New Approaches to Mapping and Managing Palaeochannel Resources in the Light of Future Environmental Change: A Case Study from the Trent Valley, UK

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ABSTRACT

Abandoned river channels may provide rich primary sources of palaeoenvironmental and cultural information elucidating landscape evolution, climate change, vegetation history and human impact, especially since the beginning of the Holocene epoch. However, although potentially an important resource, palaeochannels are not often recorded systematically and only rarely enjoy robust statutory protection (in the UK as Sites of Special Scientific Interest). In consequence, it is challenging to mitigate and manage this important geoarchaeological resource effectively within the UK planning framework. Whilst palaeochannels have long been recognized on aerial photographs and historic maps, the advent of airborne laser scanning and other remote-sensing technologies has provided a hitherto unforeseen opportunity to record such landforms and related features at a catchment scale. This paper provides a case study from the Nottinghamshire reach of the Trent Valley, where a desk-based methodology that is now being extended across the entire catchment has been developed for recording, geospatially locating and defining the attributes of observed palaeochannels. After outlining the methodology, we consider how this approach to resource management can aid archaeological research and future heritage management, especially in the light of predicted climate and environmental change.

Introduction

The planform morphology and dimensions of relict river channels (palaeochannels) preserved in contemporary and former floodplains around the globe have long provided geoarchaeologists with evidence for past river evolution and former hydrological conditions, knowledge of which they have dovetailed with the archaeological record [1,2,3]. These abandoned channels act as natural sediment traps and, within the temperate zone, where water tables have been historically high, many preserve organic-rich palaeobiological remains such as pollen, insect and plant material capable of providing high-resolution proxy records of climate, vegetation and land-use[4]. Furthermore, since earliest prehistory riparian corridors have provided rich food resources, materials for construction and pathways through the landscape, while in later prehistory they acted as conduits for the trade and exchange of goods and as funerary and ritual foci. Therefore, as well as containing natural palaeoenvironmental information, palaeochannels and adjacent floodplains can often preserve significant cultural remains such as timber platforms, brushwood trackways[5], bridges[6], log boats[7], as well as human and animal remains[8] and semi-precious metalwork[9]. Furthermore, associated natural organic-rich remains and ecofacts provide opportunities to establish high-resolution

geochronologies using radiocarbon dating and dendrochronology, whilst optically-stimulated luminescence can be applied to inorganic sands and silts[10].

However, despite their significant environmental and cultural potential and ubiquity, palaeochannels are rarely protected or considered as independent archaeological entities in the UK planning process. Where they are robustly protected through statutory legislation, for example as Sites of Special Scientific Interest (SSSI), this can be on the basis of their geomorphology (for example, the River Dane, at Swettenham, Cheshire; Geological Conservation Review number 2945). More often, however, palaeochannels are robustly protected for reasons of their biodiversity value (for example, Ashmoor Common SSSI, near Clifton, River Severn; Geological Conservation Review number 2866). In the short and long term, the lack of understanding of a catchment's palaeochannel resource is ultimately detrimental to the understanding of the wider archaeological record and landscape development. Furthermore, where palaeochannels are identified and examined as part of archaeological mitigation, this is usually conducted on a site by site basis rather than by considering the potential of individual features at a reach- or catchment-scale. Systematically mapping and characterising palaeochannels across a wider landscape provides opportunities to reflect critically on the value of individual features and to create rigorous management frameworks for such resources. This is important not only for assessing the impacts of development on palaeochannels as heritage assets, but also for contextualising and mitigating the effects of future climatic and environmental change[11].

The River Trent is notable amongst British lowland river systems for the high channel mobility it has exhibited throughout the majority of the Holocene. This has led, in turn, to the abandonment and preservation of numerous palaeochannels across its postglacial floodplain as well as significant archaeological remains beneath and within the alluvium[12]. In 1998, Nottinghamshire County Council provided funding for a pilot study to map the palaeochannel resource of the county using a variety of vertical aerial photographs, identifying as a result 253 discrete channels[13]. In 2003, this aerial photograph survey was extended across the counties of Derbyshire, Leicestershire, Lincolnshire, North Lincolnshire and Staffordshire, as part of a *Trent Valley GeoArchaeology project* funded under the auspices of the *Aggregates Levy Sustainability Fund* (ALSF)[14,15]. Whilst these studies provide benchmark datasets, advances in remote-sensing technologies in the last two decades, particularly lidar collected by the Environment Agency, provide significant opportunities for a higher resolution review of the entire Trent Catchment. In 2014, Historic England agreed to fund a further stage of work focusing principally upon the evidence provided by lidar, augmented by aerial photography and historic mapping[16] (Table 1). This paper provides an insight into this project, its methodology and preliminary results in Nottinghamshire, before exploring the broader significance of the project in terms of managing vulnerable archaeological resources.

Methodology

It is beyond the scope of this paper to provide an in-depth review of lidar, but exemplars of its application can be found in numerous papers[17, 18, 19, 20, 21].

The project aimed to identify, map and catalogue all palaeochannels as a series of shapefiles using QGIS (version 2.6), which could be delivered to the appropriate Historic Environment Record (HER). The palaeochannels mapped previously[22,23] were also digitised for comparison with the new datasets.

This first phase of the project covered the main valley floor and tributary valleys of Nottinghamshire, extending over a total area of 2160km^2 (Figure 1). Within Nottinghamshire, the main valley floor itself covers a stretch of approximately 80km and an overall area of 239km^2.

The initial study of Malone[24] identified palaeochannels from a number of discrete features observed in aerial photographs, including sinuous hedge lines and field boundaries, areas of standing water and soil marks, and was further adapted by Baker[25]. For the present study, several extra categories of feature were added, reflecting the enhanced resolution of data provided by lidar imagery (Table 2).

Lidar digital surface model (DSM) data was downloaded from the Environment Agency website (www.geomatics-group.co.uk). 2m resolution scanning data was available across the entire county but, where available, higher-resolution (1m) data was analysed in preference. The data was processed using SAGA (System for Automated Geoscientific Analysis): an open-source GIS programme (www.saga-gis.org). It was processed in multiple tiles, with parameters adjusted for areas no larger than 2,500 hectares. These tiles were exported as GeoTiffs using a graduated colour spectrum, and all hill-shaded data was exported using a grey-scale spectrum. These two lidar outputs were overlain and compared during palaeochannel identification and categorisation in QGIS.

Building upon the analyses of aerial photographs undertaken previously[26,27], this project aimed to review all county-held aerial photography taken since 2000. This dataset proved to be a very limited resource and it was decided to focus efforts instead upon the open-source Google Earth online database (https://www.google.co.uk/earth/) which had been compiled within the study area between 1999 and 2012. Within this timeframe, every available image was considered and assessed, as different land-use practices and weather conditions at the time of image collection can affect the visibility of soil- and cropmark features. Once identified, each visible palaeochannel feature was traced using the 'Add polygon' function in Google Earth and imported into QGIS as a separate KML file.

The final dataset that was used to assess the palaeochannel record was the archive of Ordnance Survey (OS) 1st edition six inch maps that is available freely in the database of the National Library of Scotland (www.nls.org.uk). This internet GIS tool permits the user to superimpose transparent historic maps over Google Earth imagery, allowing a direct comparison between past and present channels. As it used Google Earth data, the shapes of the maps recorded on the National Library of Scotland mapping system were recorded in Google Earth polygons and were exported to QGIS as KML files.

Using QGIS, the raster lidar and hill-shade data were analysed visually, and all identified palaeochannels were drawn in polygon shape files. The KML files produced during the analysis of historic maps and aerial photography were loaded into the same GIS file. The shape files were numbered sequentially and classified by reference to the descriptive variables defined in Table 2; unlike earlier palaeochannel mapping projects, channels in this study could be defined on the basis of multiple categories instead of just one.

Within the attribute database, the primary source for each feature was described (lidar, aerial photograph or historic mapping) together with details of other information such as palaeoenvironmental potential and age. Such additional information is currently lacking for the

majority of features, but the database has been designed so that it can be updated as new data are generated.

Whilst creating polygons of individual features has been a relatively straightforward process, the size of the dataset created challenges. Cataloguing features sequentially throughout the entire catchment created a large and virtually unusable database; organising them by tributary was relatively more manageable, although in some smaller systems less than 10 palaeochannels were recorded. As a compromise solution, therefore, the final palaeochannel resource product is organised by 10km grid square, permitting palaeochannels to be downloaded in a similar fashion to Ordnance Survey mapping and lidar data tiles.

Results

The 1998 survey of the Nottinghamshire valley floor using aerial photography produced 258 individual entries[28]. The Nottinghamshire shapefile includes the location of 896 shapefiles of palaeochannels across the main valley floor, with a total of 2,655 shapefiles across the entire county.

In the main valley floor, most of the palaeochannels were identified as depressions in the land surface, indicating the abandonment of channels in favour of another course without complete siltation of the channel (categories 1 and 2, Table 2). While this is the most common palaeochannel type, this does vary across the county. For example, near Littleborough in the lower Trent (Figure 2), palaeochannel depressions coincide closely with contemporary narrow channels, sometimes also marked by a sinuous hedgerow (categories 5 and 8, Table 2), indicating their continued natural use or reuse for land drainage; in the latter case, cleaning of the feature may have impacted on its palaeoenvironmental potential. Further upstream, particularly south of Nottingham, there are fewer palaeochannel features, but those present are often intimately and complexly associated with ridge and furrow earthworks. In some instances, it is possible to determine the progression and to provide relative dates for these landforms and earthworks; for example, in some cases ridge and furrow is recorded overlying or truncated by palaeochannels, whilst elsewhere the ridge and furrow has been realigned and reinstated after a palaeochannel has cut through it. In the tributary valley of the River Derwent around Little Eaton, similar patterns have been observed and it has been suggested tentatively that significant erosion of ridge and furrow was associated with enhanced fluvial activity during the Little Ice Age[29]; this argument, however, has yet to be corroborated by absolute dating.

Mapping of palaeochannels has also drawn attention to the close relationship of these landforms to the many gravel 'islands' of the main valley floor, formed by isolated remnants of late Pleistocene terrace (the Holme Pierrepont Sand and Gravel). Many of these landforms provide foci for contemporary settlements (Figure 3). This is a pattern that extends back in the archaeological record to the earliest postglacial hunter-gatherers, and this juxtaposition of wetland and dryland environments affords significant opportunities for palaeoenvironmental reconstruction.

Within the tributary valleys of Nottinghamshire, generally fewer palaeochannels have been recorded, reflecting their relatively narrow floodplains which lack accommodation space for both channel migration and preservation. Where valley sections expand, palaeochannels become more prevalent, but they are often narrow, mirroring the size of the postglacial streams in those areas. Occasionally, relict channels within tributaries can be traced to farmsteads, indicating that they may

have formed components of mill systems. Whilst the tributaries themselves may lack ubiquitous palaeochannels, complex patterns are recorded at their confluences with the main river: for example, around the Erewash and Soar confluences with the Trent. Often these patterns are made more prominent by ridge and swale topography (category 7, Table 2).

Whilst the study area is largely rural, both the main river and its tributaries also flow through urbanised areas such as the City of Nottingham, and this provides an additional challenge for palaeochannel identification. The DSM does not prove particularly helpful in these instances since, even by stripping the buildings away, the viewer is left with a landsurface that is artificial 'made ground'. For this reason, few palaeochannels were identified in urban areas, although a notable example is the one which was adapted (in part) to form the Nottingham and Beeston Canal through Nottingham.

In areas where two or more datasets were used, lidar generally revealed the highest number of palaeochannels. However aerial photographs and historic mapping added a few features that were not identifiable through topography and occasionally provided historic dating and context. Quarrying has long been a notable feature of the main Trent Valley and a number of its tributaries, especially since the early 1930s and the introduction from the USA of ready-mixed concrete technologies[30]. In these mineral extraction zones, the analysis of multiple datasets proved particularly useful since historic maps often provided the only evidence for palaeochannels. In other quarried areas, aerial photographs from the early 2000s showed sites prior to extraction, while lidar data taken after quarrying provided a record of the palaeochannels that have been destroyed or occasionally preserved in quarry environments. However, if preserved, these features may be impacted by associated dewatering activities[31,32].

Prior to this study, it was recognised that some of the identified features would have been the subject of geoarchaeological investigations, providing additional information on the landform: for example, radiocarbon dates defining chronologies and palaeoecological data characterising palaeoenvironments. Although not part of the scope of this project, this information was noted in the GIS database where known, although the number of such additional records is very small (<1%). A future aim is to enhance this database as opportunities arise, especially as part of the mitigation process.

Significance of this Work

Palaeochannels have the potential to preserve significant cultural and palaeoenvironmental archives capable of elucidating climate, vegetation and land-use histories, and may also incorporate important interstratified cultural and ecofactual remains. They are, however, at significant risk of direct destruction from developments such as quarrying and indirectly as a result of dewatering. To date, their statutory protection within the UK planning framework has been limited and consideration of palaeochannel assets in the archaeological mitigation process is generally on an *ad hoc* basis. The mapping of palaeochannels at the county scale, as described in this paper (and ultimately at the catchment scale), provides the potential for these geoarchaeological and palaeoenvironmental resources to be considered either singularly or as part of a wider range of features; this will permit the development of a strategic framework for their management and for further research. To the knowledge of the authors, this is the first time such a large-scale mapping exercise combining lidar, aerial photography and historic mapping has been conducted in the UK,

certainly within the framework of the historic environment planning process. Large-scale palaeochannel mapping exercises have been undertaken elsewhere, notably in the Rhine-Meuse delta of the Netherlands, but such work has been driven primarily by the academic geomorphological research community[33,34].

In addition to the threats associated with development and water resource exploitation, future environmental change associated with climate change may also impact on the long-term preservation of these resources in valley floors[35,36]. However, not all changes might be negative, and there may be positive benefits. In particular, the need to create washlands to store water during extreme floods and in response to sea level rise may well lead to an expansion of wetlands, although this might impede the future investigation of some palaeochannel resources.

Conclusions

The methodology described here, which has been developed for the construction of the Nottinghamshire palaeochannel database, provides a valuable tool for management of these important heritage assets and for the development of research and mitigation strategies. The database can be consulted from the desk-based assessment stage of any project and used without the expertise required to manipulate raw lidar data.

It is clear from the results of this project that lidar is a particularly effective tool for identifying and mapping palaeochannels, although there are limitations to its use that should not be understated. Fine-grained alluvial, colluvial or aeolian deposits, for example, can blanket palaeochannels, while ploughing can also smooth out topography. Neither lidar nor any other single dataset can provide evidence for all extant palaeochannels, but this project has demonstrated how a combination of remotely-sensed image analysis, combined with other low-cost desk-based methodologies, can map a high percentage of the palaeochannels without the need for intrusive ground investigations.

The free use of lidar for research purposes, combined with the analysis of historic map and aerial photographic data, has increased the number of known and formally recorded palaeochannels in the Nottinghamshire Trent Valley by over 300%. Widespread use of the database will allow developer-funded archaeologists to obtain insights into floodplain landscapes prior to ground investigations without the necessity for additional desk-based analyses. Multiple research projects will also benefit from the large-scale database, which provides the opportunity to address questions on either a site-based or landscape scale. The Trent catchment thus provides clear evidence of the potential of palaeochannel mapping using current technologies, and it is hoped that the trials of multiple methodologies identified here and the potential outputs will encourage the production of similar databases both nationally and internationally.

Notes

1. Brown et al., "Late Holocene channel changes."

2. Bunbury et al., "Stratigraphic landscape analysis".

3. Bogemans et al., "The evolution of the sedimentary environment".

4. Parker et al., "Late Holocene geoarchaeological investigation."

5. Gearey et al., *Down by the river*.

6. Ripper and Cooper, *The Hemington Bridges*.

7. Howard et al., "Assessing riverine threats to heritage assets."

8. Ripper and Beamish, "Burnt mounds and bog bodies."

9. Mullin, "The river has never divided us."

10. Brown et al. See note 1 above.

11. Lewin, "The English floodplain."

12. Knight and Howard, *Trent Valley Landscapes*.

13. Malone, *Geomorphology from aerial photography*.

14. Baker, *The Trent Valley*.

15. Baker, "The palaeochannel record of the Trent Valley."

16. Knight et al., *Enhancing the palaeochannel database*.

17. Challis, "Airborne laser altimetry."

18. Bewley et al., "New light on an ancient landscape."

19. Jones et al., "High resolution interpretive geomorphological mapping."

20. Crutchley and Crow, *The Light Fantastic*.

21. Bennett et al., "Airborne spectral imagery."

22. See note 13 above.

23. See note 14 above.

24. See note 13 above.

25. See note 14 above.

26. See note 13 above.

27. See note 14 above.

28. See note 13 above.

29. See note 7 above.

30. Cooper, *Laying the Foundations*.

31. French, "Hydrological monitoring of an alluvial landscape."

32. French, "Over, Cambridgeshire".

33. Berendsen and Volleberg, "New prospecting in geomorphological and geological mapping."

34. Berendsen et al., "The use of GIS."

35. Howard et al., "The impact of climate change".

36. Macklin and Lewin, "Alluvial responses to the changing Earth system."

Notes on contributors

Dr Samantha Stein joined Trent & Peak Archaeology in 2014 as geoarchaeologist after completing her PhD on the landscape and geoarchaeology of the Viking overwintering camp at Torksey in the Trent Valley. Her geoarchaeological interests across the Midlands and the North includes micromorphology, sediment analyses, deposit modelling, and innovative ways of applying optically stimulated luminescence dating to archaeological contexts.

Dr David Knight is Head of Research at Trent & Peak Archaeology and has over 27 years experience of working in the East Midlands. He is particularly interested in the later Bronze and Iron Ages, the archaeology and landscape of the Trent Valley and prehistoric ceramics.

Dr Steve Malone has over 25 years experience as a field archaeologist, project manager and consultant on projects throughout the East Midlands and East of England. He has a particular research interest in the use of Lidar data for landscape and archaeological research.

Dr Andy J. Howard was a Senior Lecturer for over a decade at the University of Birmingham before the closure of the Institute of Archaeology & Antiquity in 2013. He now runs his own landscape research consultancy as well as holding a Honorary Fellowship within the Department of Archaeology at the University of Durham.

Dr Chris Carey gained a PhD in archaeometallurgy from the University of Exeter and is now a Senior Lecturer in Geoarchaeology within the Department of Environment and Technology at the University of Brighton.

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List of Figures

Fig 1. Map of the palaeochannel resource for the Nottinghamshire reach of the Trent Valley. The locations of Figures 2 and 3 are shown and palaeochannels are identified by the orange-brown colours on the map. Contains Ordnance Survey data © Crown Copyright and database right 2017.

Figure 2. Lidar image of palaeochannels (shown in grey) mapped in the vicinity of Littleborough on Trent, Nottinghamshire. Not the large meander loop fed by a network of smaller channels. This image illustrates the changes in morphology of palaeochannels on the 1st Terrace to palaeochannels on the present floodplain. The example of the settlement of Littleborough, in the north east part of this image, also demonstrates how flooding, palaeochannel, and drainage formation has shaped earlier and later settlement patterns. The island itself has two tiers, with all post-Roman (including present) settlement corresponding to the higher part of the island, and a larger Roman settlement of *Segelocvm* situated on the lower part of the island. Settlement changes are hypothesized to have occurred during periods of climate change resulting in the flooding of the lower part of the island, and creation of further drainage channels relating to palaeochannels.

Figure 3. Lidar image of palaeochannels mapped in the vicinity of Barton-in-Fabis, Nottinghamshire. The gravel island upon which the village of Barton-in-Fabis is situated is slightly raised above the floodplain, and is emphasised by the surrounding palaeochannels. This example illustrates the close relationship between areas of habitation and the formation of palaeochannels Ridge and swale topography, illustrating past migration of the River Trent, is also clearly seen.
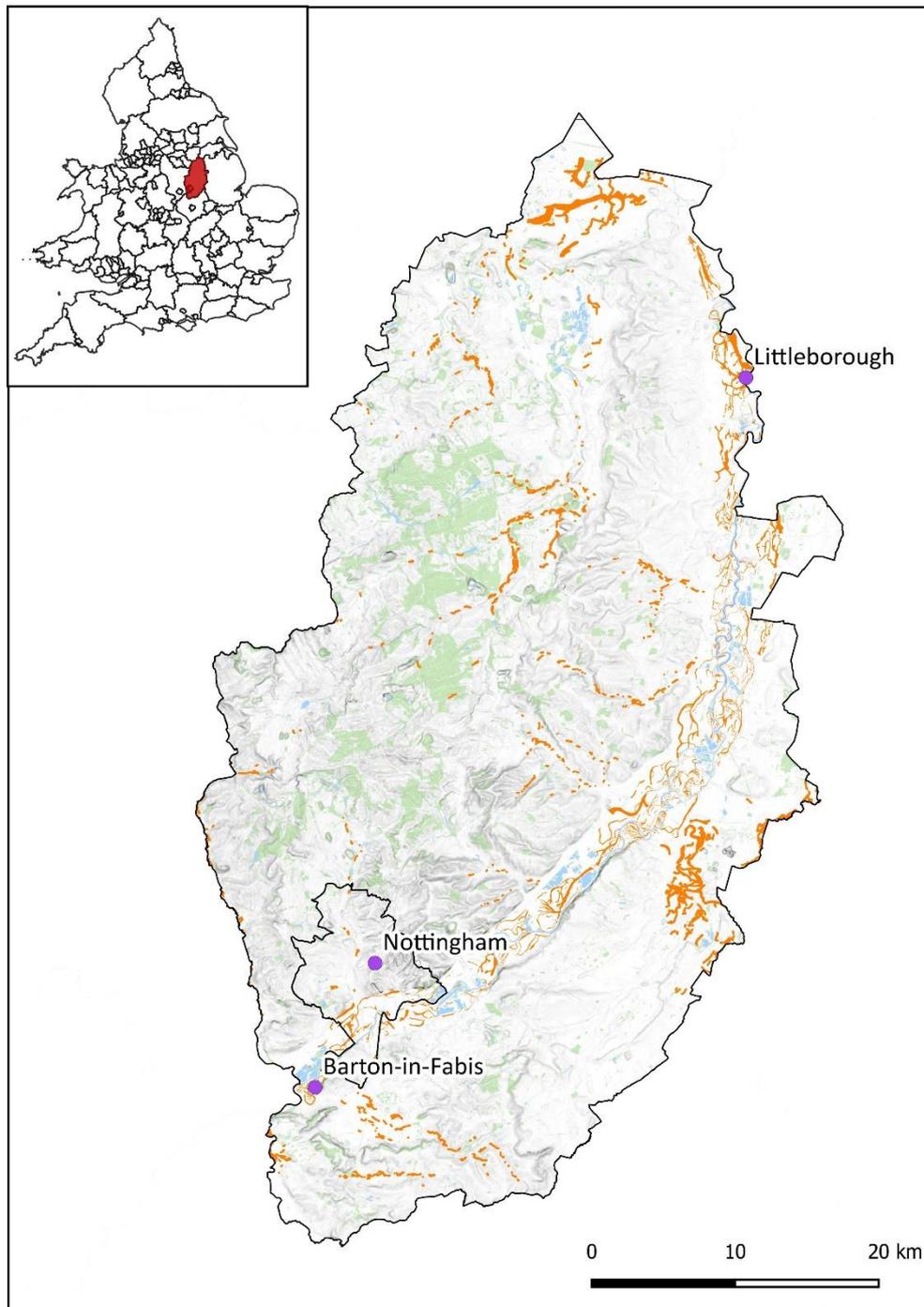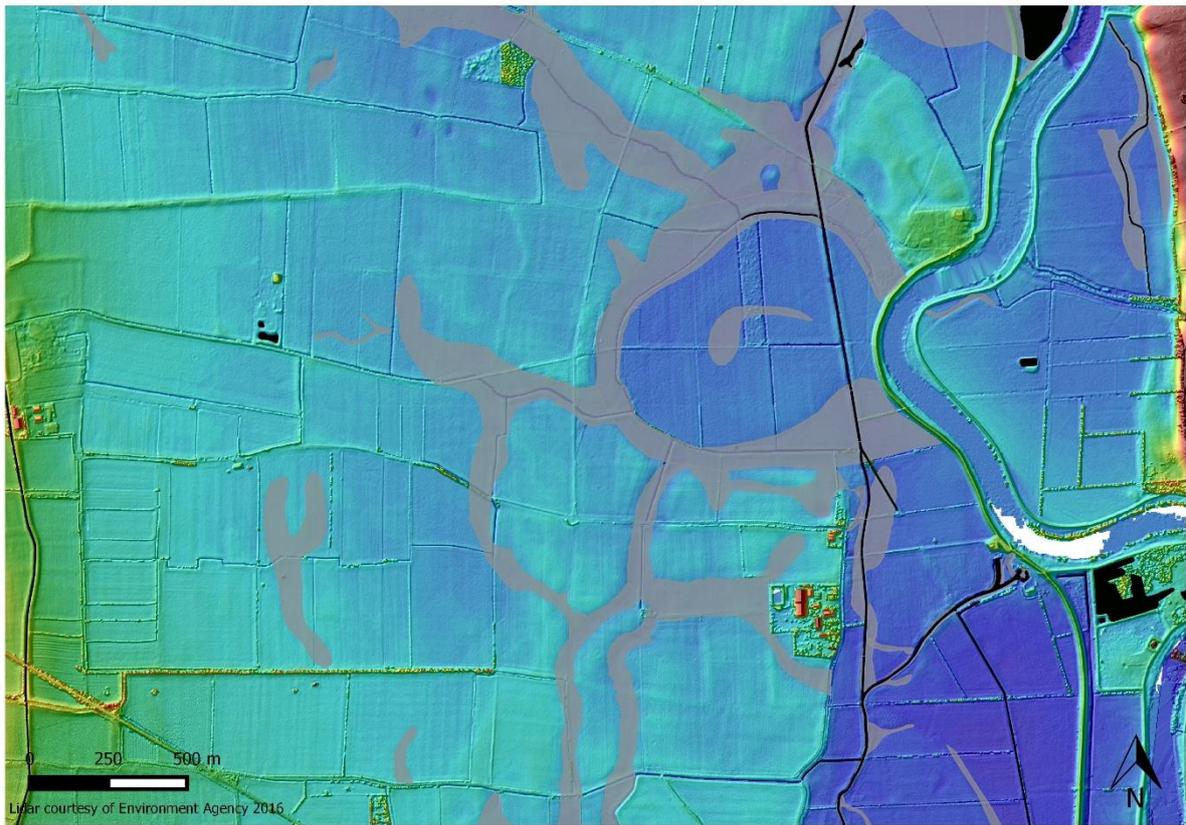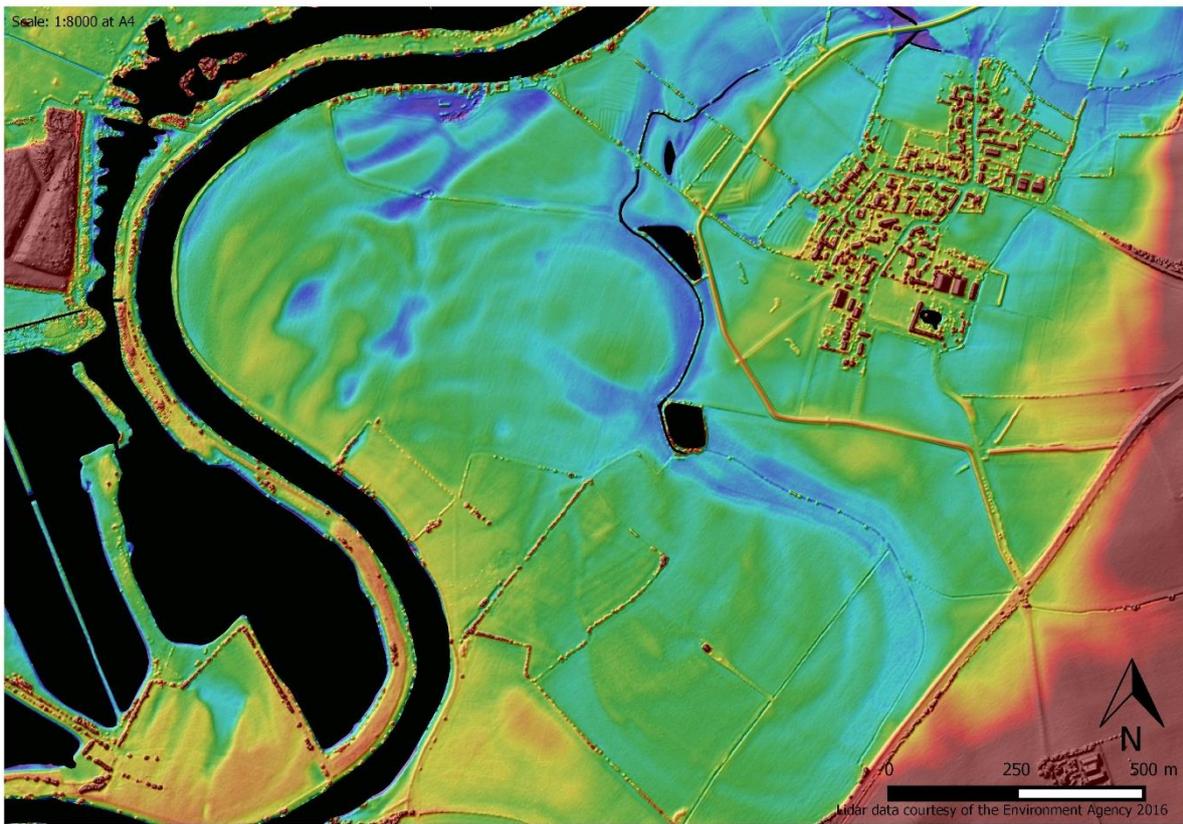
Figure 1

Figure 2

Lidar courtesy of Environment Agency 2016

Figure 3

Table 1. Data sources employed during the present study.

Data type	Source	Use
LiDAR	Environment Agency	Construction of natural landscape DTM for creation of geo-referenced file and catalogue of visible palaeochannels
Post-2000 aerial photography	Google Earth	Creation of geo-referenced file and catalogue of visible palaeochannels
Historic mapping	National Library of Scotland	Identification of historic palaeochannels and creation of these historic channels.

Table 2. Parameters used to identify palaeochannels (based upon Malone [1998] and Baker [2003], with the addition of Categories 8 and 9 as part of the most recent project described here).

Number on polygon shape file	Manifestation of palaeochannel
1	Standing water
2	Depression
3	Crop/soil moisture
4	Vegetation
5	Field boundary/hedgerow
6	Parish boundary
7	Ridge and swale
8	Drainage channel
9	Raised feature