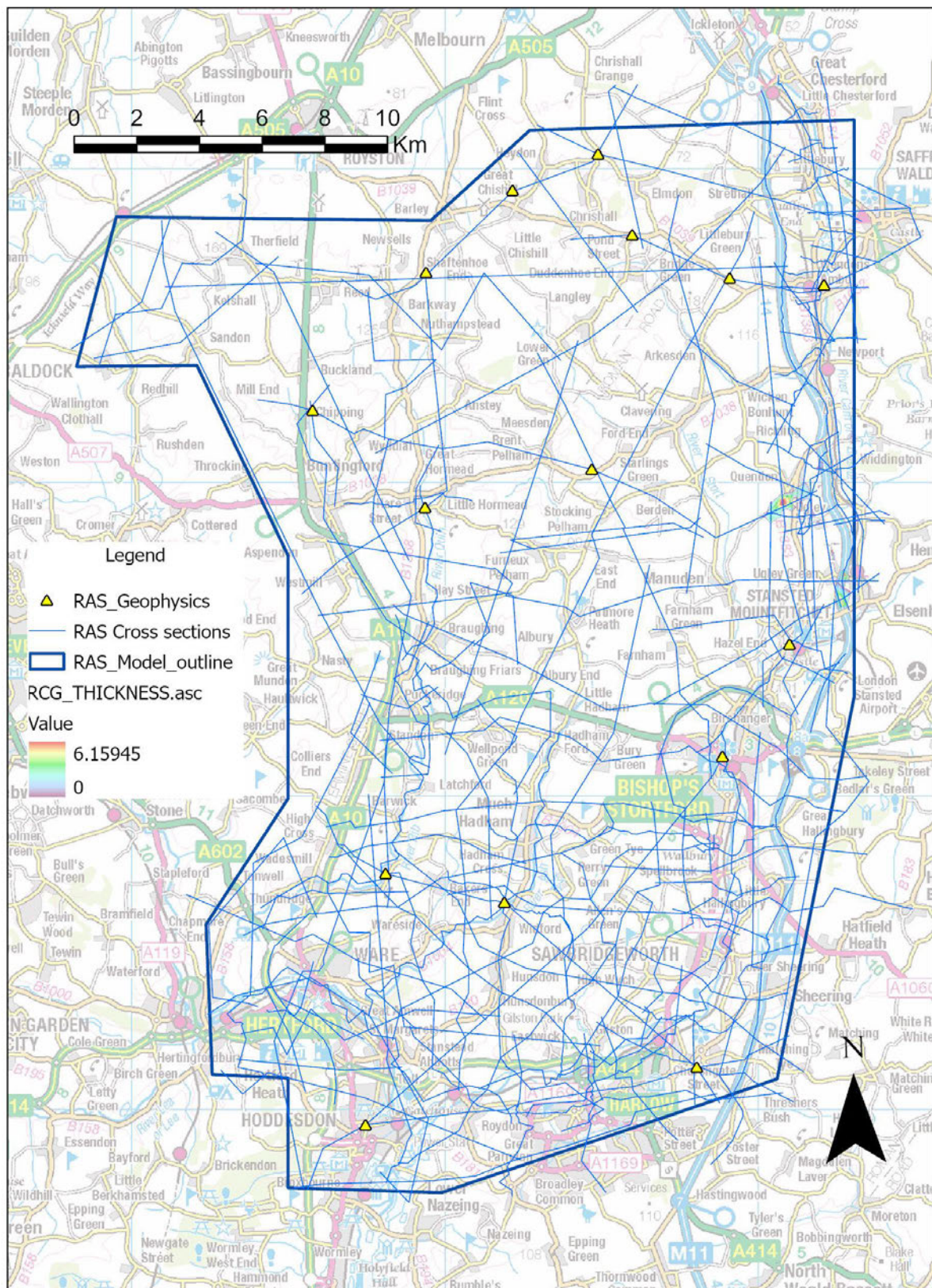
LAMBETH GROUP



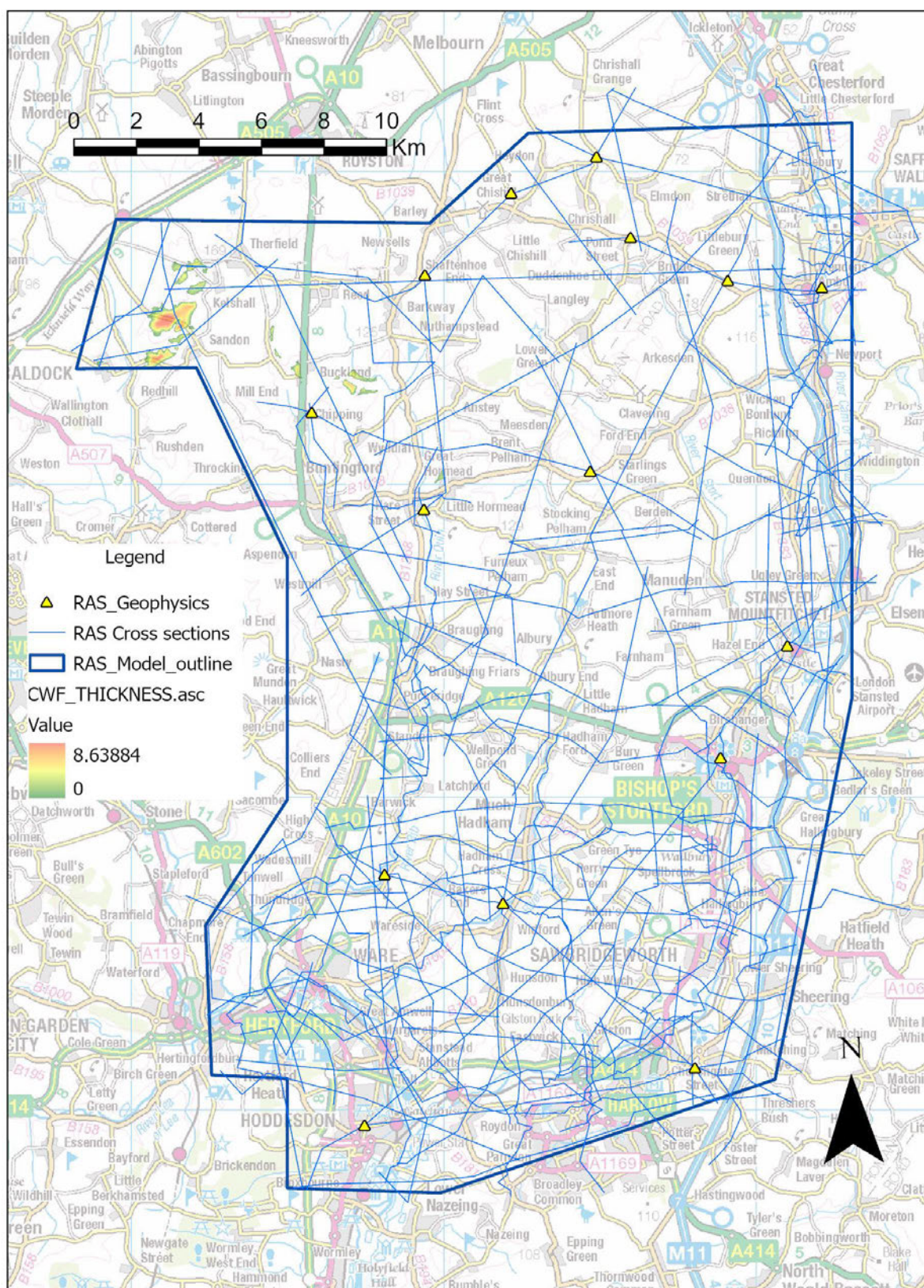
LONDON CLAY FORMATION



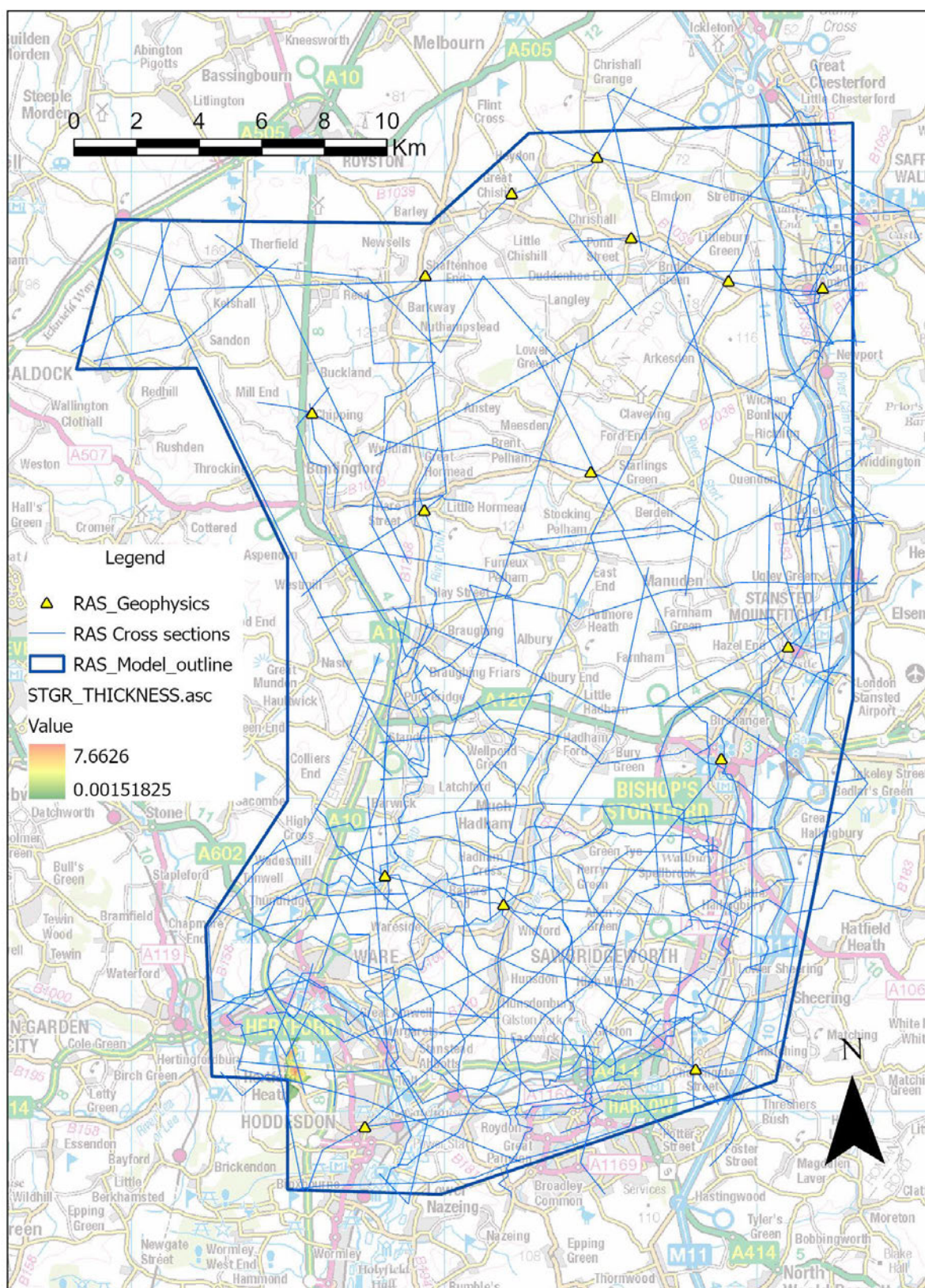
RED CRAG FORMATION



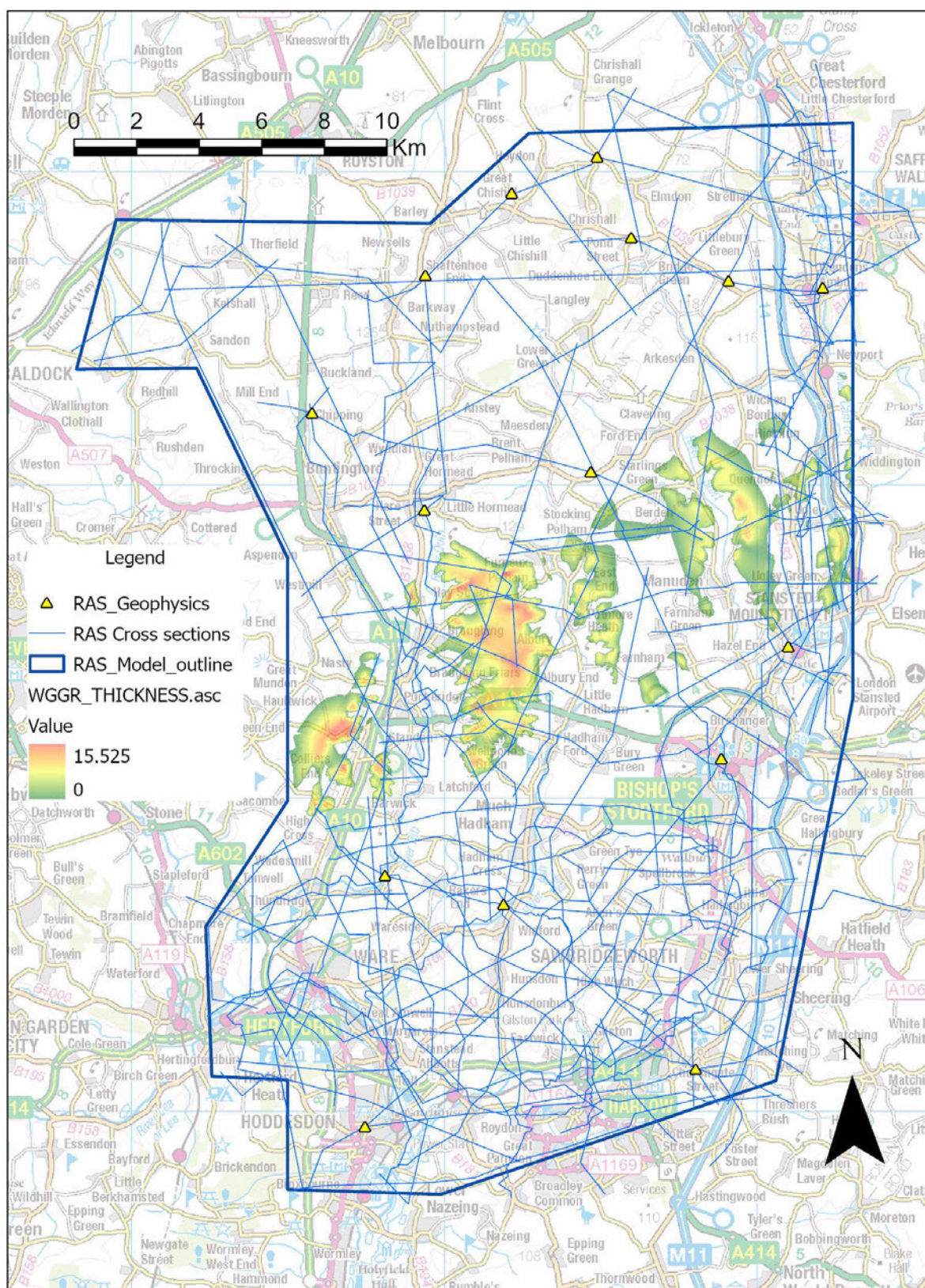
CLAY-WITH-FLINTS



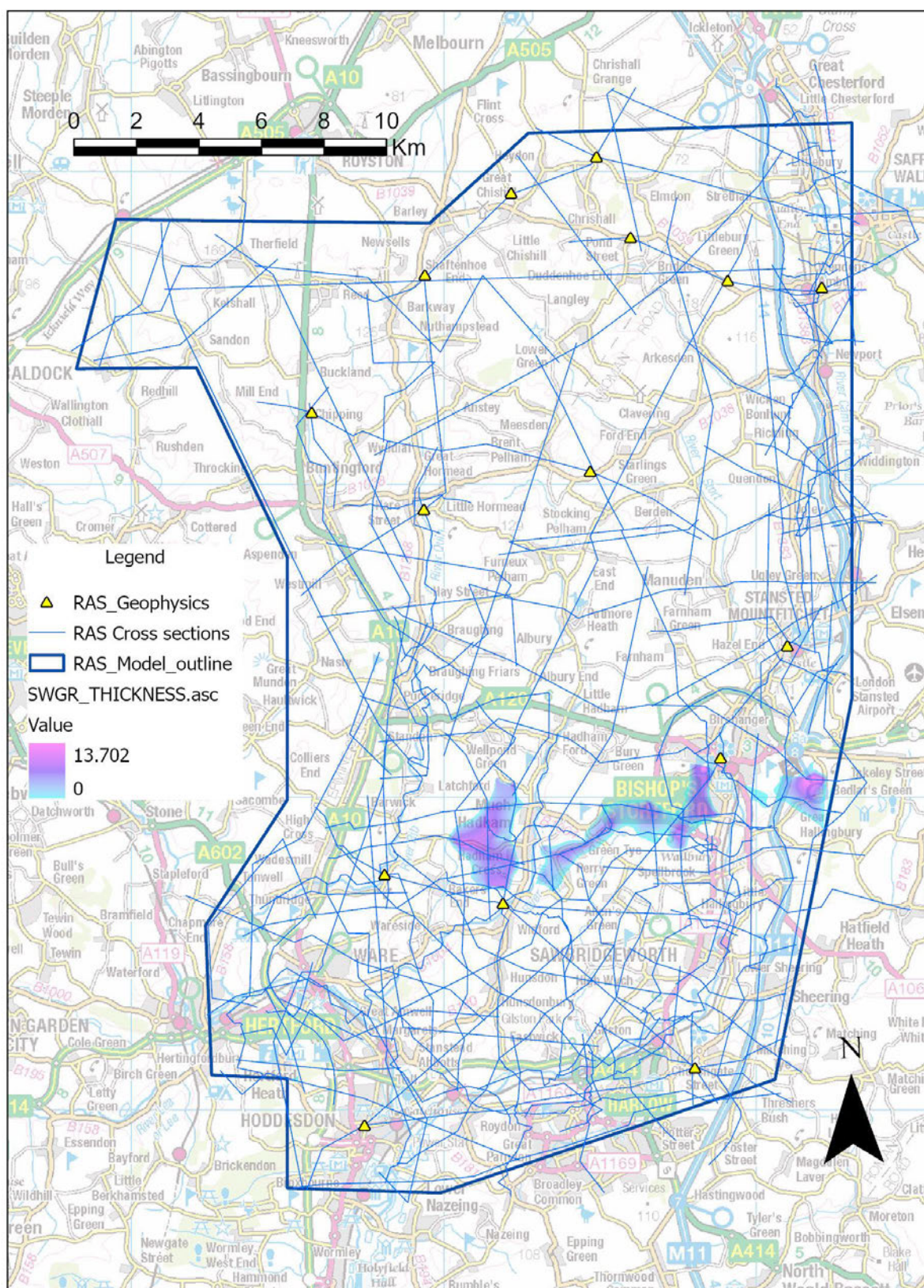
STANMORE GRAVEL FORMATION



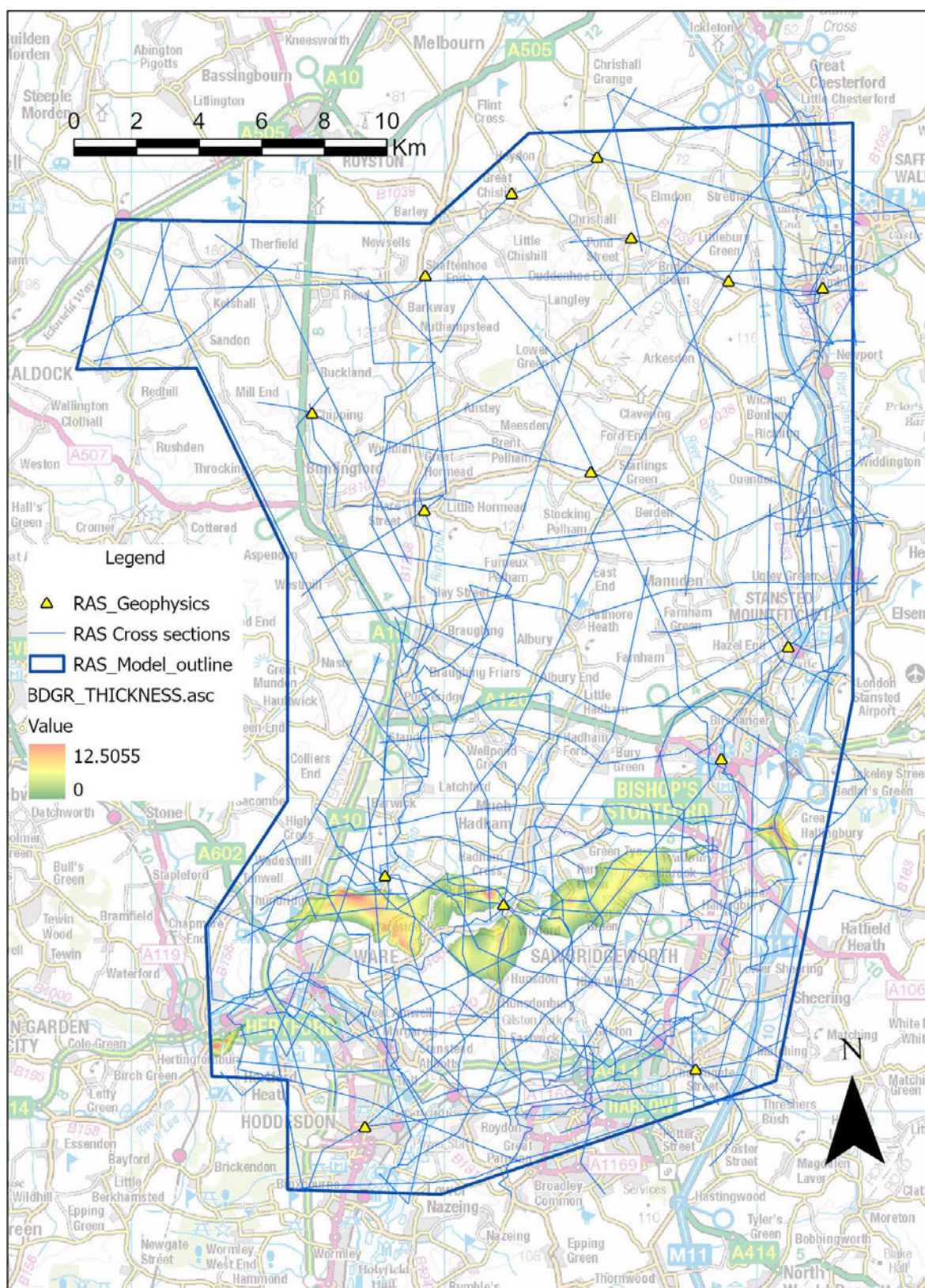
WESTLAND GREEN GRAVEL (PALEO-THAMES TERRACE)



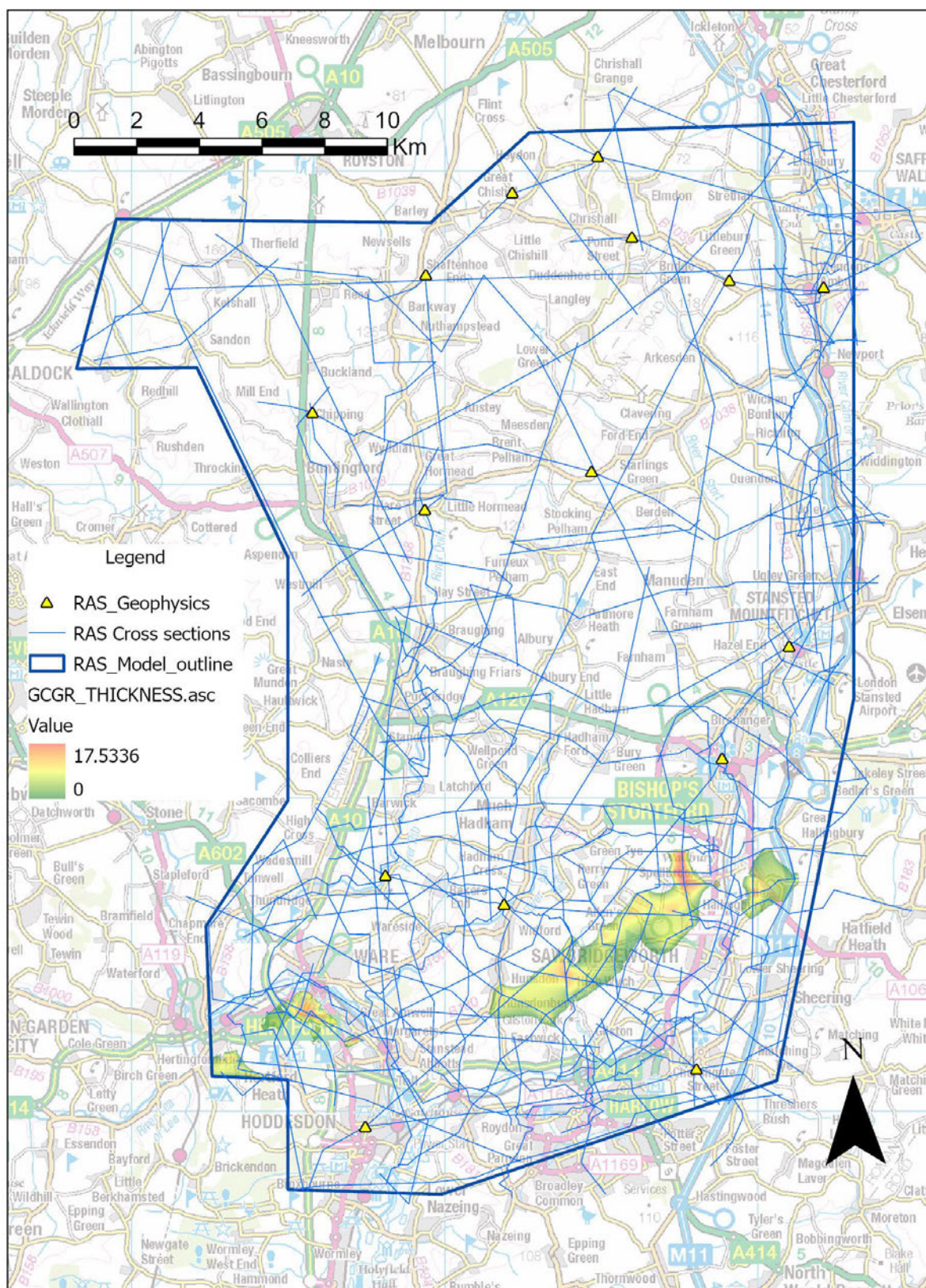
SATWELL GRAVEL (PALEO-THAMES TERRACE)



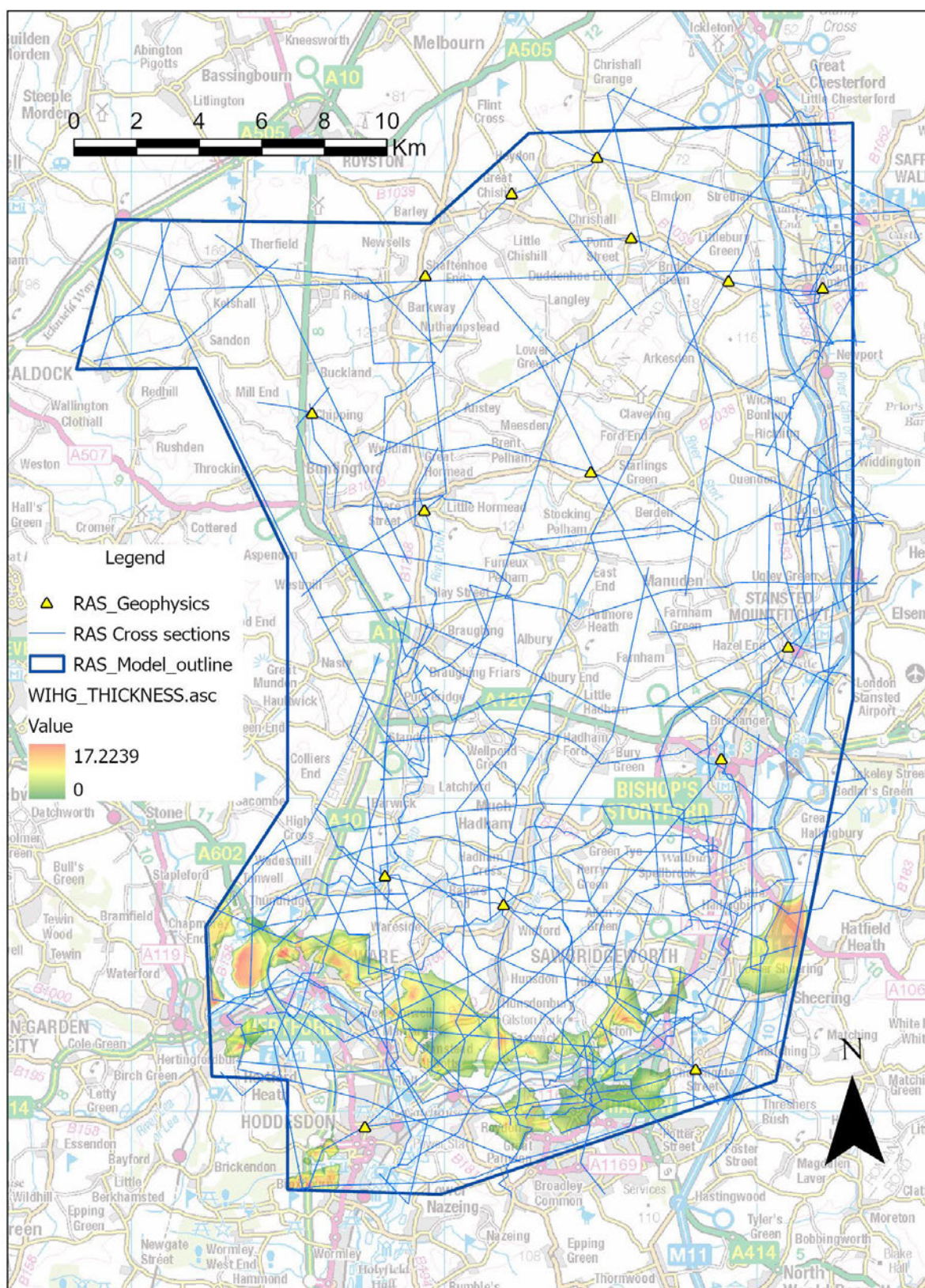
BEACONSFIELD GRAVEL (PALEO-THAMES TERRACE)



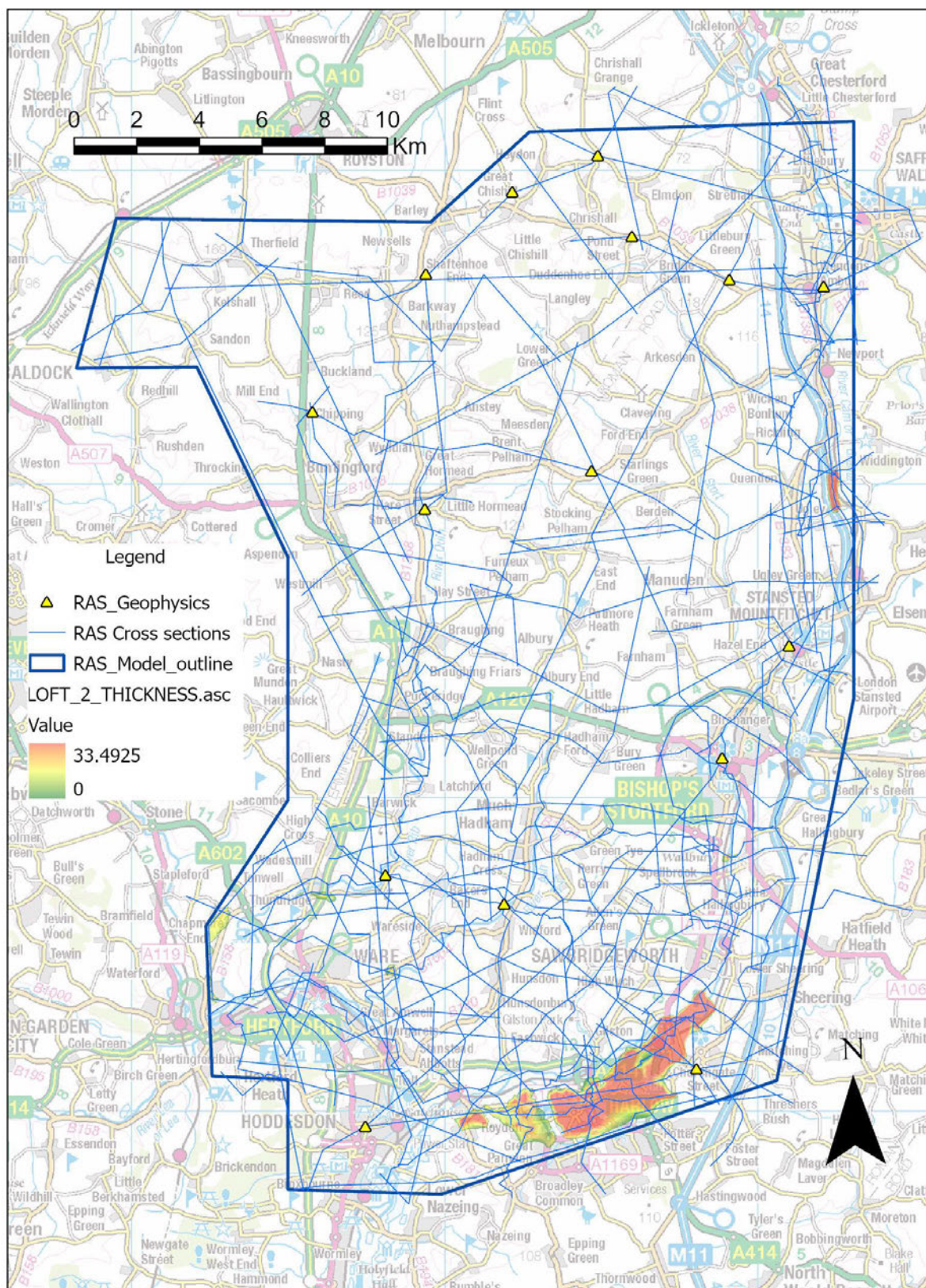
GERRARDS CROSS GRAVEL (PALEO-THAMES TERRACE)



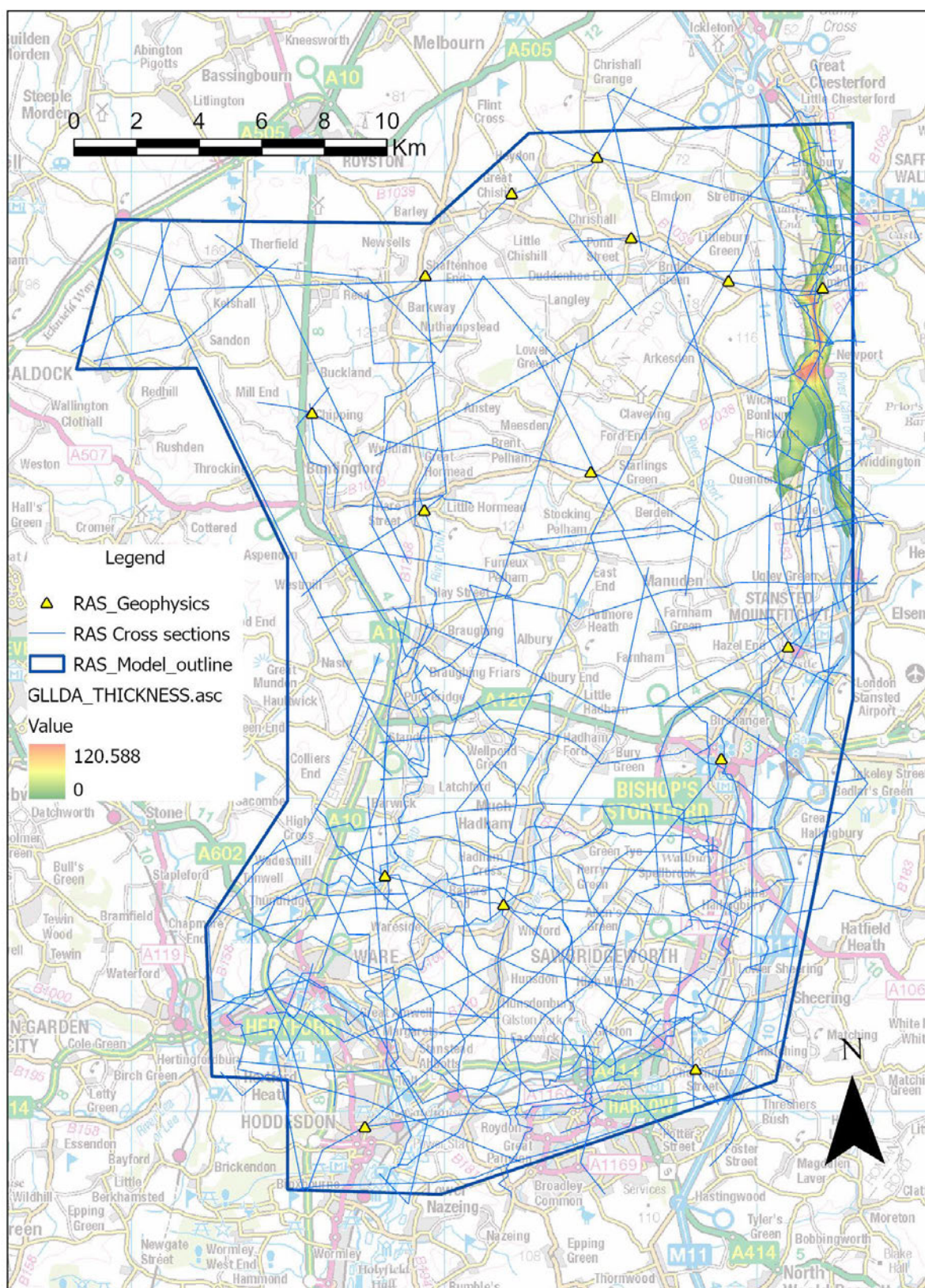
WINTER HILL GRAVEL (PALEO-THAMES TERRACE)



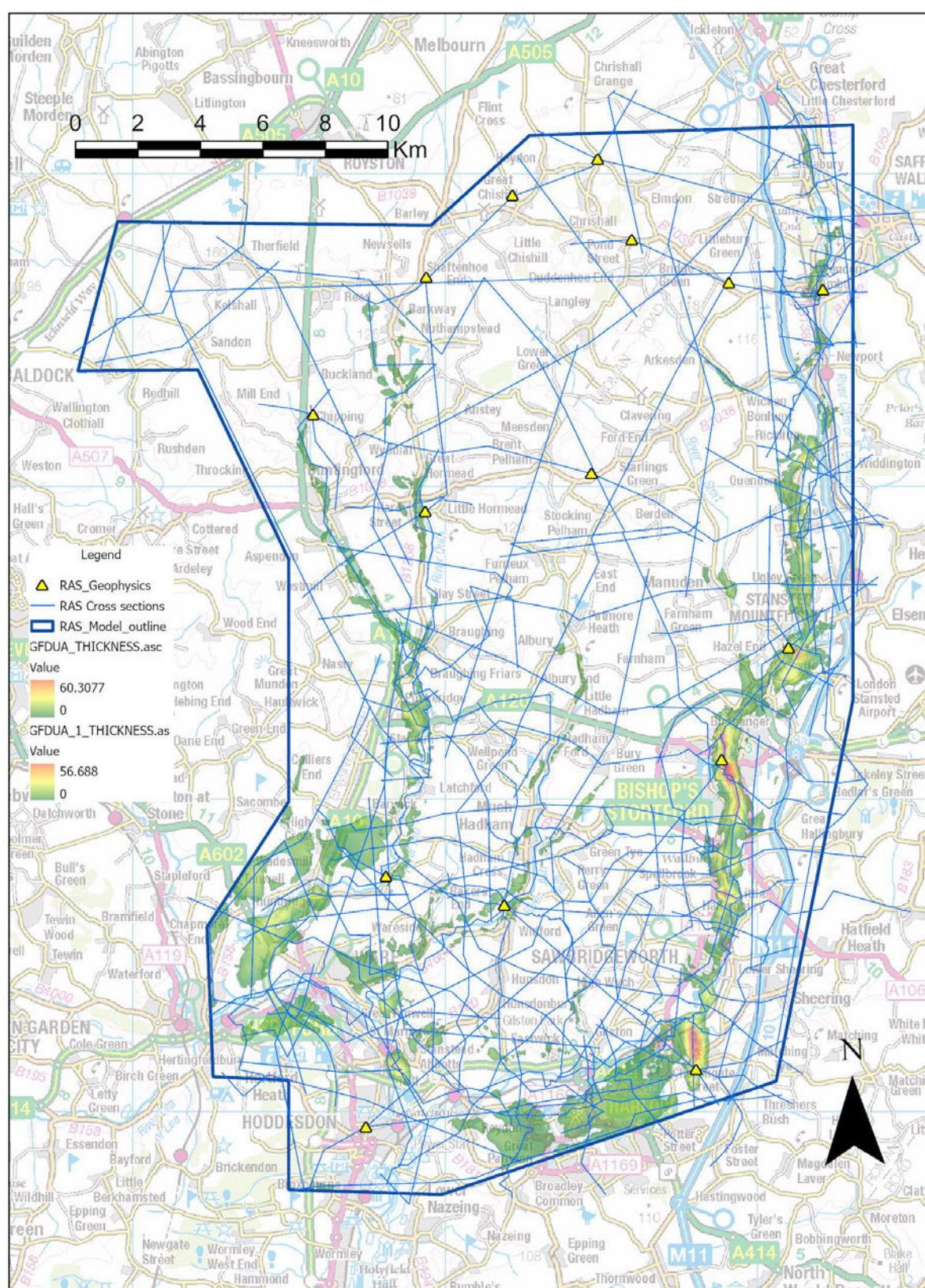
LOWESTOFT TILL (ANGLIAN) LOWER



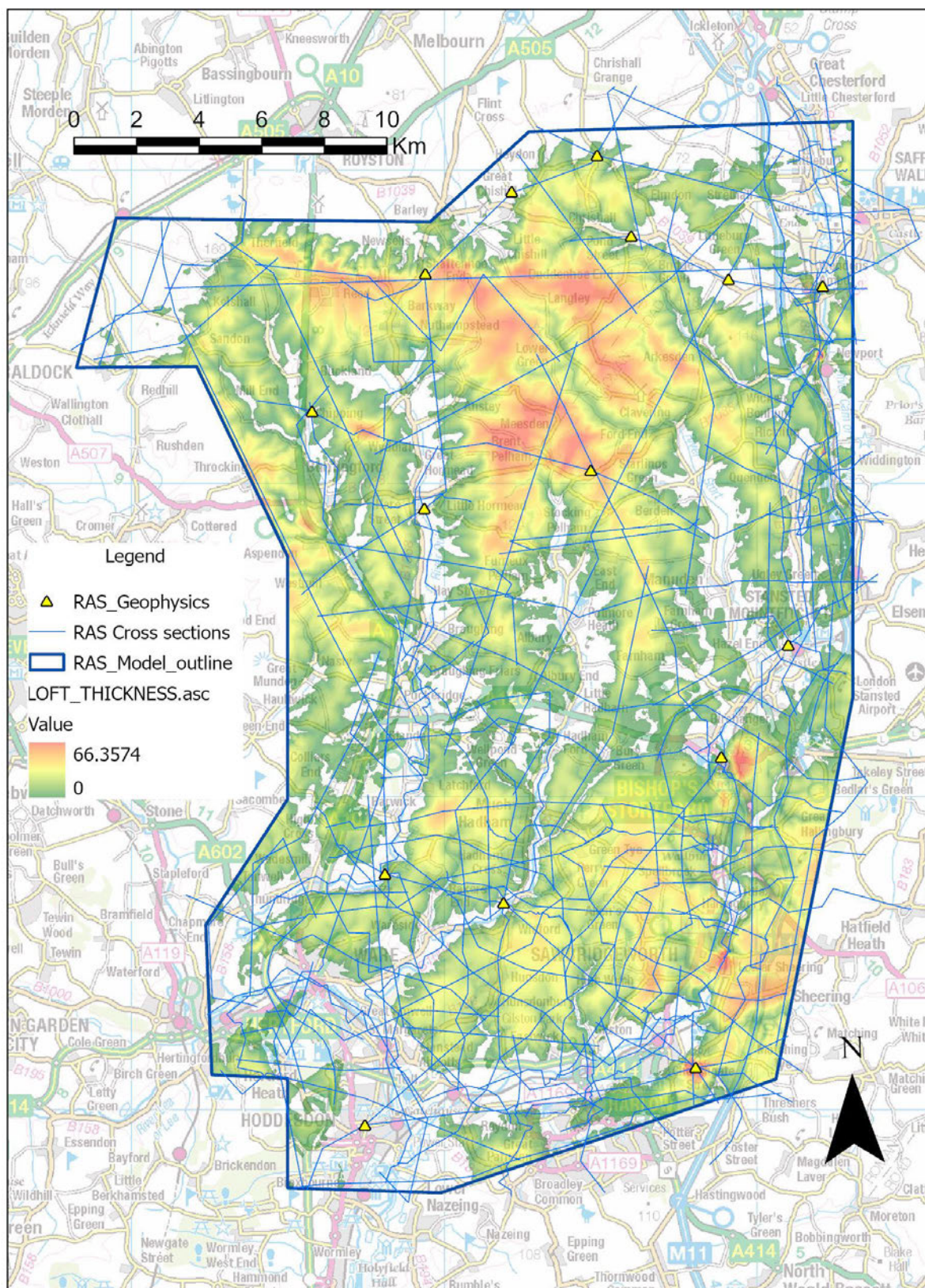
GLACIOLACUSTRINE DEPOSITS (ANGLIAN)



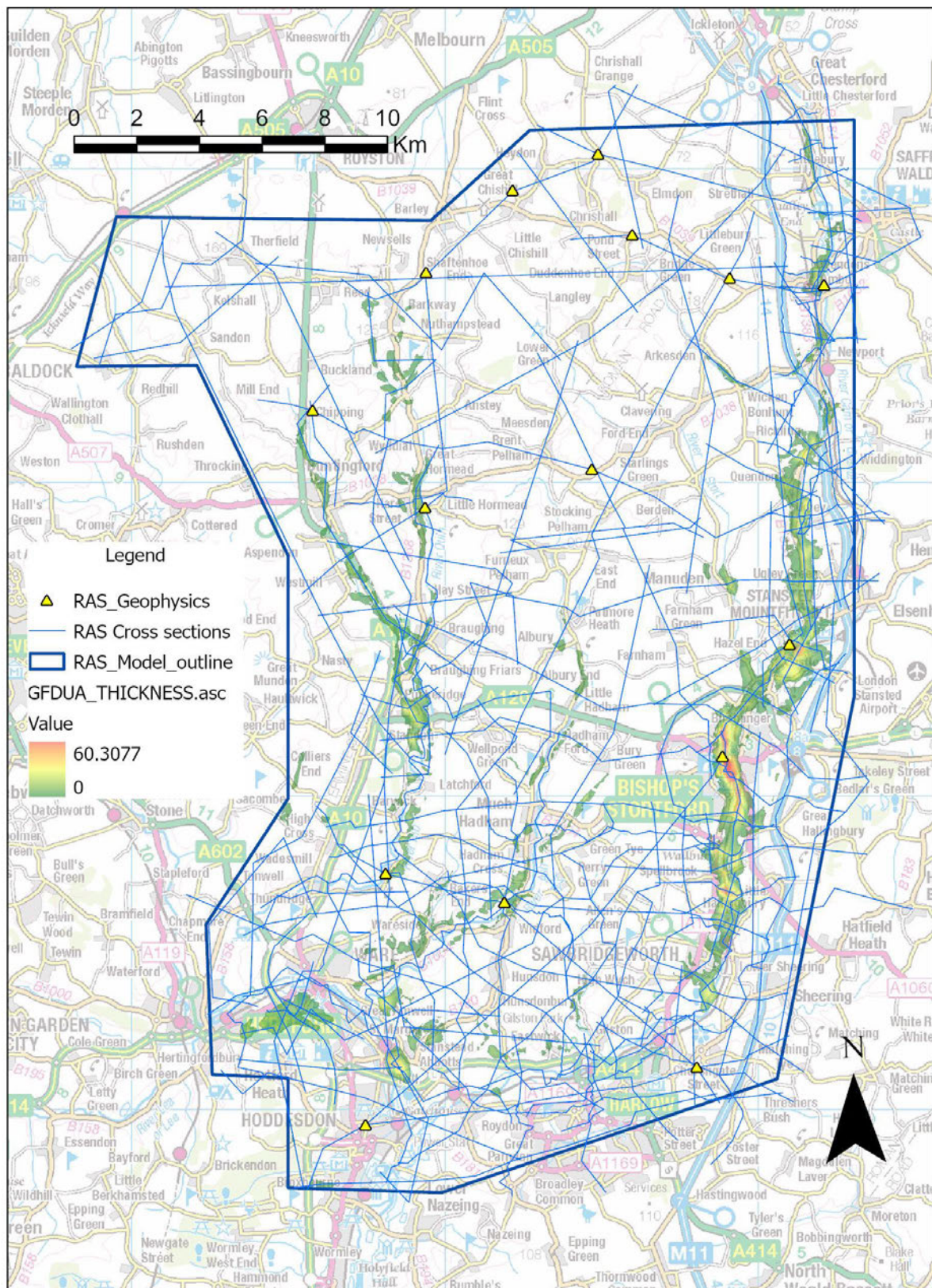
GLACIOFLUVIAL DEPOSITS (ANGLIAN) LOWER

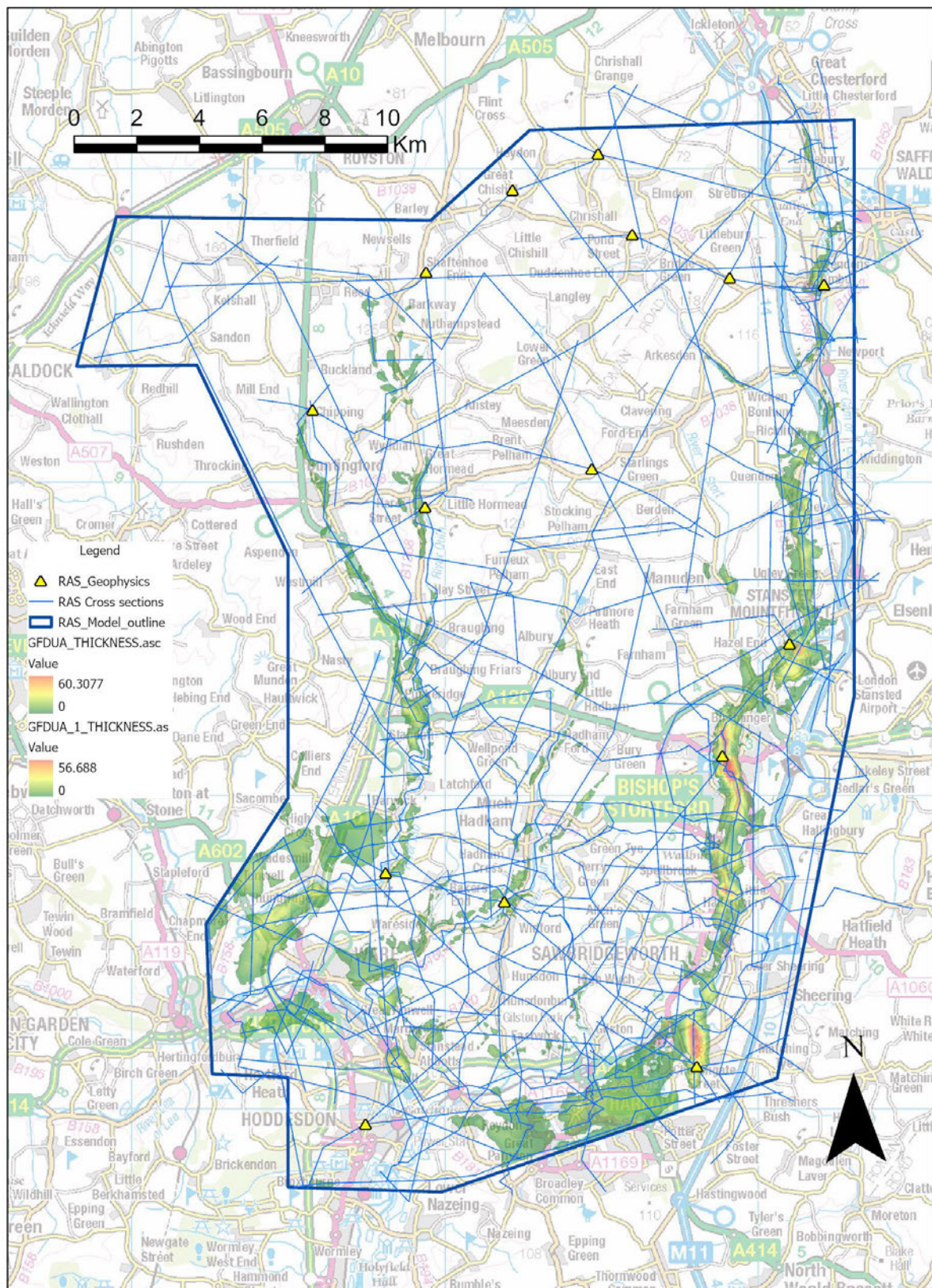


LOWESTOFT TILL (ANGLIAN) UPPER

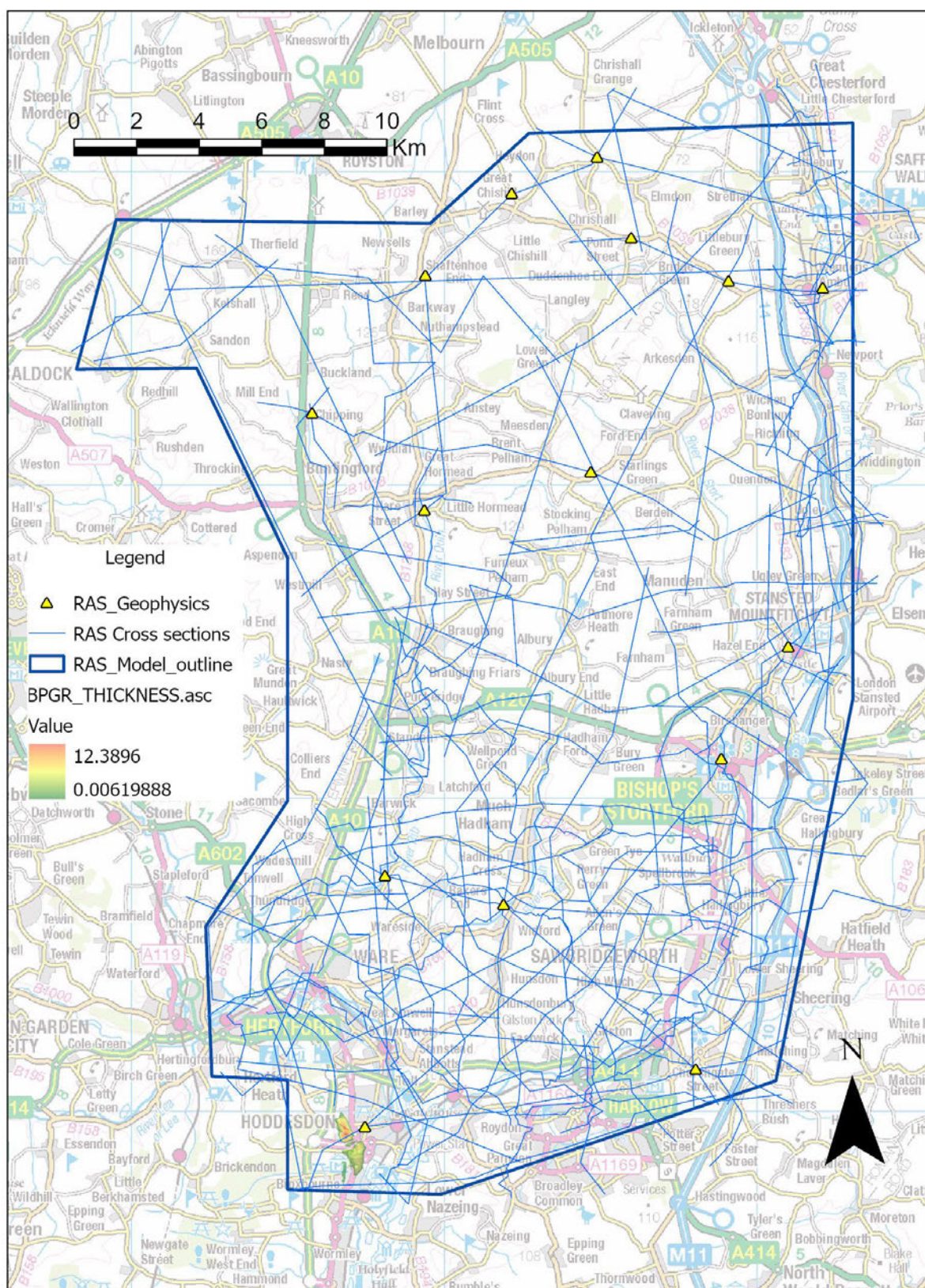


GLACIOFLUVIAL DEPOSITS (ANGLIAN) UPPER

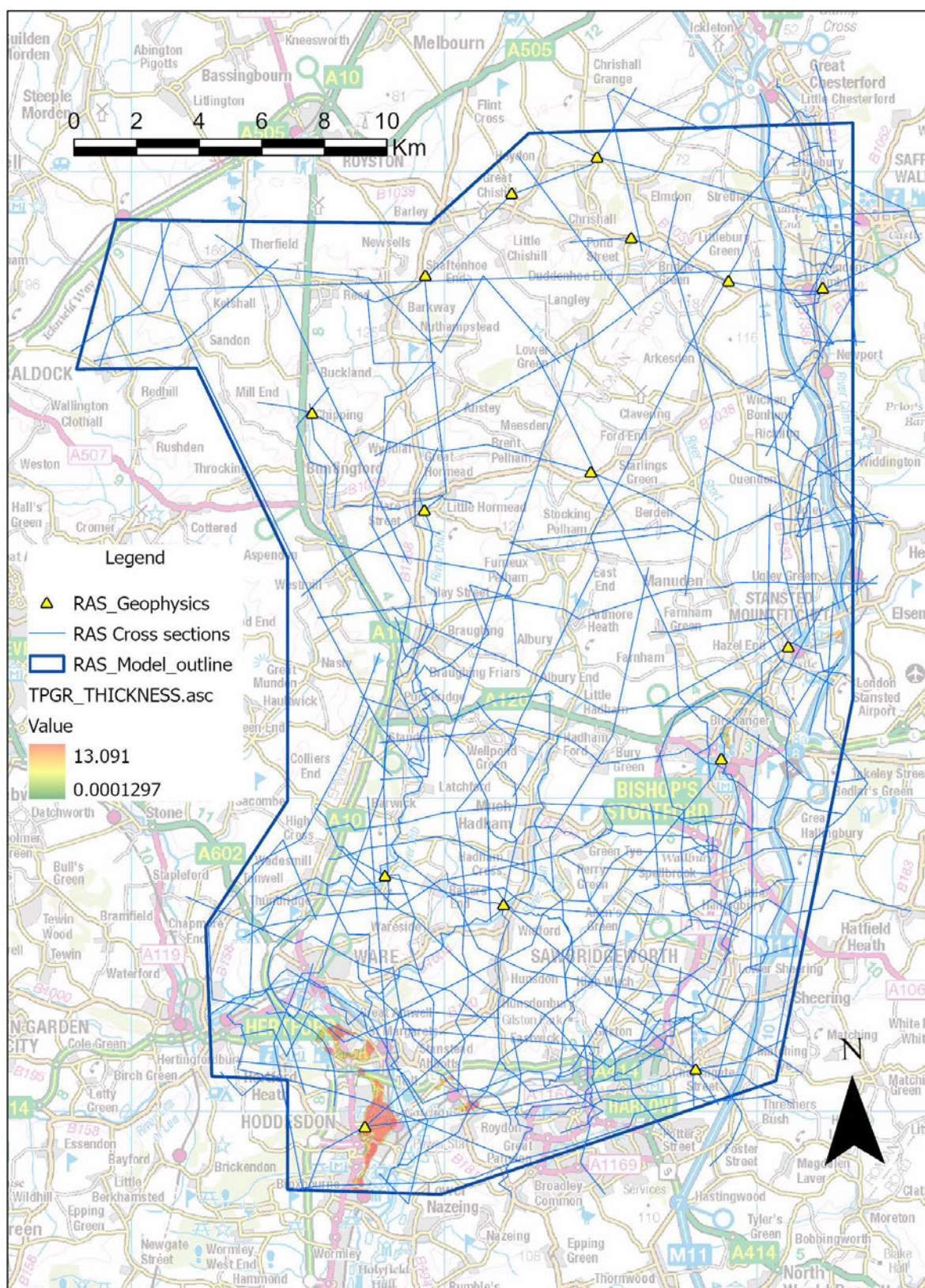




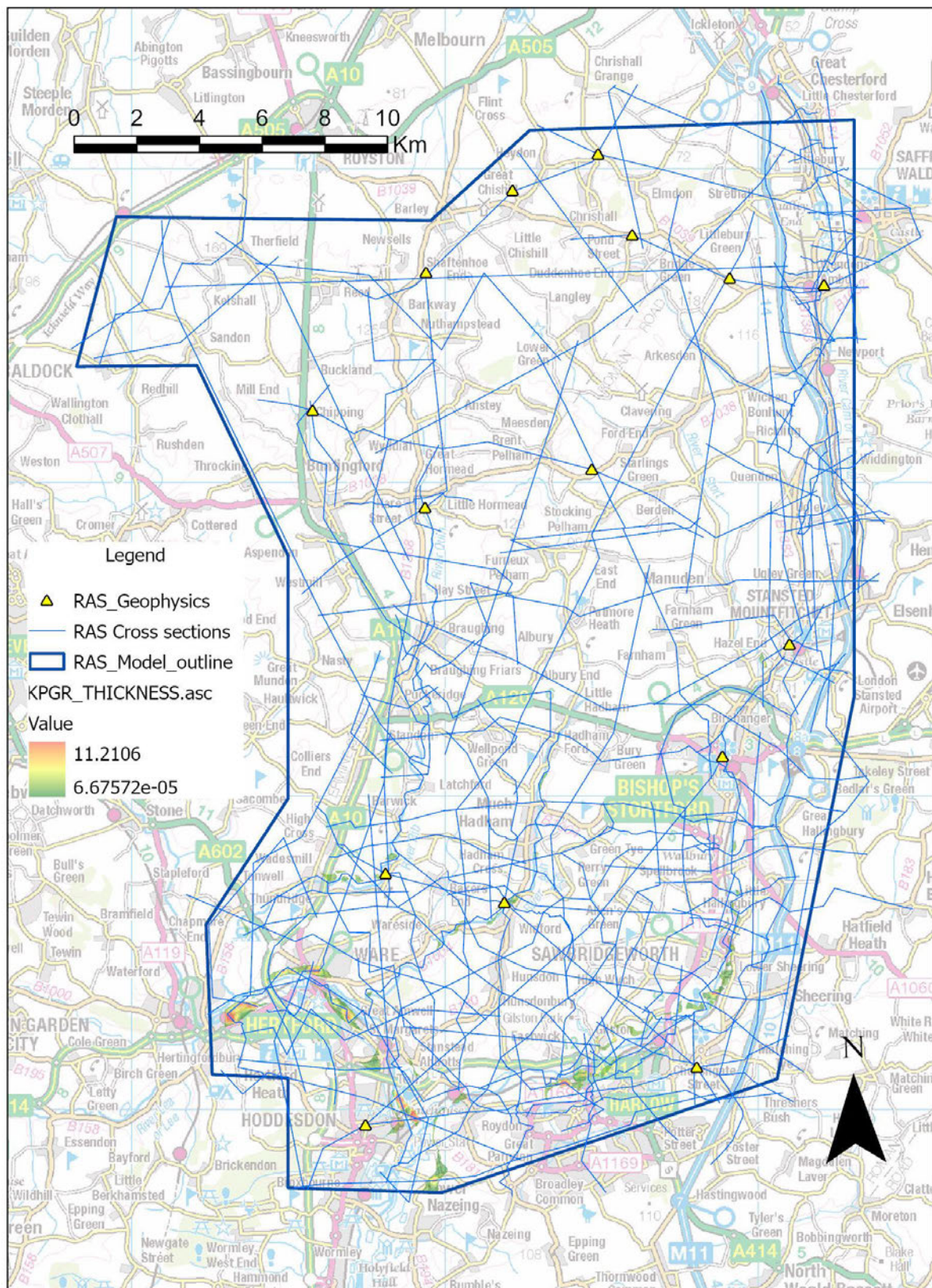
BLACK PARK GRAVEL (POST ANGLIAN TERRACE)



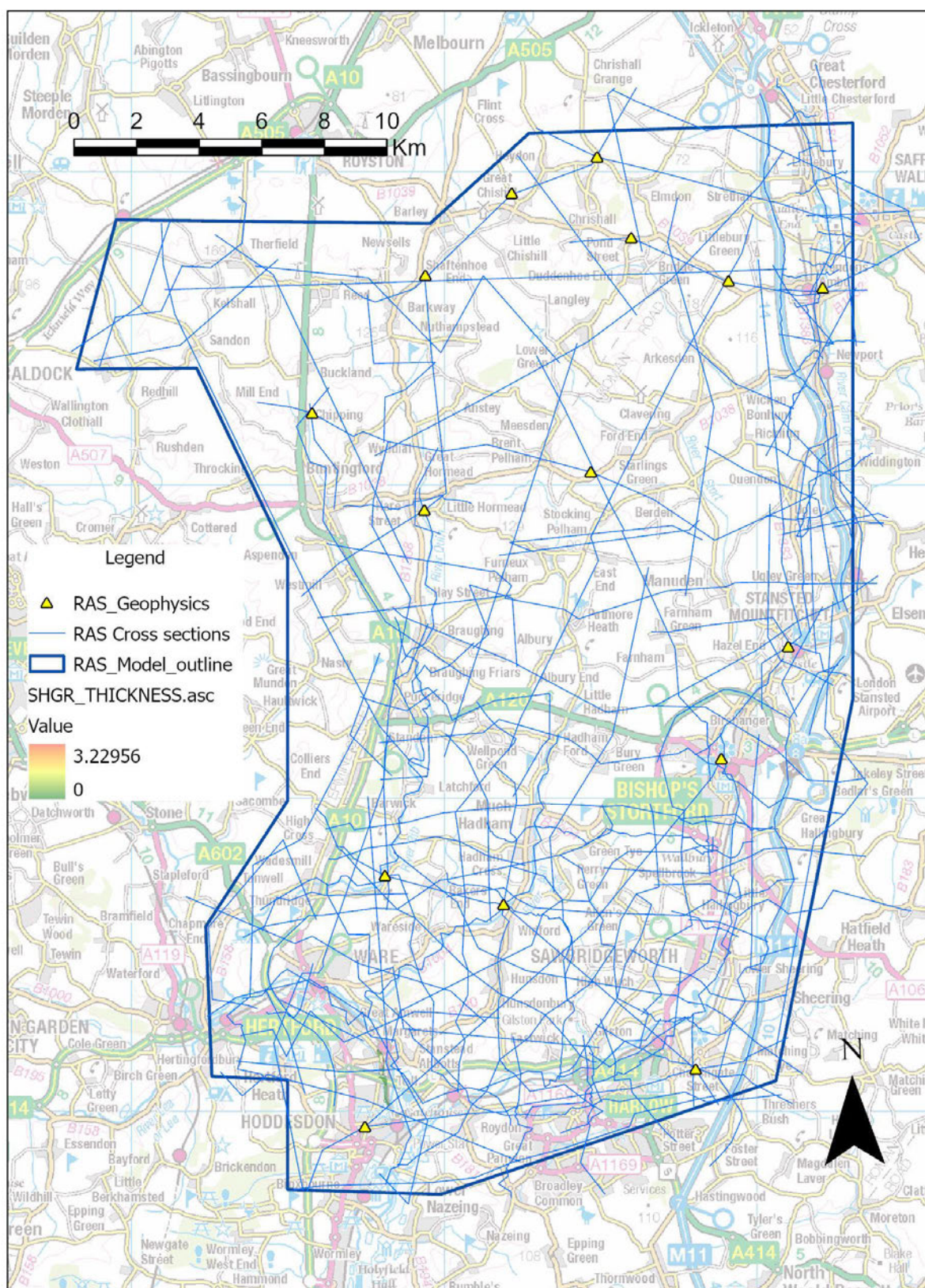
TAPLOW GRAVEL (POST ANGLIAN TERRACE)



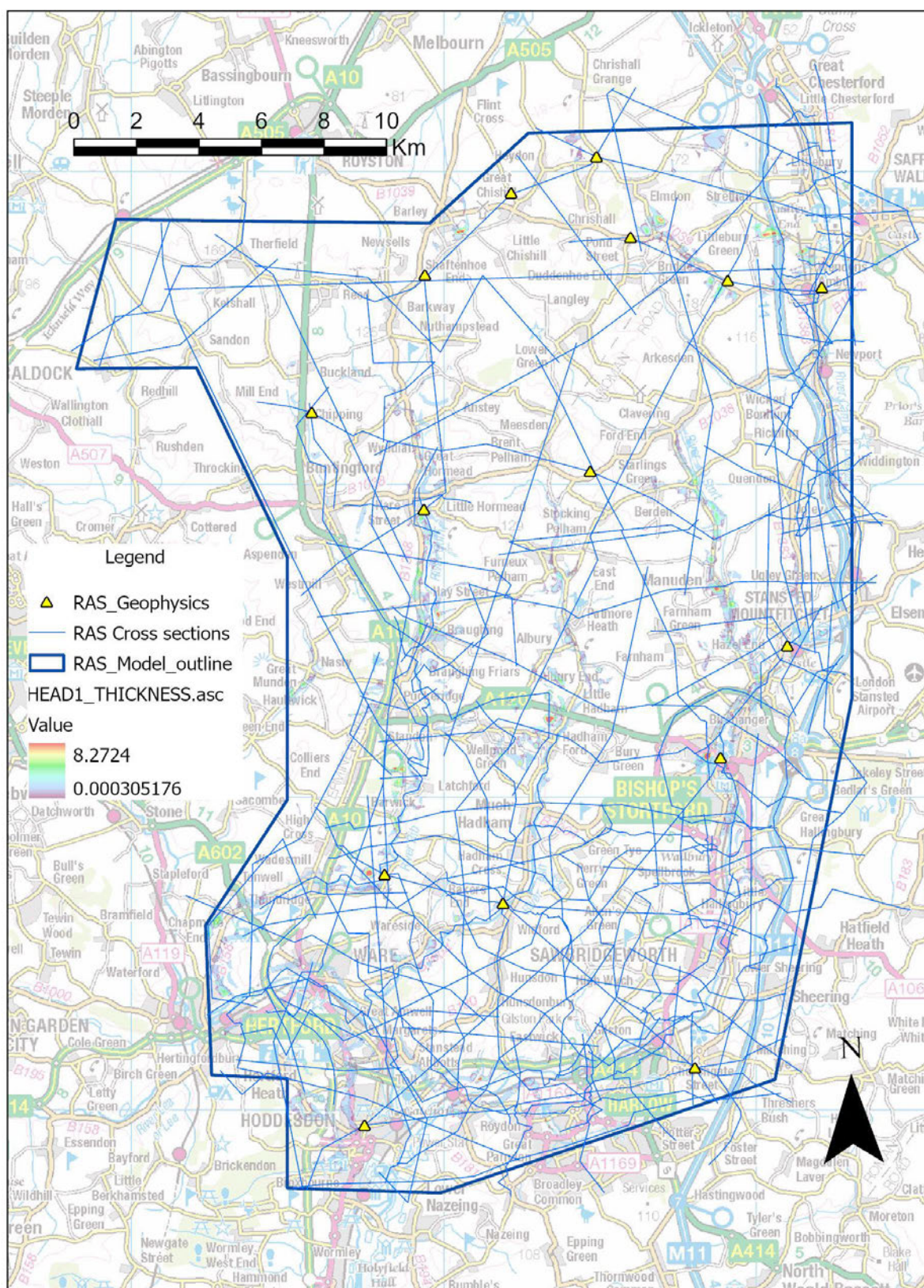
KEMPTON PARK GRAVEL (POST ANGLIAN TERRACE)



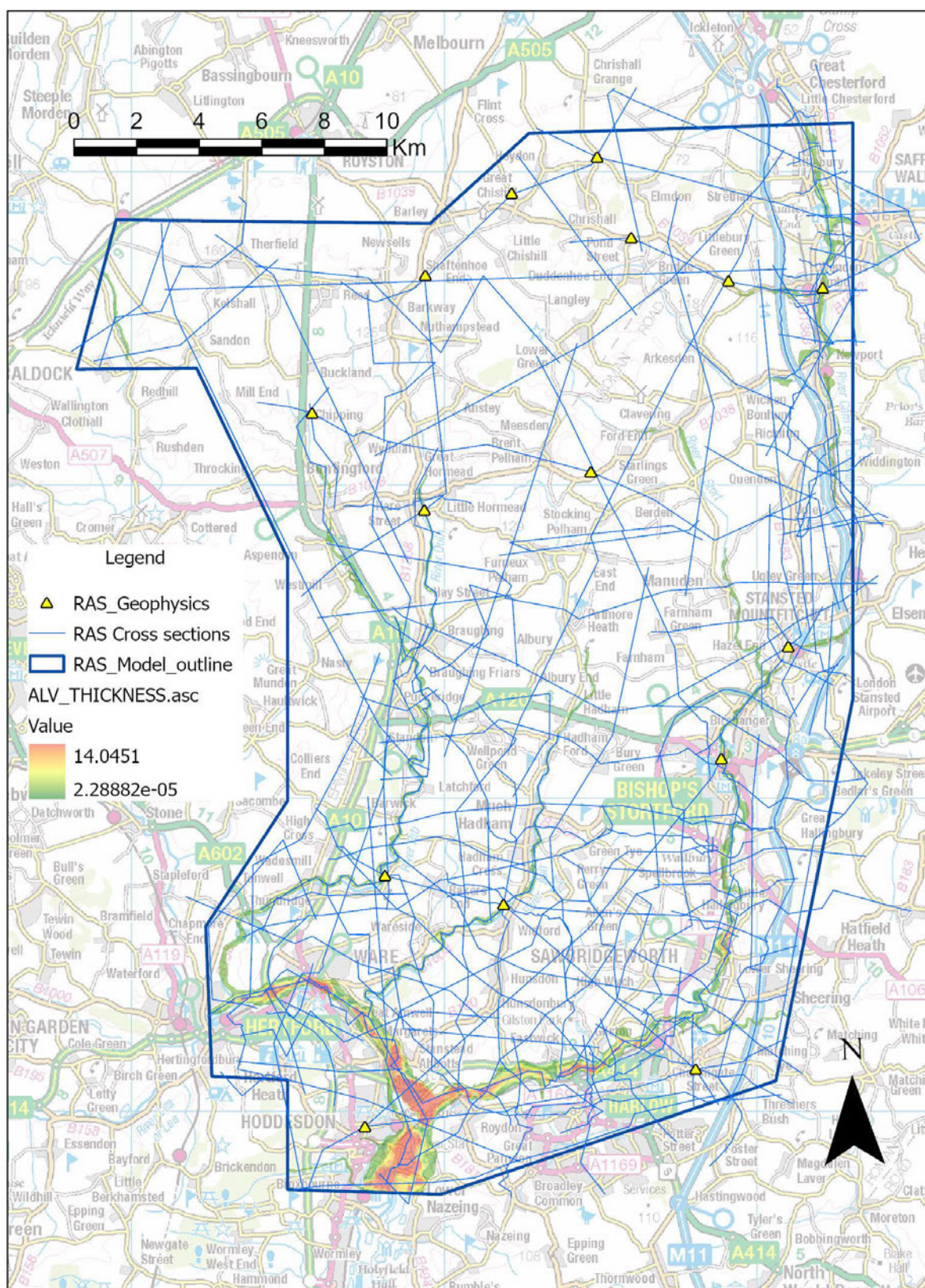
SHEPPERTON GRAVEL (POST ANGLIAN TERRACE)



HEAD 1



ALLUVIUM



HEAD

