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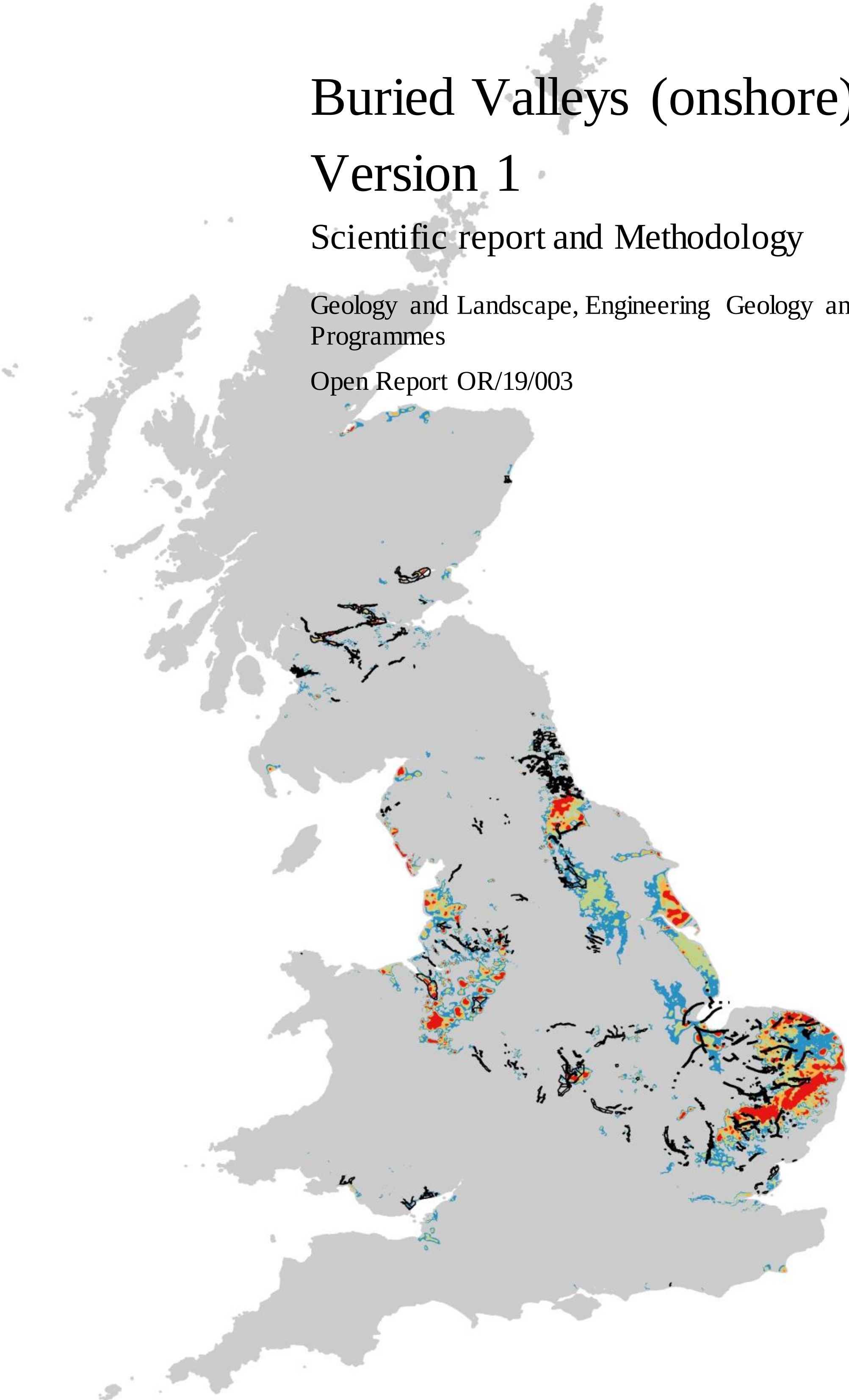
Buried Valleys (onshore) Version 1

Scientific report and Methodology

Geology and Landscape, Engineering Geology and Infrastructure Programmes

Open Report OR/19/003



BRITISH GEOLOGICAL SURVEY

GEOLOGY & LANDSCAPE, ENGINEERING GEOLOGY AND INFRASTRUCTURE PROGRAMME

OPEN REPORT OR/19/003

Buried Valleys (onshore) Version 1

Scientific report and Methodology

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Keywords

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The buried valley onshore dataset.

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Summary

This report presents a description and review of the methodology developed by the British Geological Survey (BGS) to present our current national understanding of the onshore occurrence of buried valleys. It compiles data derived from historical publications and combines it with a semi-automated 3D modelling methodology to create an assessment of where these features might occur.

1 Introduction

1.1 BACKGROUND

Buried valleys are ancient sub-aerial (river) or subglacial drainage networks that are now abandoned and have become infilled by sediment so that they have little or no surface expression in the landscape. Their concealed occurrence can have significant and often unexpected implications for groundwater (e.g. Sandersen & Jørgensen, 2003; Cloutier *et al.*, 2008; Seifert *et al.* 2008; Oldenborger *et al.*, 2013), hydrocarbon (e.g. Huuse *et al.*, 2012) and geothermal resources (e.g. Allen & Milenic, 2003; Allen *et al.*, 2003). Buried valleys can also contain significant quantities of sand and gravel mineral resources which can act as traps for contaminants as well as pathways into groundwater aquifers.

The British Geological Survey (BGS) has recognised and identified buried valleys through its survey activities since the 1870's (Mellard Reade, 1873) although no compiled data set has ever been produced. Since the 2000's BGS has also published a Superficial Deposits Thickness Model (SDTM) which models variation in thickness of natural superficial deposits across Great Britain (Lawley and Garcia-Bajo, 2009). However, one limitation of this methodology is that it under-represents the spatial occurrence of linear features such as buried valleys (Kearsey *et al.*, 2018).

This work attempts to compile what is currently known about buried valleys from historic survey activities. It also employs a semi-automated method to identify areas of significant superficial deposits thickening based on our current onshore borehole dataset. It cannot be used to say where buried valleys are not present; but it does indicate the locations where based on the recorded evidence and expert knowledge a geologist has interpreted the presence of buried valley.

1.2 DEFINITION OF A BURIED VALLEY

The British Geological Survey has no formal definition of a buried valley. The Encyclopaedia of Geomorphology (Goudie, 2013) defines a buried valley thus:

> "A buried valley is the bedrock expression of a valley buried by more recent deposits."

They usually exhibit little or no surface expression in the landscape (Figure 1) and can only be verified using boreholes (e.g. Kearsey *et al.*, 2019) or using geophysics (e.g. Sandersen & Jørgensen, 2003). They can be formed by a range of processes including;

(i) Sub-aerial fluvial incision (e.g. Dyer, 1975; Swift *et al.*, 1980; Rose, 1989; Bozzano *et al.*, 2000; Bridgland, 2010);

(ii) Glacial over-deepening to form U-shaped valleys, which can then become partly-submerged and filled by younger sediment (e.g. Holtedahl, 1967; Nesje & Whillans, 1994);

(iii) Incision by subglacial meltwater beneath glaciers and ice sheets (e.g. Ó Cofaigh, 1996; Præg, 2003; Hooke & Jennings, 2006; Lutz *et al.*, 2009; Kehew *et al.*, 2013).

They may also be polygenetic in origin, having been formed by two or more of these processes (e.g. Huisink, 2000; Huuse & Lykke-Andersen, 2000; Montgomery, 2002).

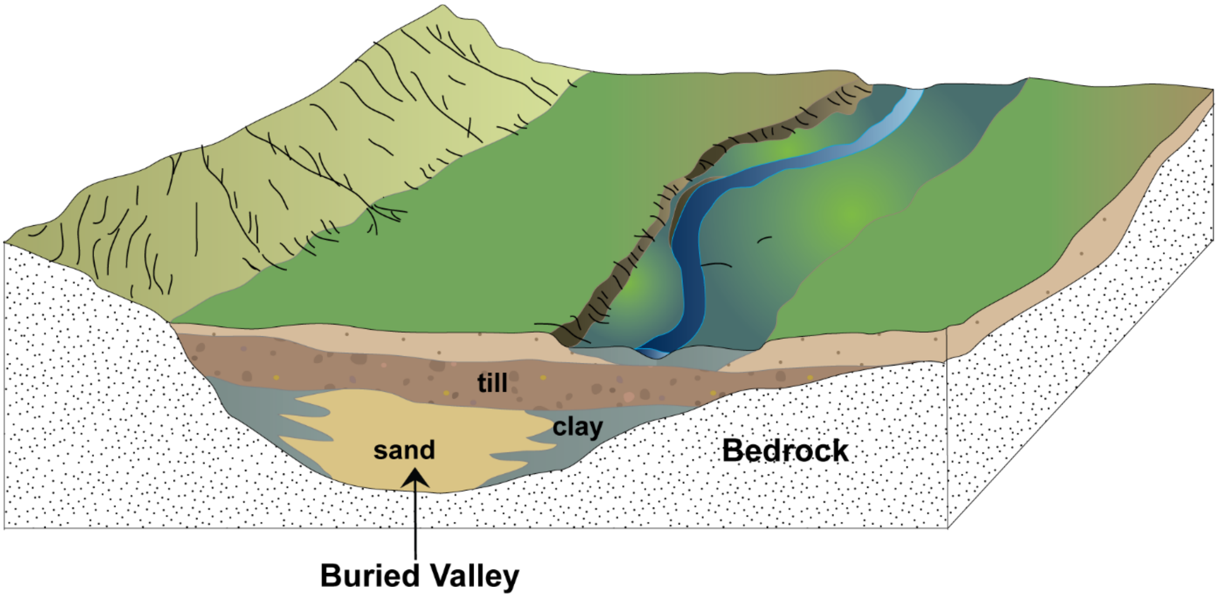

Figure 1. A stylised example of a buried valley. Note how it is offset from the modern river system. The sequence of sediment infilling the buried valley is purely illustrative and in reality the fill of a buried valley can vary greatly between valleys.

There is no minimum depth or width for these buried valleys as described in the literature. It is evident from reviewing the published BGS memoirs and reports that the term 'buried valley' is used for a large range of features which range in depth from tens to hundreds of metres. Furthermore, the depth of the features, or the evidence upon which they have been identified with, is not often recorded in the reports.

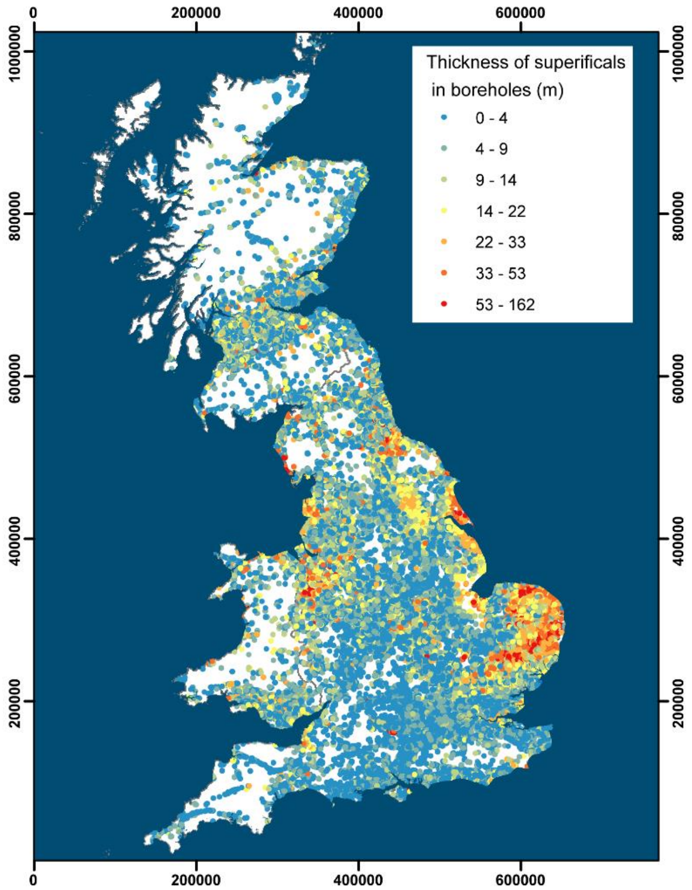

Figure 2. Distribution of boreholes that prove the thickness of superficial deposits in the Great Britain. Contains Ordnance Survey Data © Crown Copyright and database rights 2019. Ordnance Survey Licence no. 100021290. Created using ArcGIS. Copyright © Esri.

The National Superficial Deposit Thickness Model (Lawley and Garcia-Bajo, 2009) is currently derived from by 293,988 boreholes (Figure 2) that prove the thickness of superficial deposits across the Great Britain. These show that the average thickness of superficial deposits is 8.35 m and that 75% of the boreholes have superficial thicknesses of less than 10.50 m (Figure 3). Buried valleys themselves are continuous linear depressions within the dataset, whereas depressions that possess no clearly-defined linearity are classified as significant superficial thickenings. The latter probably correspond to broader basinal areas within the landscape.

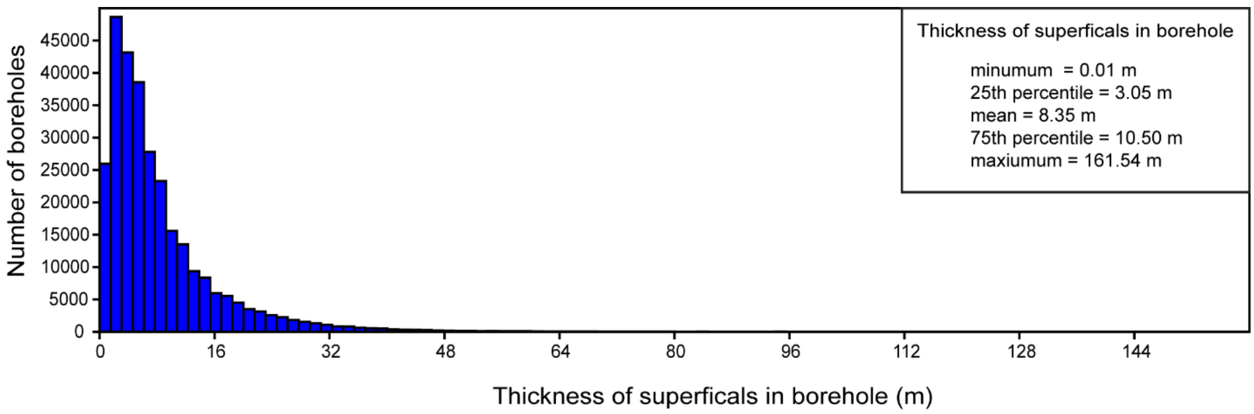

Figure 3. Thickness of superficial deposits in boreholes across the Great Britain.

1.3 OBJECTIVES

The objectives of this work are twofold:

- To compile a comprehensive dataset of where BGS historic survey activities and other published work has identified buried valleys onshore in the Great Britain.

- To use our current onshore borehole dataset to create a modelled thickness of buried valleys dataset.

1.4 WHO WOULD BENEFIT FROM THE DATASET?

This dataset is for users who are seeking information about the locations of buried valleys across Great Britain. These are important features for geologists, civil engineers, hydrogeologists and environmental scientists because they can have unexpected consequences for anyone interested in the position of bedrock or the thickness of superficial deposits. Equally this dataset will be of interest to the research community of the Great Britain as buried valleys provide detailed archives of palaeoenvironmental and landscape change.

1.4.1 Relationship to the superficial deposits thickness model

The BGS creates the National Superficial Deposit Thickness Model (SDTM) as a licenced product (Lawley and Garcia-Bajo 2009). Although the Buried Valleys (onshore) data shares some of the same input data it is not meant as a replacement but compliments the existing data.

The key differences are:

- The Buried Valleys (onshore) data is presented at a coarser scale than the SDTM Model (1:250 000 compared to 1:50 000 of the SDTM).
- The all superficial deposits between 40-161 m are grouped together in the Buried Valley dataset but are in the SDTM Model.
- The Buried Valleys (onshore) data was created through an expert driven process specifically targeted at identifying buried valleys, which has removed superficial features such as drumlins and other mounds.

Please do not use this as the Buried Valley dataset as an indicator of superficial thickness. For superficial thickness please use the National Superficial Deposit Thickness Model (SDTM).

2 Methods

The Buried Valleys (onshore) dataset contains two elements:

1) Historic references to Buried Valleys
2) Modelled Thickness of Buried Valleys.

These were created using the methods described below.

2.1 HISTORIC REFERENCES TO BURIED VALLEYS

The BGS historic literature was searched using dtSearch the BGS text searching facility. This returned 120 BGS publications plus 25 technical reports and 8 open reports that contained the phrases "buried valley", "tunnel valley", "sub-drift topography" and "drift filled channel". Of these 96 had figures or maps that had sufficient geographic information that enabled them to be georectified. Buried valleys that are shown on the marginalia of published geological maps and within BGS digital mapping data (GB Geology 1:50 0000) were also captured within the dataset. The source and type of each feature are recorded within the table of attributes of the shapefiles.

The geographic location of buried valleys from historic sources were used to create two types of data (lines and polygons), with features identified either using a centre line of the feature (for original features drawn as linear features) or the margins of the feature (for original features drawn as polygons).

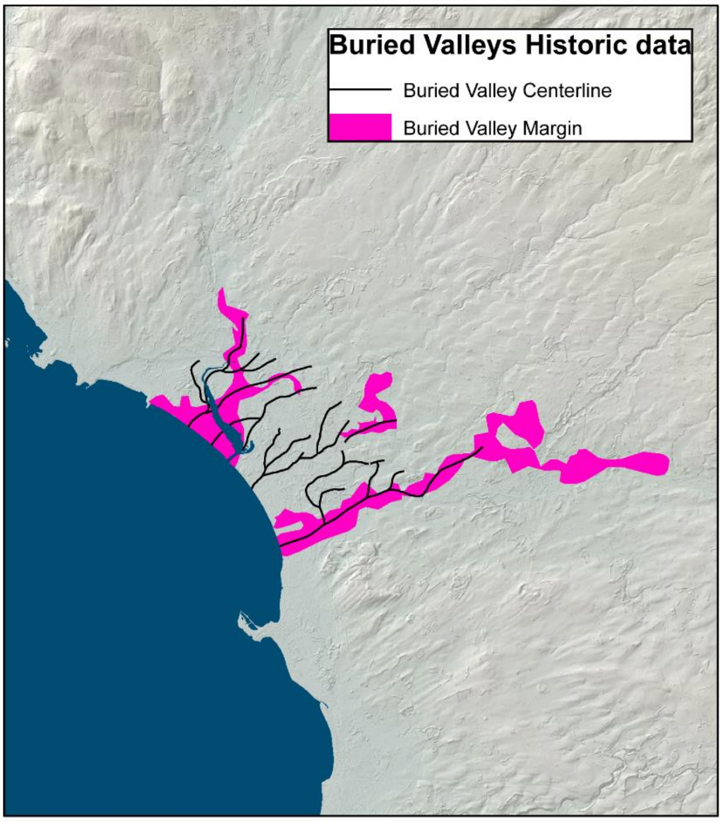

Figure 4. An example of historical buried valleys dataset showing centre lines and margins. Note the margins and centreline data in this example is drawn from different sources as a result there is difference in the precise location of the features. Contains Ordnance Survey Data © Crown Copyright and database rights 2019. Ordnance Survey Licence no. 100021290 and NEXTMap Britain elevation data from Intermap Technologies. Created using ArcGIS. Copyright © Esri.

2.2 MODELLED THICKNESS OF BURIED VALLEYS

The BGS's digital borehole database postdates most of the historical references to buried valleys. Therefore, they may be able to identify, and resolve more buried valleys, when compared to those discovered through traditional geological mapping activities. Some of these features are visible in the Superficial Deposits Thickness Model. However, it has been noted that the irregular distribution of boreholes and the gridding algorithm used in the interpolation can create apparent gaps, especially in buried valley features. Kearsey *et al.* (2018) identified that a discrete-smoothing interpolation (DSI) was better at reducing the amount of apparent gaps caused by the algorithm within buried valleys. This method was used to create a modelled thickness of buried valleys based on current onshore BGS borehole dataset.

To create this dataset two different inputs were used.

- The 2018 borehole dataset which proves the depth to geological rockhead which is currently being prepared for the new SDTM. Geological rockhead is an inferred surface that separates bedrock from superficial deposits. For the purpose of this dataset, superficial deposits encompass all naturally-occurring deposits that are of Neogene or

Quaternary age. This includes deposits of the Plio-Pleistocene Crag Group which historically have been classified on older geological maps as bedrock.

- Rock at surface from GB Geology-50 superficial geology map version 8

These datasets were imported into SKUA-GOCAD™ version 17. The input data was then modelled using a GOCAD Structural Workflow to create the discrete-smoothing interpolation. This is a two stage process:

1) First the computer creates triangular mesh based on the average data distribution (401 m) and the surface was interpolated using a DSI.
2) Secondly the error between created triangular mesh and the input data was calculated. Where the error exceeded 4 m the mesh surface is locally densified and locally re-interpolated until the error between the surface and the input data is reduced to >4 m (Figure 5).

This process creates an irregular mesh which honours the data in areas of high data density yet produces an output which has a relatively small file size.

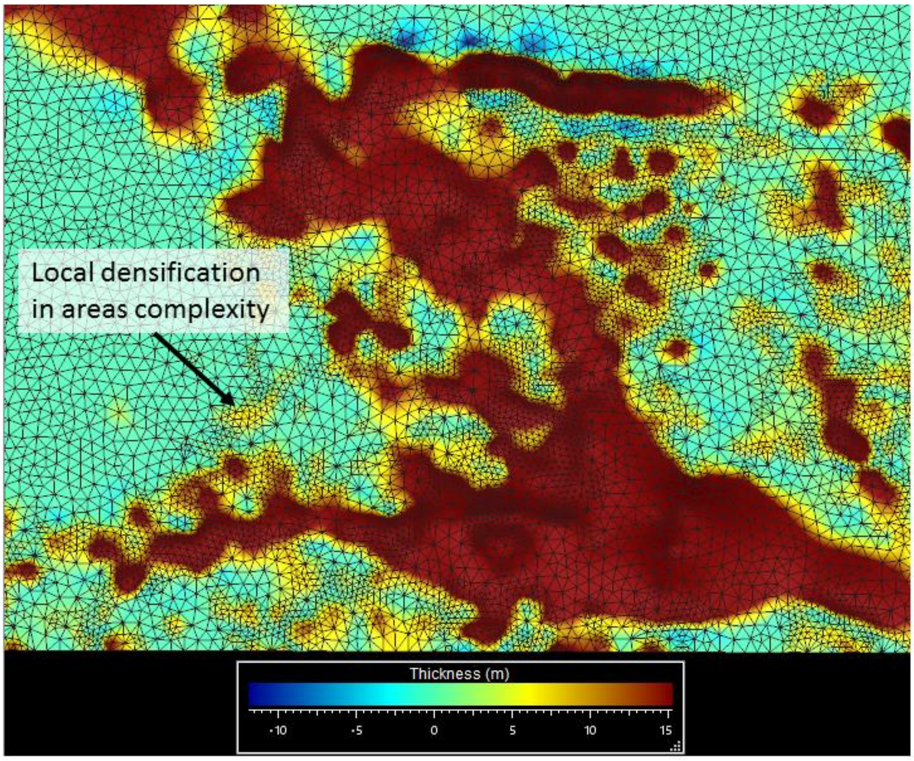

Figure 5. Modelled thickness of buried valleys discrete-smooth interpolation (DSI) created in GOCAD. The mesh has been densified in areas where the error between the final surface and the input data exceeded 4 metres.

The resulting data was then contoured at a 10 m interval and all those areas with less than 10 m of superficial deposits were deleted. The contour set was imported into ArcGIS and converted to polygons. The dataset was then manually inspected and compared to topography and input data and screened with the rules (below) to remove bull's eyes and erroneous polygons:

a) Features that were not centred on more than 5 boreholes which contain 20 m or more of superficial deposits were removed.
b) All occurrence of superficial greater than 40 m were merged in to the 'greater than 40 m' polygons.

3 Results

3.1 HISTORICAL DATASET

The historical dataset contains interpretations of buried valleys from 96 different publications (Appendix 1) which range in age from 1926-2018. Due to their enigmatic nature and the lack of a systematic definition, buried valleys have been interpreted historically in a variety of ways. Sometimes the scientific rationale for their interpretation has been clearly outlined but this is not always the case. In some instances, different data sources interpret the same features differently. In cases of multiple interpretations no judgement has made and all interpretations are included. This enables the user to visualise the diversity of interpretations (Figure 6) and obtain a rudimentary understanding of uncertainty of their location.

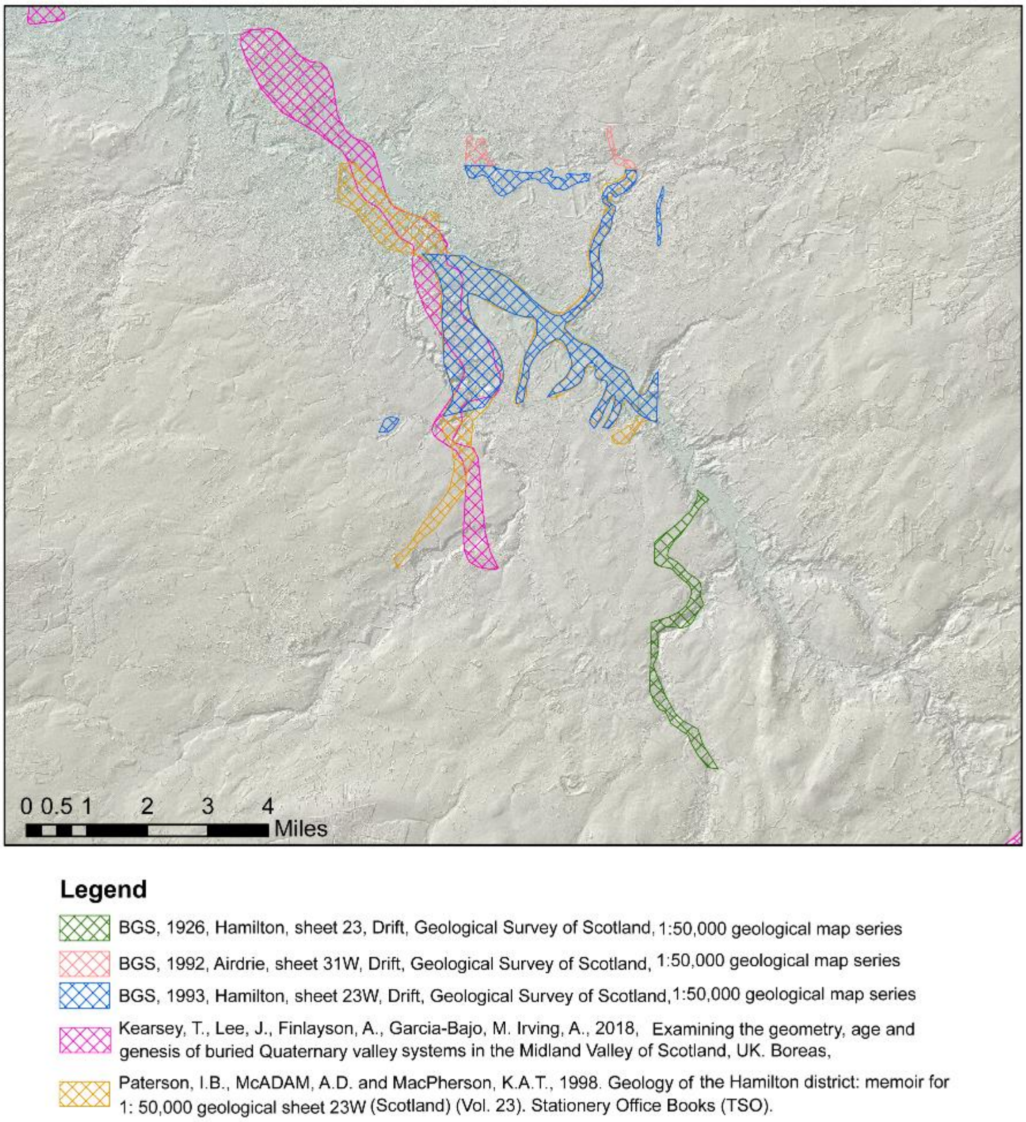

Figure 6. Multiple interpretations of the position of a set of buried valley margins. The colours pick out different interoperations of the locations of the positions of the features. Contains NEXTMap Britain elevation data from Intermap Technologies. Created using ArcGIS. Copyright © Esri.

The historical dataset identifies locations of buried valleys as far north as Aberdeen and as far south as Brighton, however within a specific feature interpretations often vary about the degree of interconnectivity within a feature (Figure 7). Many interpretations of buried valleys assume connectivity between individual data points enabling them to be illustrated as linear features. However, the base of many buried valleys – especially those formed or shaped subglacially, can be highly irregular reflecting a highly-dynamic relationship between flow regime and competence of the channel bed. Subsequently, interpretations of the interconnectivity of buried valleys should be considered with caution and within the context of the spatial distribution of the constraining data. The dataset can also be biased spatially by local areas of interest and boundaries between map sheets reflecting individual field geologist's knowledge and interpretation.

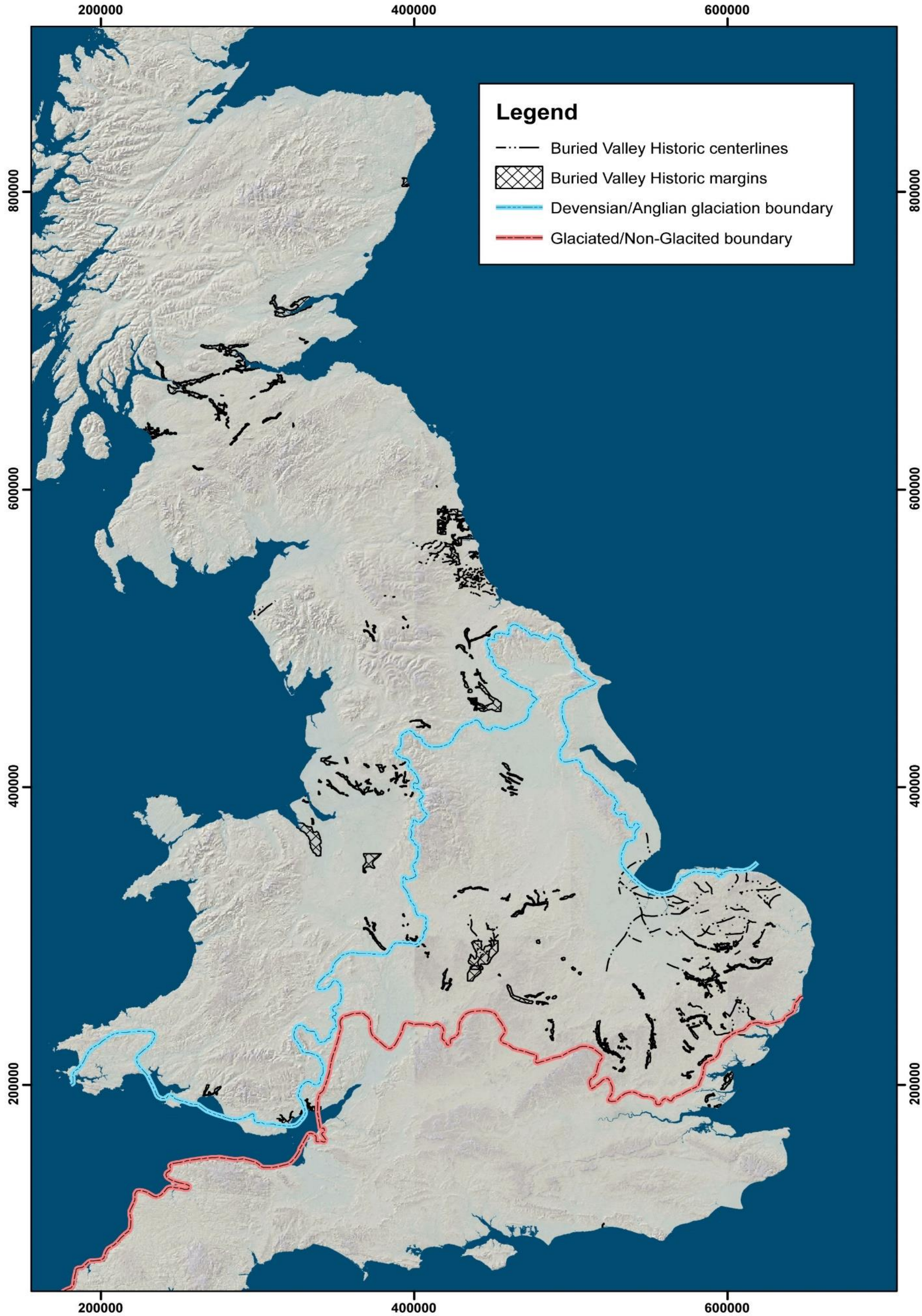

Figure 7. Historical dataset contains interpretations of buried valleys from 96 different publications. The glacial limits are from Booth *et al.* (2012, 2015). Contains Ordnance Survey Data © Crown Copyright and database rights 2019. Ordnance Survey Licence no. 100021290 and NEXTMap Britain elevation data from Intermap Technologies. Created using ArcGIS. Copyright © Esri.

3.2 MODELLED THICKNESS OF BURIED VALLEYS

Many of the buried valleys from the historical dataset correspond to linear features identified as areas of significant superficial thickening created from the boreholes dataset (Figure 8). In areas which include Newcastle, Northallerton, Liverpool and Manchester there is better apparent definition of the shape and depth of these features than is seen within the historical dataset. However, in upland areas, above 200 m O.D. (Ordnance Datum), there are an insufficient number of boreholes for the algorithms used to be able to identify buried valleys.

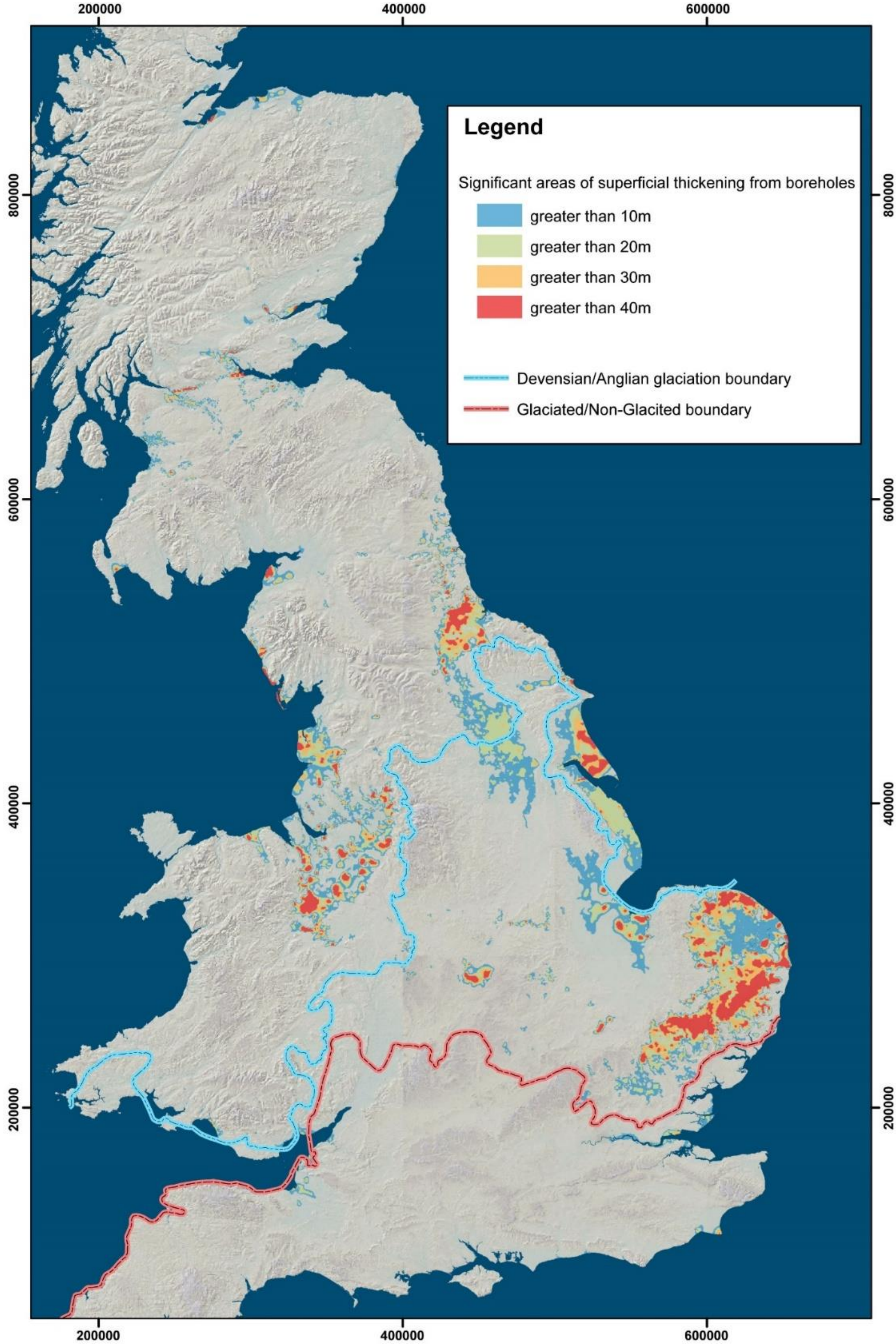

Figure 8. Modelled thickness of buried valleys interpolated from boreholes. The glacial limits are from Booth *et al.* (2012). Contains Ordnance Survey Data © Crown Copyright and database rights 2019. Ordnance Survey Licence no. 100021290 and NEXTMap Britain elevation data from Intermap Technologies. Created using ArcGIS. Copyright © Esri.

The borehole method also picks out larger non-linear areas of thickened superficial deposits which correspond to major Plio-Pleistocene basins. The most extensive of which occurs in East Anglia and corresponds to the Crag Basin. The Crag Basin was a major depositional centre between the Pliocene and early Middle Pleistocene forming a western extension of the Southern North Sea Basin (Rose et al., 2001). It was drained into by several extensive river systems that drained central and eastern England with deposits of the Crag (marine) and Dunwich (fluvial) groups now considered to be 'superficial' deposits (McMillan et al., 2011 and McMillan & Merritt, 2012). Several other non-linear areas of thickened superficial deposits also occur including the Cheshire Basin, Vale of York and Vale of Pickering. These correspond to areas that were either glaciated or lay adjacent to the margins of the Late Devensian glaciation and formed extensive ice dammed or proglacial lake basins (Clark *et al.*, 2018).

BGS's digital borehole database contains many old or ambiguous boreholes in which the identification of the top of bedrock is ambiguous (Lawley and Garcia-Bajo 2009). The screening process, described in Section 2.2, removes features that were not centred on more than 5 boreholes which contain 20 m or more of superficial deposits (Figure 9). This process was necessary to remove bull's eyes in the dataset around isolated boreholes. Some of these deleted polygons are drumlins or areas of weathered bedrock, although, in low borehole density areas it may also remove single borehole that might indicate the presence of a buried valley. This issue is further compounded by the fact that commonly, geotechnical boreholes are terminated short of bedrock if the surface is not intersected within 20–30 m of the ground surface. So the centre of deep buried valleys may not be penetrated by boreholes. In the future as the BGS's digital borehole database increases it may be possible to improve the resolution of this dataset and identify more buried valley features.

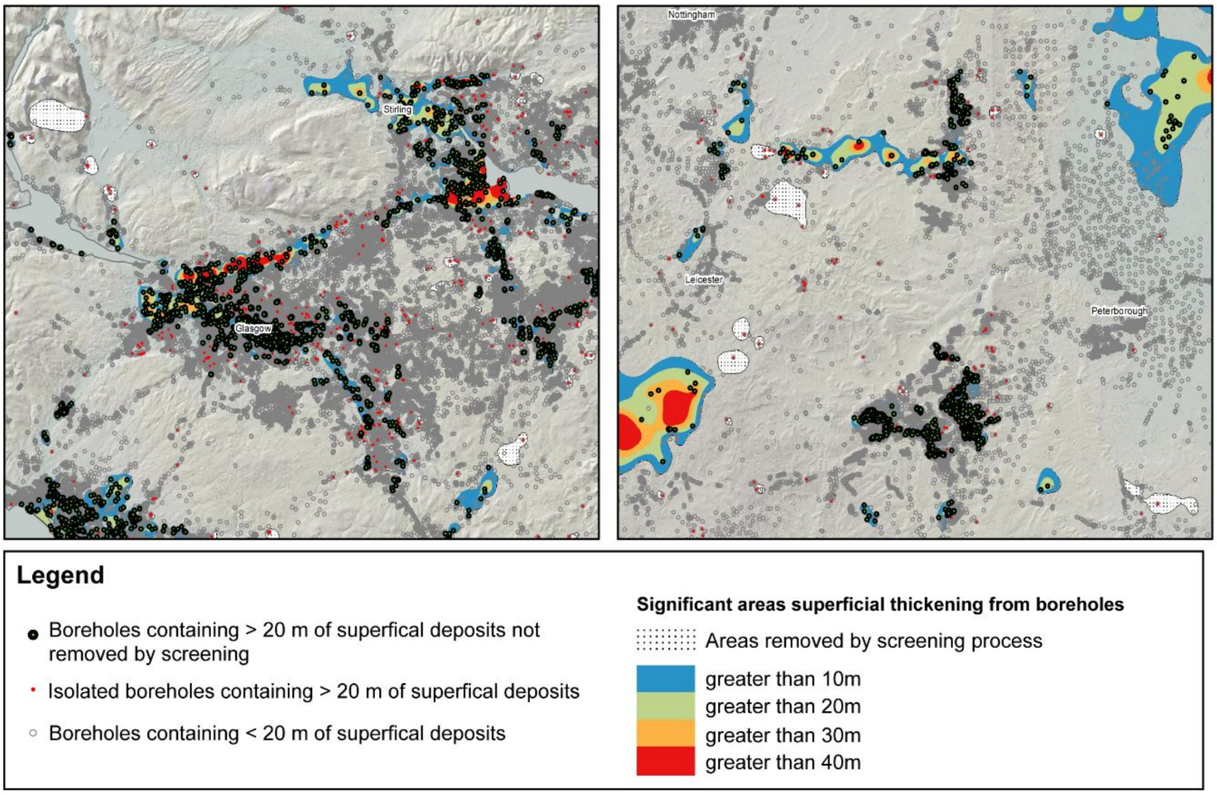

Figure 9. The results of the screening process of the Modelled thickness of buried valleys dataset. Contains Ordnance Survey Data © Crown Copyright and database rights 2018. Ordnance Survey Licence no. 100021290 and NEXTMap Britain elevation data from Intermap Technologies. Created using ArcGIS. Copyright © Esri.

4 Discussion

Buried valleys, by their nature, have little or no surface expression in the landscape. This means that they are extremely hard to map in the subsurface without the use of airborne geophysics (e.g. Sandersen & Jørgensen 2003). Such data is not available nationwide across the Great Britain but its use in Denmark has revolutionised understanding of the sub-drift rockhead surface (Høyer et al., 2011, 2015) and in-turn the management of water resources (Viezzou et al., 2013; Vilhelmsen et al., 2018). The results presented here represent the best current understanding of where such features may occur onshore based principally upon borehole records.

However, it should be noted there are almost certainly buried valleys that have not been identified as part of this dataset especially in areas of limited borehole coverage. The dataset should only be used to indicate where there is evidence that a buried valley may be present. Absence of evidence does not equal evidence of absence. Also, because many of the references used in this dataset were figures from reports and papers, we recommend that the data set has a nominal scale of 1:250 000. If a buried valley appears in the historical datasets (Figure 7) and the modelled thickness of buried valleys interpolated from boreholes (Figure 8) the feature is more likely to exist.

Depth information for a feature can be derived from the modelled thickness of buried valleys contour dataset, but the depth of those features greater than 40 m are combined in to one depth category which ranges from 40-162 m. These depths were combined due to relatively low numbers of boreholes that prove over 40 m of superficial deposits. Higher resolution contouring of such low-resolution data typically introduces 'bulls eye' artefacts into the dataset. This can be misleading to the user by implying a geometry to the buried valley that is not real.

Equally, as stated previously in Section 3.2, the areas of significant thickening derived from the boreholes dataset also incorporates basinal areas such as the Crag Basin and former glacial lake basins. These feature may obscure the presence of more subtle linear buried valleys.

The Buried Valley dataset described here represents a baseline of BGS' current understanding of the locations of buried valleys onshore in the Great Britain based on our currently held historical literature and borehole data. It is inevitable that some of the information may be in the light of further evidence be deemed incorrect, and require rejecting or revising. This dataset will form the basis of future research in to these features and be periodically updated to include new information becomes available.

If you have evidence of a buried valley that is not part of this dataset we would be very interested to evaluate it and consider including in future versions. Please email enquiries@bgs.ac.uk

5 Technical Information

5.1 DATA DESCRIPTION

The buried valley dataset is provided in three GIS format (ESRI shapefiles) layers. For ease of use the layers should be displayed in the following order:

- Buried Valley Historic centrelines
- Buried Valley Historic margins
- Modelled Thickness of Buried Valleys

5.2 SCALE

The buried valley dataset is produced for use at 1:250 000 scale providing 250 m ground resolution.

5.3 FIELD DESCRIPTIONS

Each buried valley theme (GIS map layer) contains a series of attribute fields specific to the data they contain for example the historic buried valleys include a reference field describing the data source.

Table 1 Attribute table field descriptions for Buried Valley Historic centrelines and Buried Valley Historic margins.

FIELD NAME	FIELD TYPE	DESCRIPTION
REFERENCE	Text	The reference from which the data was drawn from
FEATURE	Text	The name of the dataset: e.g. Buried Valley Historic centrelines
SCALE	Text	The scale used to prepare the digital data: e.g. 250000 for 1:250 000
VERSION	Text	Version number and attribute level of the digital data: e.g. v1.0

Table 2 Attribute table field descriptions for Modelled thickness of Buried Valleys from boreholes themes

FIELD NAME	FIELD TYPE	DESCRIPTION
FEATURE	Text	The name of the dataset: e.g. Buried Valley Historic centrelines
THICKNESS	Text	Thickness of superficial deposits based on a computer interpolation
SCALE	Text	The scale used to prepare the digital data: e.g. 625000 for 1:625 000
VERSION	Text	Version number and attribute level of the digital data: e.g. v1.0

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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://envirolib.apps.nerc.ac.uk/olibcgi.

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Appendix 1

The table below lists all the references used in the historical dataset.

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BGS, 1969, NZ35NE, Geological Survey of England and Wales 1:10,000 geological standard	Margin
BGS, 1969, Towcester, sheet 202, Solid and Drift. Geological Survey of England and Wales, 1:50,000 geological map series	Margin
BGS, 1970, Chelmsford, sheet 241, Solid and Drift. Geological Survey of England and Wales, 1:50,000 geological map series	Margin
BGS, 1970, SP83NE, Geological Survey of England and Wales 1:10,000 geological standard	Margin
BGS, 1970, SP83NW, Geological Survey of England and Wales 1:10,000 geological standard	Margin
BGS, 1970, SP83SE, Geological Survey of England and Wales 1:10,000 geological standard	Margin
BGS, 1976 TG20NE, Geological Survey of England and Wales 1:10,000 geological standard	Margin
BGS, 1980, Northampton, sheet 185, Solid and Drift. Geological Survey of England and Wales, 1:50,000 geological map series	Margin
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