SOUTH LINCOLNSHIRE FENLAND LIDAR (SLLP09)

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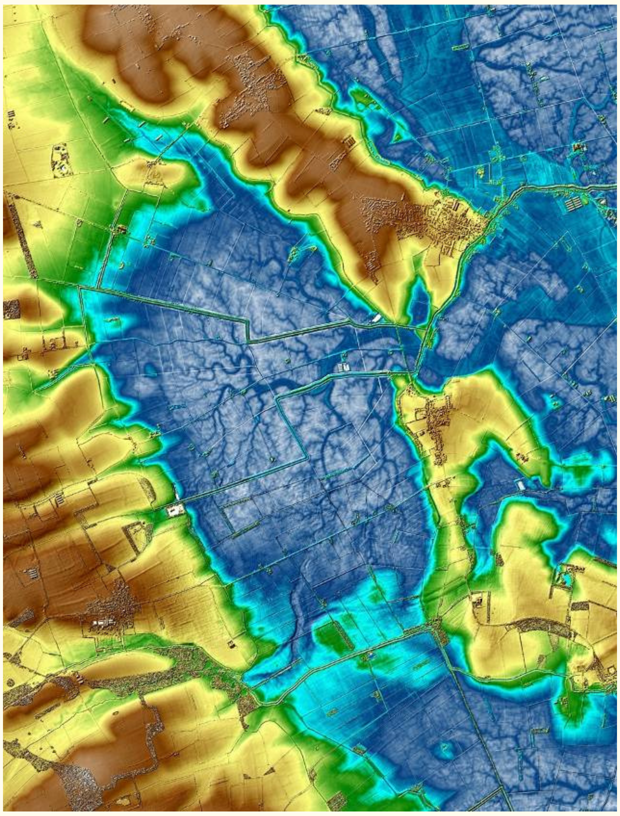

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South Lincolnshire Fenland Lidar

CONTENTS

List of Figures

1 Summary

The Environment Agency has undertaken extensive Lidar survey within the Lincolnshire Fenland. Previous work by APS using Lidar in the Witham Valley has demonstrated the potential of this data for understanding the palaeo-environment and archaeology of the Lincolnshire Fenland when processed to enhance the very small topographic variations within these low-lying landscapes.

The current project, funded by English Heritage, has expanded the areas thus treated to include the south Lincolnshire fenland. The final processed dataset comprises all of the EA data currently available for the Lincolnshire fens, covering 2025km^2 *and comprising in excess of 500 million data points.*

The project has been successful in its principal aim of producing a processed dataset which will be more readily accessible through the HER and provide a tool for planning archaeologists both at county and district level.

The processed data-set will contribute widely to the study of the archaeology of the Fenland, but in many ways the greatest advance here is in illuminating the landscape context of sites and monuments where no other source of information can provide such detail over such a large area.

2 Introduction

2.1 Description of the Project

2.1.1 Lidar survey has significant potential for landscape study in the Lincolnshire Fenland. The Environment Agency Lidar dataset for the area represents an enormous potential resource. Although lodged with the HER this dataset is not easily available to researchers without specialist knowledge of processing. The northern part of the Fenland has already been processed (by Heritage Trust of Lincolnshire at our expense). The aim of this project is to see the southern Lincolnshire Fenland (broadly on a line from the village of Swaton in the west [TF10/40] across through Kirton to that coast at TF 40/40) brought up to the same standard using the same methodology. The processed data has been output as georeferenced imagery which will allow wider and easier access to the data and its understanding and interpretation. The chief archaeological aim of the Project is to enable accurate predictive modelling for the locations of sites partially or wholly buried under flood silts of post Roman date and to record an environmental and landscape context for all sites in the Fenland.

2.2 Background

2.2.1 Detailed descriptions of Airborne Laser Altimetry, more often referred to as Lidar (for Light Detection and Ranging) are available in existing studies (Challis 2004; Bewley *et al.* 2005). Lidar uses the properties of coherent laser light, coupled with precise spatial positioning (through the use of a Differential GPS) to produce horizontally and vertically accurate elevation measurements. This data has considerable potential for archaeological research in terms of mapping archaeological sites where features survive as upstanding earthworks, for identifying depressions where organic sediments may be preserved and more generally for providing landscape context in areas of very low relief where existing topographic mapping lacks detail. Within the marginal landscapes of the Lincolnshire fenland this topographic context is crucial to the understanding of past human use of the landscape and Lidar survey provides unprecedented detail of this subtle topography.

1.2.2 The Environment Agency (EA) has undertaken extensive areas of Lidar survey in coastal zones and river valleys for the purposes of flood risk management. Heritage Trust of Lincolnshire has established expertise in working with EA data provided through the Witham Valley Archaeological Research Committee (WVARC) which has demonstrated the potential for the use of this data in mapping the landscape of the Fens (Malone forthcoming; UKAS07; CAA08; AARG08). The initial dataset made available to WVARC concentrated on the course of the River Witham and its northern catchment (Figure 1). Substantial further survey by EA during 2005 led to availability of greater coverage for the Witham valley and Lincolnshire fenland (Malone 2007; 2008). There remain some gaps in the survey, however, most notably a large salient in the south of the county, from Great Postland, up to Weston and southeast to Tydd St Mary. A stretch of coast east of Boston at Butterwick also remains unsurveyed; other small gaps in the coverage are of less note.

2.3 Business Case

2.3.1 Lincolnshire and the Fenland region have a remarkable and much-studied archaeological and environmental background. To the data assembled by early researchers such as Phillips (1970) much was added as part of the English Heritage funded Fenland Project in the 1980s and 1990s (Hall and Coles 1994). The Fenland Project demonstrated the scope for and advantage of combining environmental and archaeological data by placing the evidence for the numerous sites, particularly of the Roman period onwards, onto maps of the reconstructed contemporary environment. The environmental maps showed the contemporary and extinct creeks which were plotted during fieldwalking and hand drawn in the volumes. These creeks, also known as roddons, were key to understanding the development of the Fenland as they represent slightly elevated locations which attracted all the early and subsequent settlement. It is these minor, but hugely significant, changes in elevation which Lidar picks out.

2.3.2 Understanding of the early settlement and industry (particularly saltmaking) of the Fenland region was one of the achievements of the Fenland Survey but this could only be undertaken with confidence in the west of the Fenland area. To the east, the creeks/roddons broadened and flattened out and the general landscape was covered by subsequent shallow silting as a result of sea flooding. This broadening and flattening prevented the plotting of the roddons in that area by ground survey. However, manipulation of the Lidar data by Dr Steve Malone for the Witham Valley and the Northern part of the Lincolnshire Fens (Malone 2007; 2008) has demonstrated conclusively that the Lidar picks out the route of the large roddons much further seaward than could be undertaken by ground survey. Knowing from the previously studied western part of the Fenland that the sites are concentrated on the roddons this Lidar work on the northern fens has shown that this pattern continues to be visible within the silted eastern part of the Fenland. This previously unknown fact now enables predictive modelling of the locations of the early sites further seaward than considered possible previously. Recent excavation at Wygate Park, near Spalding, for example, has located a Roman settlement and saltmaking site on a major roddon, but buried by up to 0.5m of later (Saxon) silts. This site did not reveal itself during standard prospecting techniques of aerial photography, fieldwalking and geophysics. It presence might, however, have been predicted beforehand had Lidar plots been available and early, more informed, curatorial decisions made on that basis.

2.3.3 The Lincolnshire HER has access to the Lidar data. However, this is not in a format that they, and therefore those that consult the HER, can easily use. Therefore, this vital strand of information is not being made use of by curators and other HER users. At Heritage Trust of Lincolnshire we have the skills and experience to manipulate the data to bring it to a level that can be easily understood. Through previous WVARC linked projects the data for the northern part of the Fenland has been processed, at our own expense, and a series of georeferenced images created for easy access to, and presentation of, the data for this area. This project sets out to add to this existing data that for the remaining, southern, part of the Lincolnshire Fenland enabling curatorial access to the data for the entire Fenland region to the benefit of all curators, contractors, consultants and all HER users.

2.4 Research Aims and Objectives

2.4.1 While Lidar data is held by the Lincolnshire HER, this information is not easily accessible to researchers without specialist GIS skills. The Principal Aim of this project (the Primary Driver, see Appendix 1: Project Design) was to produce a processed dataset which can be more readily accessed through the HER and as a tool for planning archaeologists both at county and district level.

2.4.2 Studies of the Fenland landscape benefit particularly from a wide area perspective. The existing format of the Lidar data held at county level, based on 2km squares, limits the possibility of taking this wider perspective, thereby impeding understanding. In addition to a mosaic of 5km squares, the project has also produced larger scale seamless georeferenced imagery allowing easy comparison between the areas previously studied (the Witham Valley and the northern Lincolnshire Fenland down to a line from TF10/40 to TF40/40) and the current project area, which is all the remainder of the Lincolnshire Fenland south of that line.

2.4.5 The principal target was to elucidate the pattern of roddons, extinct watercourses, rather than small scale topographic features, the interpretation of which would require greater input. This pattern is largely self-evident (the colour-scales have been selected expressly to demonstrate this) especially when viewed on the larger scale. However, neither images nor continuous raster grid surfaces have the same GIS utility as polygons and ultimately digitising of features or definition of landscape zones would clearly be appropriate.

3 Methods

3.1 Environment Agency Lidar data is provided in ESRI ASCII grid format. Each .asc file covers an area 2km by 2km and each tile contains one million data points. Three different data sets are available for each tile:

i) the unfiltered elevation data;
ii) filtered data, with vegetation and tall buildings removed and ground levels at these points interpolated
iii) points altered during the filtering process.

However, the filtering processes are unsuited to the sort of fine archaeological or topographical detail of relevance here (Challis 2004, 25) and all processing has been undertaken on the unfiltered Digital Surface Model dataset. The vertical accuracy of the 2m-centre data is quoted as +/-15cm. Relative (point to point) accuracy, more relevant for detailed archaeological mapping, is higher at 5-7cm (Jones et al. 2007, 1576)

3.2 EA Lidar data tiles were read directly into MapInfo 9.5 to create a continuous raster grid surface model. This is the preferred technique for preserving data integrity, and is relatively fast. For presentational purposes an alternative technique involving Inverse Distance Weighting has been found effective. This introduces some smoothing, reducing noise and visible survey-swathe boundaries in the data, but is more time-consuming and is best suited to smaller-area, detailed plans or 3D-perspective views.

3.3 Parameters for processing and presentation were trialled with EA survey data as part of WVARC projects. The colour ramp was designed to produce the best definition of the roddons and extinct creeks within the Witham Valley and Fenland basin between 0m and 3m above Ordnance Datum. Because of the way the colour shades merge and the way the intervening shades appear to the eye, the steps in the chosen colour sequence are not even (0.00m-1.50m-2.50m-3.00m-5.00m) but the overall effect is close to a more even interval. Figure 3, showing the colour scale overlain with 1m contours, demonstrates the effect. The most marked change in the white-dark blue transition occurs at 1.00m OD; cyan and green shades come in slightly before the 2.00m and 3.00m contours; yellow is most noticeable from about 4.00m with a stronger line at 5.00m. A merging colour scale was selected as being most expressive in depicting landforms and earthwork features, but this does lend some subjectivity to the perception of contour intervals. The 'upland' was not part of the specific focus of this project and is represented with a single brown shade, most intense at 10.00m fading to a white above. Negative values are not separately represented but form part of the white scale (this is of most relevance within East Fen where large areas fall below 0m O.D. but also applies to areas within Borough Fen and Dyke Fen). With Mean High Water along the Wash coast falling at *c*. 3m O.D., the chosen colour ramp also provides a good representation of the coastline and salt marshes. In the context of rising sea-levels and coastal change, it is worth noting that all of the areas coloured blue in the accompanying plots are below the *current* Mean High Water level.

3.4 Working with this pre-defined colour scale each ESRI SHP file was opened and thematic mapping properties for the raster grid merged with the colour scale gradually building up a mosaic out of the 2km by 2km squares. The size of the mosaic thus produced is limited practically by the availability of computer memory and processing power. Even as processed imagery this is an issue for end users. However, the full resolution dataset will be most useful on a site by site basis and best explored over a range of a few kilometres. Consequently, processing proceeded on the basis of 10km grid squares with georeferenced imagery output as 5km x 5km blocks.

3.5 Artifical 'sunlight' has been used to emphasise subtle earthwork features. As a standard this has been applied as a low light illuminating features from the north-west. While not preserving an exact correspondence of point value to colour shade, such 'hill'-shaded imagery provides the clearest representation of the micro-topography of the survey area. This technique can prove ineffective, however, where features are aligned on or very close to the axis of illumination (Devereaux et al. 2008), some features in fact becoming virtually invisible. As a consequence best practice is to use illumination from more than one direction in order to get the most information out of the plots. This is less of an issue for the large scale sinuous roddons within the fenland, the mapping of which was the principal aim of the project (see Figures 4 and 5 comparing two such plots for TF21SW and TF11SW; the differences are much more marked in the latter). However it is recognised as a potential limitation on the utility of the processed dataset and a second set of imagery, lit from the northeast, has consequently been provided for the 'upland' areas on the western margin of the survey area.

3.6 The mosaic blocks have been output as GeoTIFF files at a resolution which preserves the level of detail present in the original. Each file is 2500 x 2500 pixels preserving the representation of each Lidar survey data point as a single pixel shaded according to the pre-defined colour ramp. These georeferenced image files are platform independent and can be incorporated directly into most standard GIS systems including the Lincolnshire HER's ExeGesis system. The full file listing of the processed imagery appears as Appendix 2. A key to the layout of the processed survey blocks is provided in Figure 2.

3.7 Further processing of the image data was undertaken within Adobe Photoshop to produce a seamless jpg image of the whole survey area at resolutions suitable for printing to A0 and A1 formats (and smaller where required), in order to provide further options for dissemination or display of the data. Posters in A0 and A1 format have also been designed giving detail of the project, its sponsors and results to aid in such dissemination (Fig. 6).

4 Results

4.1 The primary product of the project is the processed imagery data-set now lodged with the Lincolnshire HER (see Appendix 1). This comprises all of the Environment Agency Lidar data currently available for the Lincolnshire Fenland, some 500 million data points covering an area of some 2025km^2 (see Fig. 6). The full potential of this data-set will take much further exploration, but a number of themes are considered below as an illustration, and first step, towards realising that potential.

4.1.1 The River Witham

Results in the Witham Valley have been described in detail elsewhere (Malone forthcoming). The Palaeoenvironmental Research Design for the Witham Valley drawn up at the first Witham Archaeological Seminar identified mapping of the micro-topography of the study area as a priority (French and Rackham 2002, 41). At the time the aerial photographic record was seen as the best approach to prospection and it was hoped that further study might allow mapping of the dendritic creek system of the inter-tidal zone and identification of palaeochannels and buried floodplain and fenland deposit zones. The results of the Lidar mapping answer the first parts of this spectacularly well. Although this dendritic network of channels is visible from the air as both crop- and soil-marks at the right times of year, and the larger elements are susceptible to ground-based mapping, Lidar survey uniquely gives us direct measurement of the elevation of individual roddons and allows these to be mapped across the whole landscape.

South-east from Heighington Fen all the way to Boston, the main channels of the estuarine river and the dendritic network of salt-marsh creeks of the Bronze Age are strikingly evident and provide unprecedented detail (Fig. 7: *cf* for example Wilkinson 1987; French and Rackham 2002, 34 Fig.1). These channels were formed in an estuarine environment at the greatest extent of marine incursion. A sinuous channel, widening from 50-100m to 300m or 400m in width, runs down the centre of the valley, branching just beyond Sots Hole to merge again before the Timberland Delph into a main channel 800-1000m across now falling into the western half of the valley and touching the valley side at Billinghay. Continuing south and east it receives the outflow from Digby Fen and the River Bain and drainage from Holland and West Fens widening ultimately to 2.6km to pass just north of Boston before being lost beneath more recent coastal silting. Running within the top of this estaurine roddon a narrow channel, some 10m-20m across and only 0.3m-0.4m in depth, follows a sinuous course down the valley apparently falling in with a more recently active channel some way north of Langrick Bridge. This presumably represents the final active drainage within this channel system although further work would be required to elucidate the chronology. The post-medieval, pre-canalisation, channel can be seen from Chapel Hill all the way down to Boston to one side or the other of the modern cut (cf. for example Pitchford's survey of 1733 prior to the cutting of this channel: Wheeler 2008, No. 14). The 'long reach' from which the name Langrick is derived is very marked and very regular (Fig. 8). It seems clearly artificial, but must be of early date, for the *magna langraca* is so named as early as 1162 (Cameron 1998, 77). At Langrick Bridge the channel divides with one arm running south to Hubbert's Bridge and perhaps to Swineshead (but it becomes less clearly defined here and other routes seaward via Kirton might be sought).

A similarly complex history can also be seen at Dogdyke, where the River Bain enters the valley floor just south of Tattershall (Fig. 9). A broad depression, some 200m across marks an early course of the river cutting down into the valley floor to 0.8-1.0m OD. Within and over this a large sinuous roddon is evident. Widening from 30m to 100m in width, this is filled to a level of 1.7-1.9m OD. Just to the east of the river, on the margins of the depression, an island of higher ground can be seen centred on TF 2050 5535. Fieldwalking and excavation undertaken during the Fenland Project identified Mesolithic and Neolithic activity on this island (Lane and Trimble forthcoming). In these periods the river probably ran in a slight valley, but the ground here is higher, if only just, than the elevation of the roddon and would have remained as an island of dry land even in the period of activity of this later channel. The site was identified and investigated through the normal suite of archaeological techniques; the Lidar survey adds context, mapping the subtleties of the channel forms and marginal 'islands' to an extent which would otherwise have proved difficult to achieve.

The drainage pattern within these fenland areas is dominated by the peculiar inverted relief of the roddon systems, with former water-courses expressed in the Lidar plots because they are *higher* than the surrounding ground. However, the pattern of down-cutting channels on the fen-edges is equally well represented with potential insights into the settlement of the fen margins alongside river channels which would have been tidal even this far inland at the greatest extents of marine influence (Fig. 10).

4.1.2 Barrow cemeteries

The topographical context of Bronze Age barrow cemeteries is often key to the understanding of their placement. In these landscapes of very low relief, this is not always evident using conventional mapping. The Lidar survey plots provide a clear insight into the siting of these monuments at valley-side and fen-edge locations (Fig. 11). As a prospection method, the technique has its limitations: ploughed out barrows, or those just emerging from the peat cannot be detected and clearly many of these cemeteries are more extensive than the Lidar would show. However, those that *do* show are in many cases the best preserved, still extant as measurable earthworks, however slight.

4.1.3 Roman settlement in the Fens

The intimate connection of Roman settlement in the fens with the micro-topography of the roddon systems has been long demonstrated (Hallam 1970). However, mapping of these natural features was not attempted for the maps presented in The Fenland in Roman Times (Phillips 1970). In contrast, the methodology of The Fenland Project specifically sought to map these features and place the distribution of sites in this landscape context (Hall 1987; Hayes and Lane 1992, 7-8). The ground-based survey methodology (supplemented by air-photographic plotting in Cambridgeshire), although time consuming, produced very accurate maps of the roddon systems only now superseded by the Lidar plots (Fig. 12). However, little distinction could be made for differing levels of silting within the roddons, which can show stratigraphic relationships between drainage systems of different dates (see for example the west-east and later north-south drainage of East Fen: Fig. 13); nor could the systems be followed on the ground as far seaward where they become broadened and flattened and where later silt overburden masked any surface soil differences.

The Lidar survey plots are georeferenced allowing other datasets to be easily superimposed. Overlaying of NMP aerial photographic plotting demonstrates quite simply the added value of the topographic context (Figs 14 (NMP) and 15 (the Fenland in Roman Times plot of the same area similarly treated); cf. also Fig. 26 for an area on the fen-edge).

Surviving earthwork sites within the fen are expressed well in the survey plots (Fig. 16). The ditched boundaries of the Horbling Fen settlement (Scheduled Monument 20812) are clear and the plot demonstrates well how the settlement location is influenced by the local topography of roddons. Even on ploughed out sites the Lidar data can show survival of hollows along the former trackways (eg LI216; not to be confused with the slight ridges forming an envelope pattern caused by ploughing). Some things can be deceptive, however. The Roman site at Park Farm in Deeping Fen (SM LI227) shows with remarkable clarity as upstanding features. The Lidar survey has in fact recorded differential crop growth over the buried ditches (at just 2m in width and 8-15cm in height these are at the limit of the Lidar sensitivity but show remarkably well nonetheless). Looking slightly further afield, the southern edge of the survey area encompasses part of the Peterborough District of Cambridgeshire including the site of the Iron Age 'marsh fort' in Borough Fen (SM PE222).

4.1.4 The Car Dyke

One of the most extensive monuments of the Roman period, the Car Dyke skirts the fen edge from Peterborough to Lincoln (Simmons and Cope-Faulkner 2004). Its course falls within the western margins of the current survey area which covers the entire route from Peakirk in the south to its northern end just east of Lincoln, thus excluding only the southernmost 10.5km of its 92km length. The Roman date of the feature, long a subject of debate (*op. cit.* 162-3) has been amply confirmed by recent work in Washingborough (LAS 2005). The question of its northern terminal and approach to Lincoln (Simmons and Cope-Faulkner 2004, 157-61) is clarified by a combination of Lidar mapping and field survey (Malone forthcoming; Rackham forthcoming); the dyke is truncated by a channel of early medieval date and the terminal lost.

The Car Dyke is visible as an earthwork feature in the Lidar plot for much its length, especially in its southern section, from Heckington to Market Deeping (Fig. 17) with a channel 12-15m in width running between banks 20m-30m across. The banks survive up to 1.2m in height; even where ploughed out and no more than 0.3m-0.4m in height they are clearly represented in the Lidar plot which shows a much greater length of surviving bank than is evident in other forms of recording. As with much else seen within these plots, the Lidar provides unprecedented landscape context (Fig. 18).

4.1.5 The Bourne-Morton Canal

The canal runs from just outside Bourne on the fen edge northeast across Dyke Fen to Morton Fen where it runs into a sinuous watercourse. The feature is very evident on aerial photographs and its course well mapped (Phillips 1970, Map 3; NMP). Interpretation/ function has been a matter of some debate (Hallam 1970, 32; Simmons 1979; 1980; Hayes and Lane 1992, 122-6). A section cut through it at Cross Drove, Morton showed the channel to survive to in excess of 2m in depth, having been some 10-11m in width, but later re-cut to a width of 5.5m and depth of 1.2m (Crowson *et al*. 2000, 129-134). One kilometre to the west, in Dyke Fen the upper part of the channel had eroded as the peat wasted leaving only 0.4m depth of basal silt surviving. (*op. cit*. 131).

Lidar survey shows the canal to survive as an intermittent earthwork *c*. 10-15m in width and varying in height from *c*. 0.15m to 0.50m with a surface level of 0.84m to 2.3m O.D. (Fig. 19). Within the central part of its course in Dyke Fen there is no trace within the Lidar. At its northeastern end it is evident as a broad elevated band 30-40m in width and 0.4-1.0m in height with a surface level of 1.84-2.09m O.D. running into a sinuous watercourse. Deflation of the surrounding peatlands has had the curious effect of leaving the silted-up watercourse standing proud as a positive feature. The former height of the peat within the Fen remains unknown. As noted by Hayes and Lane (1992, 125) for the canal to have operated as a navigable watercourse all the way into Bourne would have required either that a lock system was established at the landward end, or that the water level be maintained at a height of 4-5m across the Fen (but the extent of deflation of underlying deposits is a question for all levels quoted here). Previous survey had been unable to determine the eastward course of the waterway with which the canal connected. The Lidar plot demonstrates its connection with a natural waterway initially running southeast but then turning north and east becoming a wide estuarine channel, widening to at least 2km in width before eventually becoming masked by the higher silts of Bicker Haven and the medieval Welland (Fig 19). This is the estuary feeding most of the salterns along this central fen and may have represented one of the main coastal approaches in this period (Fig. 20).

Other roads and canals are also visible leading from the western fen edge: the road across Horbling Fen, evident on cropmark plots, and presumed to constitute the eastern end of the Salter's Way on its approach to the vicinity of Donington (Hallam 1970, 30-1), survives as an intermittent earthwork, 15-20m in width but only 15-20cm in height; the Rippingale Minor Canal (Hayes and Lane 1992, 84) is likewise evident as an earthwork 12-15m in width and up to 0.3m in height crossing Rippingale Fen and as a slight hollow further west as it meets the fen edge. A further artificial watercourse noted by the Fenland survey (*op. cit.* 189, Site DSJ15; the Prior's Meadow canal) is less obvious, but can also be seen to survive as an earthwork up to 20m in width and c. 015m in height running out from the fen edge at Deeping St James to join an early course of the River Welland. The Baston Outgang, on the other hand, has left little measurable trace. Across the peat fen it has been noted as a linear band of gravel, presumably the capping of a long-destroyed wooded causeway (Hayes and Lane 1992, 171) but in contrast to the silt-filled canals leaves little material trace. At its eastern end, on the silts, it is marked by parallel ditches on aerial photography. A slight hollow marks its course past Rookery Farm until it disappears beneath later silts after turning to the northeast.

4.1.6 Medieval salterns

These can be very visible and easily mapped from the air. However, they stand out particularly well in the Lidar plots against the low relief of the surrounding fenland. Three major concentrations can be seen (Fig. 21): the Friskney and Wrangle tofts along the northwestern shore of The Wash; in Bicker Haven, extending up towards Donington in the west and Swineshead in the north; and at Holbeach Hurn beyond the medieval sea-bank. The Friskney and Wrangle tofts in particular stand out as a significant landscape feature along the northern shore of the Wash, all the more remarkable in that they are almost entirely man made. Records within the HER for Medieval salterns vary in treatment. Some sites are merely recorded as point data, others have been recorded as polygons. In neither case does the record match the evident extent of medieval saltmaking in and around Bicker Haven, along Wrangle and Friskney Tofts and at Holbeach Hurn and Saracen's Head (see below). Lidar plots will provide a significant tool for the management of this resource.

4.1.7 Medieval earthworks

Evaluation of the Lidar survey dataset as a prospection technique in the Witham valley, highlighted its potential, although with some caveats over interpretation (Crutchley 2006). A more recent project looking at an area on the Derbyshire/Staffordshire border (Challis et al. 2008) recorded a large number of features previous overlooked by the relevant HERs. However, the vast majority of these were remains of medieval ridge and furrow field systems which had been selectively excluded from the existing record and would clearly have been mappable by other sources had there been a desire to do so. Within the Lincolnshire Fens data-set medieval earthworks are visible all along the fen-edge uplands. Surviving earthwork ridge and furrow is well represented, but even where this is ploughed out the broader, more substantial headlands survive, often as long sinuous banks, sometimes apparently representing an earlier phase of land division than the last extant ridge and furrow (Figs 5, 22). Comparison with NMP plotting shows that although the ridge and furrow is easily picked up, these other features are often not recorded.

4.2 Comparison with existing HER records

Figure 23 gives a general view of the relationship of Roman period records within the HER to the overall Fenland topography. In order to investigate this relationship in more detail, data on Iron Age, Roman and Medieval salterns were obtained from the Lincolnshire HER and overlain on the Lidar plots. Fig 24 shows Iron Age and Roman salterns northwest of Spalding (point symbols and polygons indicate sites with evidence of salt-making; in many cases this represents merely one phase of use with more extensive settlement developing later). These show very clear relationships to the roddon systems aiding in interpretation of the active channels at certain periods (cf. Fig. 20 and the channels linking to the Bourne-Morton Canal). Further salterns could be expected on the margins of these channels as they run seaward. Masked by later silts, these represent a challenge to prospection techniques, but would be far better preserved than those long under the plough.

The higher saltern mounds of the medieval period are clearly expressed in the Lidar plots. Detailed examination will doubtless show many more, less immediately obvious. Even within the major complexes these appear in many cases to be more extensive than the HER records would indicate (Fig. 25). Reference to the GeoTiff imagery, easily opened as a layer within the GIS, will allow these to be updated or sites targeted for further investigation.

5 Conclusions and Recommendations

The project has been successful in its principal aim of producing a processed dataset which will be more readily accessible through the HER and provide a tool for planning archaeologists both at county and district level. Data has already been transferred to the Lincolnshire HER and to the Heritage Trust of Lincolnshire Planning Team and meetings held with representatives of both bodies in order to demonstrate how the data can be used in conjunction with their GIS systems.

The full potential of the data-set will take much further exploration. The themes explored in Section 4 demonstrate its potential to contribute widely to the study of the archaeology of the Fenland. Each would be worthy of further more systematic study.

Mapping of individual topographic or archaeological features in vector format suitable for incorporation within the GIS would enhance use of the dataset within the HER allowing inclusion of individual features within the database.

The pattern of dendritic channels/roddons is very clear in the processed Lidar data set. Although polygons have greater utility for many GIS applications, in practice the fine detail is almost impossible to digitise. However, there are clear stratigraphic relationships between different drainage regimes and the level of silting within the roddons has potential for elucidating the chronology (accepting that the levels now pertaining may not be the exact levels originally existing). Mapping of the larger roddons, roddon systems and final active channels as GIS polygons tagged with levels (average levels / range of levels) would enhance the data-set.

Undoubtedly, there is much more to be gleaned from detailed study of the Lidar plots, but such study has been made possible by the provision of a uniform processed data-set. In many ways the greatest advance here is in illuminating the landscape context of sites and monuments in the Fenland where no other source of information can provide such detail over such a large area.

6 Acknowledgements

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8 Abbreviations

AARG08	Aerial Archaeology Research Group 2008, Ljubljana
APS	Archaeological Project Services
CAA08	Computer Applications in Archaeology 2008, York
EA	Environment Agency
EH	English Heritage
HER	Historic Environment Record
NMP	National Mapping Program
UKAS07	UK Archaeological Science 2007 Conference, Cambridge
WVARC	Witham Valley Archaeological Research Committee

Appendix 2

Survey Products (provided on accompanying DVD)

GeoTiff imagery

TF06NE.tif
TF06SE.tif
TF07SE.tif
TF07SW.tif
TF10NE-2.tif
TF10NE.tif
TF10NW-2.tif
TF10NW.tif
TF11NE.tif
TF11NW-2.tif
TF11NW.tif
TF11SE.tif
TF11SW-2.tif
TF11SW.tif
TF12NE-2.tif
TF12NE.tif
TF12NW-2.tif
TF12NW.tif
TF12SE-2.tif
TF12SE.tif
TF12SW-2.tif
TF12SW.tif
TF13NE.tif
TF13NW.tif
TF13SE.tif
TF13SW-2.tif
TF13SW.tif
TF14NE-2.tif
TF14NE.tif
TF14NW-2.tif
TF14NW.tif
TF14SE-2.tif
TF14SE.tif
TF14SW-2.tif
TF14SW.tif
TF15NE.tif
TF15NW.tif
TF15SE.tif
TF15SW.tif
TF16NE.tif
TF16NW.tif
TF16SE.tif
TF16SW.tif
TF17SW.tif
TF20NE.tif
TF20NW.tif
TF21NE.tif
TF21NW.tif
TF21SE.tif
TF21SW.tif
TF22NE.tif
TF22NW.tif
TF22SE.tif
TF22SW.tif
TF23NE.tif
TF23NW.tif
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TF24NE.tif
TF24NW.tif
TF24SE.tif
TF24SW.tif
TF25NE.tif
TF25NW.tif
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TF25SW.tif
TF26SE.tif
TF32NE.tif
TF32NW.tif
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TF33SE.tif
TF33SW.tif
TF34NE.tif
TF34NW.tif
TF34SE.tif
TF34SW.tif
TF35NE.tif
TF35NW.tif
TF35SE.tif
TF35SW.tif
TF36SE.tif
TF36SW.tif
TF41NE.tif
TF41NW.tif
TF42NE.tif
TF42NW.tif
TF42SE.tif
TF42SW.tif
TF43NE.tif
TF43NW.tif
TF43SE.tif
TF43SW.tif
TF44NE.tif
TF44NW.tif
TF44SW.tif
TF45NE.tif
TF45NW.tif
TF45SE.tif
TF45SW.tif
TF46SE.tif
TF46SW.tif
TF55NE.tif
TF55NW.tif
TF55SW.tif
TF56SE.tif
TF56SW.tif

MapInfo Tab files
Seamless combined imagery: SLLP09 WholeSurveyj.jpg; SLLP09 WholeSurvey.ecw; SLLP09FensN.ecw; SLLP09 FensS.ecw
Posters: SLLP09 A0 poster.pdf; SLLP09 A1 poster.pdf

Appendix 1 Project Design

Project Name:-
South Lincolnshire Fenland Lidar Processing

1. Description of the Project

1.1 Summary
1.1.1 Lidar survey has significant potential for landscape study in the Lincolnshire Fenland. The Environment Agency Lidar dataset for the area represents an enormous potential resource. Although lodged with the HER this dataset is not easily available to researchers without specialist knowledge of processing. The northern part of the Fenland has already been processed (by Heritage Trust of Lincolnshire at our expense). The aim of this project is to see the southern Lincolnshire Fenland (broadly on a line from the village of Swaton in the west [TF10/40] across through Kirton to that coast at TF 40/40) brought up to the same standard using the same methodology. The processed data will provide seamless georeferenced imagery which will allow wider and easier access to the data and its understanding and interpretation. The chief archaeological aim of the Project is to enable accurate predictive modelling for the locations of sites partially or wholly buried under flood silts of post Roman date and to record an environmental and landscape context for all sites in the Fenland.

1.2 Background
1.2.1 Detailed descriptions of Airborne Laser Altimetry, more often referred to as Lidar (for Light Detection and Ranging) are available in existing studies (Challis 2004; Bewley *et al*. 2005). Lidar uses the properties of coherent laser light, coupled with precise spatial positioning (through the use of a Differential GPS) to produce horizontally and vertically accurate elevation measurements. This data has considerable potential for archaeological research in terms of mapping archaeological sites where features survive as upstanding earthworks, for identifying depressions where organic sediments may be preserved and more generally for providing landscape context in areas of very low relief where existing topographic mapping lacks detail. Within the marginal landscapes of the Lincolnshire fenland this topographic context is crucial to the understanding of past human use of the landscape and lidar survey provides unprecedented detail of this subtle topography.

1.2.2 The Environment Agency (EA) has undertaken extensive areas of lidar survey in coastal zones and river valleys for the purposes of flood risk management. Heritage Trust of Lincolnshire has established expertise in working with EA data provided through the Witham Valley Archaeological Research Committee (WVARC) which has demonstrated the potential for the use of this data in mapping the landscape of the Fens (Malone forthcoming; UKAS07; CAA08; AARG08).

1.3 Business Case
1.3.1 Lincolnshire and the Fenland region have a remarkable and much-studied archaeological and environmental background. To the data assembled by early researchers such as Phillips (1970) much was added as part of the English Heritage funded Fenland Project in the 1980s and 1990s (Hall and Coles 1994). The Fenland Project demonstrated the scope for and advantage of combining environmental and archaeological data by placing the evidence for the numerous sites, particularly of the Roman period onwards, onto maps of the reconstructed contemporary environment. The environmental maps showed the contemporary and extinct creeks which were plotted during fieldwalking and hand drawn in the volumes. These creeks, also known as roddons, were key to understanding the development of the Fenland as they represent slightly elevated locations which attracted all the early and subsequent settlement. It is these minor, but hugely significant, changes in elevation which Lidar picks out.

1.3.2 Understanding of the early settlement and industry (particularly saltmaking) of the Fenland region was one of the achievements of the Fenland Survey but this could only be undertaken with confidence in the west of the Fenland area. To the east, the creeks/roddons broadened and flattened out and the general landscape was covered by subsequent shallow silting as a result of sea flooding. This broadening and flattening prevented the plotting of the roddons in that area by ground survey. However, manipulation of the Lidar data by Dr Steve Malone for the Witham Valley and the Northern part of the Lincolnshire Fens has demonstrated conclusively that the Lidar picks out the route of the large roddons much further seaward than could be undertaken by ground survey. Knowing from the previously studied western part of the Fenland that the sites are concentrated on the roddons this Lidar work on the northern fens has shown that this pattern continues to be visible within the silted eastern part of the Fenland. This previously unknown fact now enables predictive modelling of the locations of the early sites further seaward than considered possible previously. Recent excavation at Wygate Park, near Spalding, for example, has located a Roman settlement and saltmaking site on a major roddon, but buried by up to 0.5m of later (Saxon) silts. This site did not reveal itself during standard prospecting techniques of aerial photography, fieldwalking and geophysics. It presence could, however, have been predicted beforehand had Lidar plots been available and early, more informed, curatorial decisions made on that basis.

1.3.3 The Lincolnshire HER has access to the Lidar data. However, this is not in a format that they, and therefore those that consult the HER, can use. Therefore, this vital strand of information is not being made use of by curators and other HER users. At Heritage Trust of Lincolnshire we have the skills and experience to manipulate the data to bring it to a level that can be easily understood. We already have the data for the northern part of the Fenland and have, at our own expense, created a series of georeferenced images for easy access to, and presentation of, the data for this area. This project sets out to add to this existing data that for the remaining, southern, part of the Lincolnshire Fenland enabling curatorial access to the data for the entire Fenland region to the benefit of all curators, contractors, consultants and all HER users.

1.3.4. Given the huge benefits of having this data in this format, one that is accessible to the HER, the sums required are extremely low and represent excellent value for money. There is little or no risk that the work could not be completed (see below). The positive benefits of this work can already be seen on the Witham Valley and Northern Fenland equivalent plan and there is no reason why similar positive results should not be available on the proposed southern mapping.

1.3.5 The creation of the method of manipulating the data for the northern area and design of the output was the work of HTL's Dr Steve Malone and it is only sensible that Dr Malone undertakes this proposed work.

1.3.6 Although the process of creating a survey mosaic to a defined colour scale may indeed be relatively simple to those with relevant GIS knowledge and access to the right software, it is certainly not simple for many researchers with an interest in the Fens, nor indeed for the staff of the HER. Although, as active researchers in the Fens, we have frequently been told that the HER 'have the data', any request to see, for example, Roman or medieval salterns plotted against the microtopography evident within the lidar dataset could not be forthcoming at present. The North Kesteven, South Kesteven and Boston Borough curators do not have any such data and would welcome the ability to add this data to a layer of their GIS. The EA Archaeologist has expressed astonishment at what their own data can show when manipulated this way. The dataset is theoretically available, but realistically only to those with specialist skills. The aim of this project is to make this information more readily accessible and useable to archaeologists and landscape researchers in the county.

1.3.7 It is to be acknowledged that processing to a georeferenced image output fixes what should be a mutable and interrogatable data set, but the work done so far has been to establish a set of parameters that elucidate a particular, and particularly relevant, aspect of the data set and such a set of images would be of great utility.

1.3.8 MapInfo version 8 does not open ArcInfo shape files directly. Early work on the Witham valley Lidar involved conversion and importation as text files. This produced good results, but was more time intensive. Very good results were swiftly achieved working with a trial version of MapInfo 9. The additional cost of upgrading is certainly worthwhile.

1.3.9 The ***Primary Driver*** in this project equates with the English Heritage corporate Aims and Objectives listed in Appendix 1 of SHAPE - '*Help people develop their understanding of the Historic Environment'*. In particular it serves well Aim 1C – *'Make sure our professional expertise and knowledge is more accessible to others who need it'*.

1.4 Research Aims and Objectives

1.4.1 While Lidar data is held by the Lincolnshire HER this information is not easily accessible to researchers without specialist GIS skills. The **Principal Aim** of this project (the **Primary Driver,** see above) will be to produce a processed dataset which can be more readily accessed through the HER and as a tool for planning archaeologists both at county and district level.

1.4.2 Studies of the Fenland landscape benefit particularly from a wide area perspective. The existing format of the Lidar data held at county level, based on 2km squares, prevents the possibility of taking this wider perspective, thereby impeding understanding. The project will provide a seamless, georeferenced, image of the study area allowing easy comparison between the areas already studied (the Witham Valley and the northern Lincolnshire Fenland down to a line from TF10/40 to TF40/40) and the proposed area, which is all the remainder of the Lincolnshire Fenland south of that line.

1.4.3
While 1C (Making sure our professional expertise and knowledge is more accessible to others who need it) has been identified as the Principle Driver (and main aim) the proposed project fits many of items listed in EH SHAPE 2008 corporate Aims and Objectives. This project fits
1A – Ensuring that our research addresses the most important and urgent needs of the historic environment
1B – Enhancing public understanding and appreciation of the historic environment and its conservation through education and training
1C – Making sure our professional expertise and knowledge is more accessible to others who need it
1D – Developing new approaches which improve understanding and management of the historic environment
4A – Help local authority members and officers develop the skills, knowledge, advice and capacity to make the most of their historic environment
4C – Provide support and guidance to other organisations engaged in the care, study and promotion of the historic environment

1.4.4
Under the EH SHAPE 2008 list of Activity Types, Themes and Programmes the project fits
Research Themes and Programmes
A1 – Defines, characterises and analyses the historic environment
A2 – Analyses poorly understood landscapes (in particular the coastal silts)
A3 - Realises the potential of the research dividend
D1 – Quantifying and analysing the condition of the historic environment
F1 - Developing standards for Historic Environment Records
F2 – Studying and developing information management
G1 – Developing new techniques of analysis and understanding
Empowerment
C1 – Giving those with a stake in the historic environment the capacity to care for it
Enhancing Government
D4 – Helping local authorities through guidance
Heritage Management
A1 – Developing the tools for good management of the historic environment

1.4.5 The principal target is to elucidate the pattern of roddons, extinct watercourses, rather than small scale topographic features, the interpretation of which would require greater input. This pattern is largely self-evident (the colour-scales have been selected expressly to demonstrate this) especially when viewed on the larger scale. However, neither images nor continuous raster grid surfaces have the same GIS utility as polygons and ultimately digitising of features or definition of landscape zones would clearly be appropriate.

Summary of Outputs
The output of the project will be:-

a) to produce a processed dataset which can be more readily accessed through the HER and as a tool for planning archaeologists both at county and district level.

b) to provide a set of georeferenced image mosaics in GeoTiff format suitable for use in HER GIS system and further seamless georeferenced jpeg images suitable for presentation and display.

c) to provide a bound hard copy stating the methodology of the work, the results and a gazetteer of principal sites

1.5 Interfaces

1.5.1 There are no direct interfaces/connections with other single projects. However, the proposed work would have a positive effect on all future projects (including thoise for commercial purposes)carried out in the Fenland region. It should also set the standard for Lidar data manipulation for archaeological purposes elsewhere in Lincolnshire and beyond.

1.6 Communications

1.6.1 *Communications External* – External communication will be between the main stakeholders:-
Heritage Trust of Lincolnshire (Tom Lane/ Steve Malone)
English Heritage (Sponsors) (Kath Buxton)
Environment Agency (suppliers of raw Lidar data) (Phil Catherall)
Lincolnshire HER (suppliers of HER data and prime beneficiary/users/curators) (Mark Bennet).

1.6.2 All parties will be invited to an initial start-up meeting at which all agreements for supply and receipt of data will be finalised. Thereafter, it is anticipated that all communication between all parties will be by email. There may be further meetings between HTL and EH which take the form of the usual Monitoring Meetings, but, given the brevity of the project, such an interim meeting may not be necessary or possible.

1.6.3 *Communications Internal* – Internal communications will be between the Project Manager (TL) and the Data manager (SM) on an ad hoc basis, but at least weekly.

A single Highlight Report will be submitted to all the stakeholders by email midway through the life of the project. An End of Project Report will be lodged in the Project Archive

1.7 Project Review

1.7.1 Progressed will be assessed at the weekly meeting between the Project Manager (TL) and the Data Manager (SM). There will be a single review, at the end of the projected 6 week project to which the main stakeholders will be invited.

1.7.2 As the project is only of 6 weeks duration only (from receipt of data) it is not anticipated that there will be a significant overrun in time or costs.

1.8 Health & Safety

1.8.1 The company Health and Safety Statement is appended. EH has details of the HTL health and safety policies and procedures from previous projects.

2. Resources and Programming

2.1 Project Team Structure

2.1.1 Project Manager Tom Lane – will be responsible for the overall management of the project, its communications and its delivery to time and budget. Two days are allocated over a period of 6 weeks.
Data Manager Dr Steve Malone – will be responsible for the data manipulation and the quality of the final product. 18 days are allocated over a period of 6 weeks.

2.2 Methods Statement

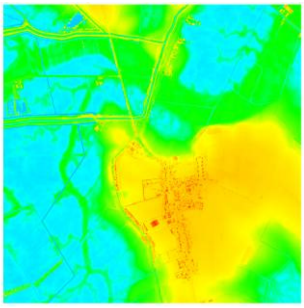
2.2.1 Environment Agency Lidar data is provided in the form of ESRI SHP files, in ASCII grid format. These can be read directly into ArcInfo or MapInfo (the latter is the platform utilised at HTL) to create a continuous raster grid surface model. This is the preferred technique for preserving data integrity, and is relatively fast. For presentational purposes an alternative technique involving Inverse Distance Weighting has been found effective. This introduces some smoothing, reducing noise and visible survey-swathe boundaries in the data, but is more time-consuming and is best suited to smaller-area, detailed plans or 3D-perspective views. Parameters for processing and presentation have already been trialled with EA survey data as part of WVARC projects. Default greyscale or colour images can be quite simply produced, but are less expressive than customised colour scales combined with artificial sunlight / relief shading designed to emphasise subtle height differences in these landscapes of very low relief.

2.2.2 Once a colour scale has been defined, it is a simple process to open the ESRI SHP file and adjust thematic mapping properties for the raster grid to merge with the predefined colour scale. In this way, a mosaic can be built up with relative ease. However, creation of large area mosaics is resource hungry – the full processed data set will be in the order of 2000km^2; some 500 data tiles, each of 1,000,000 data points – and in practice the processing will have to proceed in blocks. Moreover, incomplete overlap of some survey swathes means that there are holes in the data coverage. In many cases repeat flying provides coverage to fill these gaps, but this requires further consideration as regards choice of dataset.

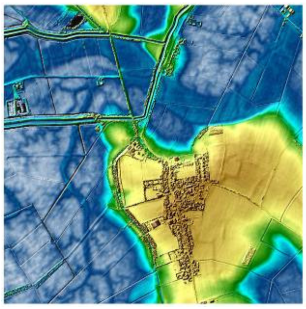
2.2.3 Output of mosaic blocks will be as GeoTIFF files at a resolution which preserves the level of detail present in the original (this depends on the size of the mosaic: for a 10km x 6km mosaic, 300dpi reproduces relevant detail). These georeferenced image files can be incorporated directly into the Lincolnshire HER's ExeGesis system.

2.2.4 Further processing of the image data will be undertaken within Adobe Photoshop to produce a seamless jpg image of the whole survey area at resolutions suitable for printing to A0, A1 and A2 formats (and smaller where required), in order to provide further options for dissemination or display of the data. Posters in A0 and A1 format will be designed giving detail of the project, its sponsors and results to aid in such dissemination.

Default greyscale



Default colour scale



Customised colour scale with artificial relief

2.2.5 Mapping of individual topographic features in vector format suitable for incorporation within the GIS would enhance use of the dataset within the HER. However, this would be difficult to quantify prior to completion of the processing. Point location and brief description could be incorporated at this stage. Further work would require cross-checking with other sources before undertaking any digitisation. Ultimately ground-proofing would also be of benefit.

2.2.6 The pattern of dendritic channels/roddons is very clear in the processed Lidar data set. Although polygons have greater utility for many GIS applications, in practice the fine detail would be almost impossible to digitise. However, there are clear stratigraphic relationships between different drainage regimes and the level of silting within the roddons has potential for elucidating the chronology [accepting that the levels now pertaining may not be the exact levels originally existing]. Mapping of the larger roddons, roddon systems and final active channels could be undertaken as GIS polygons tagged with levels [average levels / range of levels].

2.2.7 No new licences will be required to complete the work. The necessary licences will be part of the purchase of the MapInfo software. The data will be transferred to the HER digitally

2.3 Stages, Products and Tasks

Task No	Aims	Task	Performed by	Days	Cost £
1	1.3.2; 1.3.4	Data request	SM	0.5	
2	1.3.4	Start up Meeting	TL/SM	0.5	
3	1.3.4	Project Management	TL	1.5	
4	1.3.4	Obtain MapInfo	SM	---	
5	1.3.4	Creation of Mosaics	SM	5	
6	1.3.4	Export of Mosaics as Image File	SM	1	
7	1.3.2; 1.3.3;1.3.4	Combination into Seamless Image	SM	3	
8	1.3.2; 1.3.4	Conversion to compressed, georeferenced format	SM	1	
9	1.3.2; 1.3.4	Addition of HER Data	SM	1	
10	1.3.4;1.3.2	Compilation of hard document	SM	5	
11	1.3.4	Delivery of finished product	SM	1	
			Total		
			Vat @15%		
			Final Total		

Year 2008/9					
Unit Staff	**Init.**	**Per day**	**No of days**	**Cost**	**Total £**
Project Manager	TL	325	2		
Data Manager	SM	233	18		
Total Salary cost for year					
Non-staff costs					
Computer Consumables (MapInfo)					
Total non-staff costs					
Overheads					
Unit Overheads @25%					
VAT at 15%					
Project Total					

2.4 Archive

2.4.1 The archive will comprise the final hard copy report, the project correspondence (other than that of a commercially sensitive nature) and the End of Project Report. This archive will be the property of HTL and will be deposited in the HER. The finished product (database) will be submitted to the HER and be their property. EA retain copyright of the original dataset.

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Hall, D and Coles, J., 1994, *Fenland Survey: An essay in Landscape and Persistence*. Archaeological Report 1 (London: English Heritage)

Malone, S., forthcoming , 'Lidar Survey in the Witham Valley below Lincoln', Proceedings of the Witham Valley Research Group

Phillips, C.W., 1970, The Fenland in Roman Times (Royal Geog. Soc. Mongraph 5)

UK Archaeological Science 2007 Conference, Cambridge

Computer Applications in Archaeology 2008, York

Aerial Archaeology Research Group 2008, Ljubliana

Product Description

Product Number	**1**
Product Title	**South Lincolnshire Lidar Processing; Data base and hard copy**
Purpose of Product	**Create usable document for HER as set out in Aims and Objectives**
Composition	**Database; Bound hard copy**
Derived From	**EA dataset**
Format and Presentation	**Word document with plans in hard copy, plus digital imaging**
Allocated to	**Steve Malone**
Quality Criteria and Method	**Checked in house by T. Lane**
Person/Group Responsible for Quality Assurance	**T. Lane**
Person/Group Responsible for Approval	**T. Lane**
Planned Completion date	**3rd March 2009**

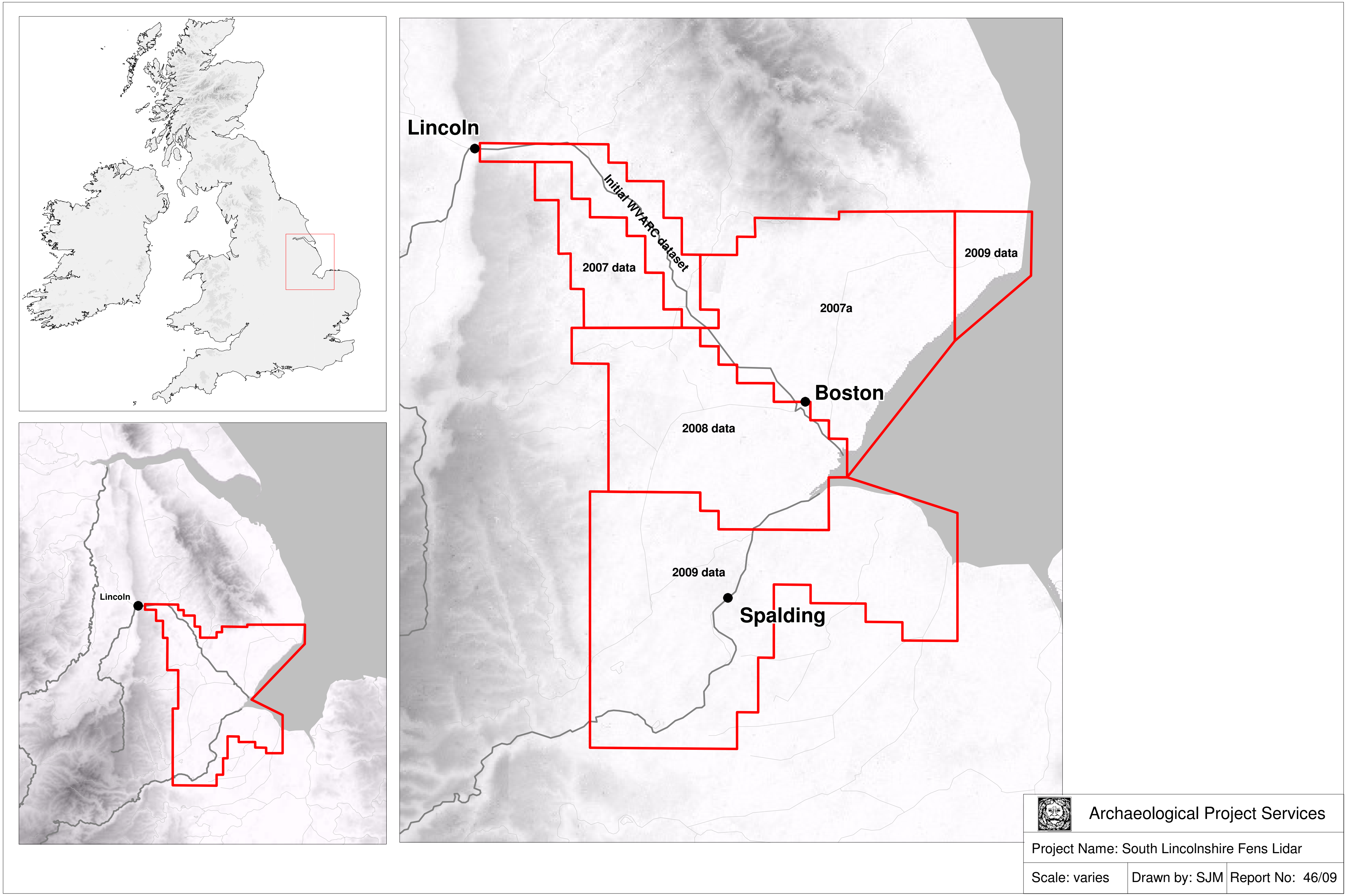


Figure 1 Location of survey areas

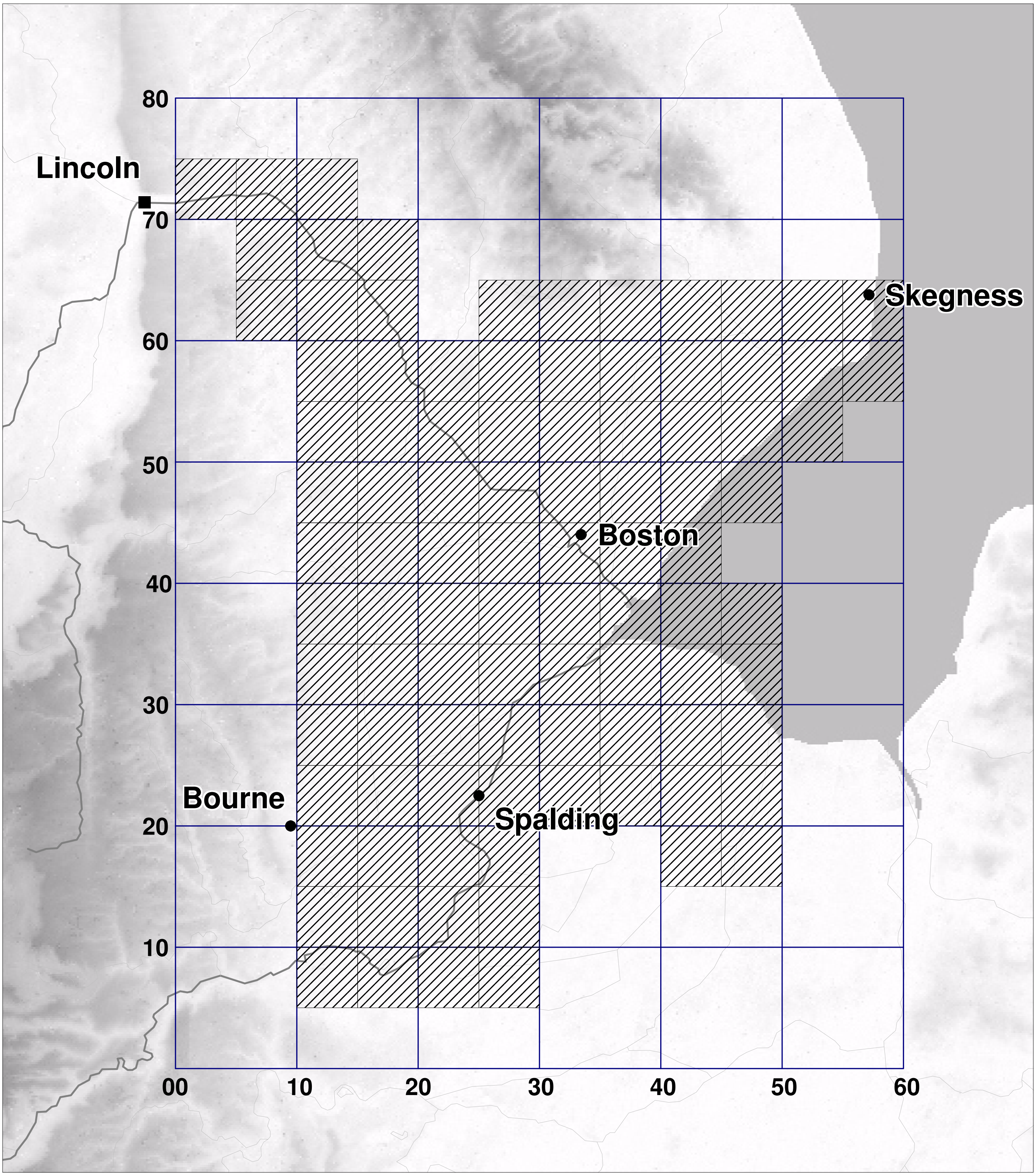


Figure 2 Key to Lidar survey areas and Geotiff imagery

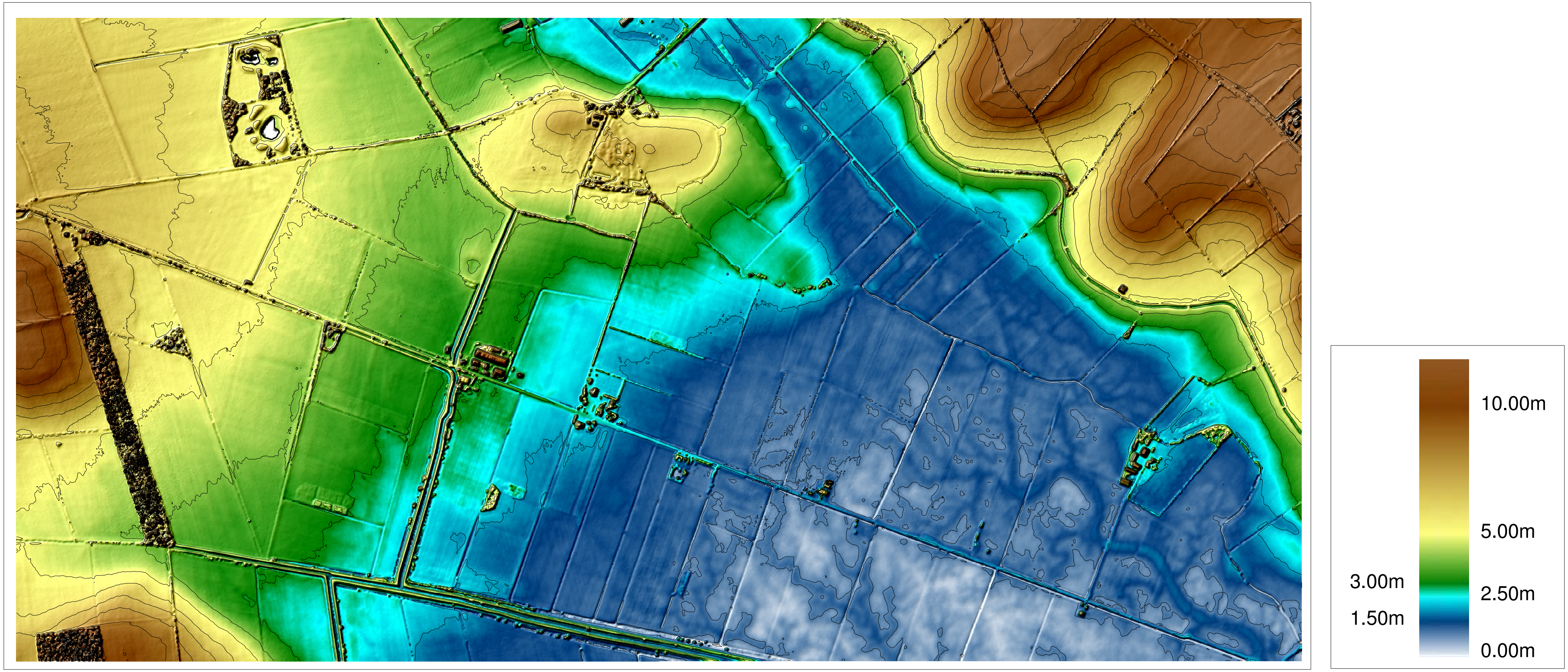


Figure 3 Catley Priory and Digby Fen showing relationship of colour ramp to 1m-interval contours

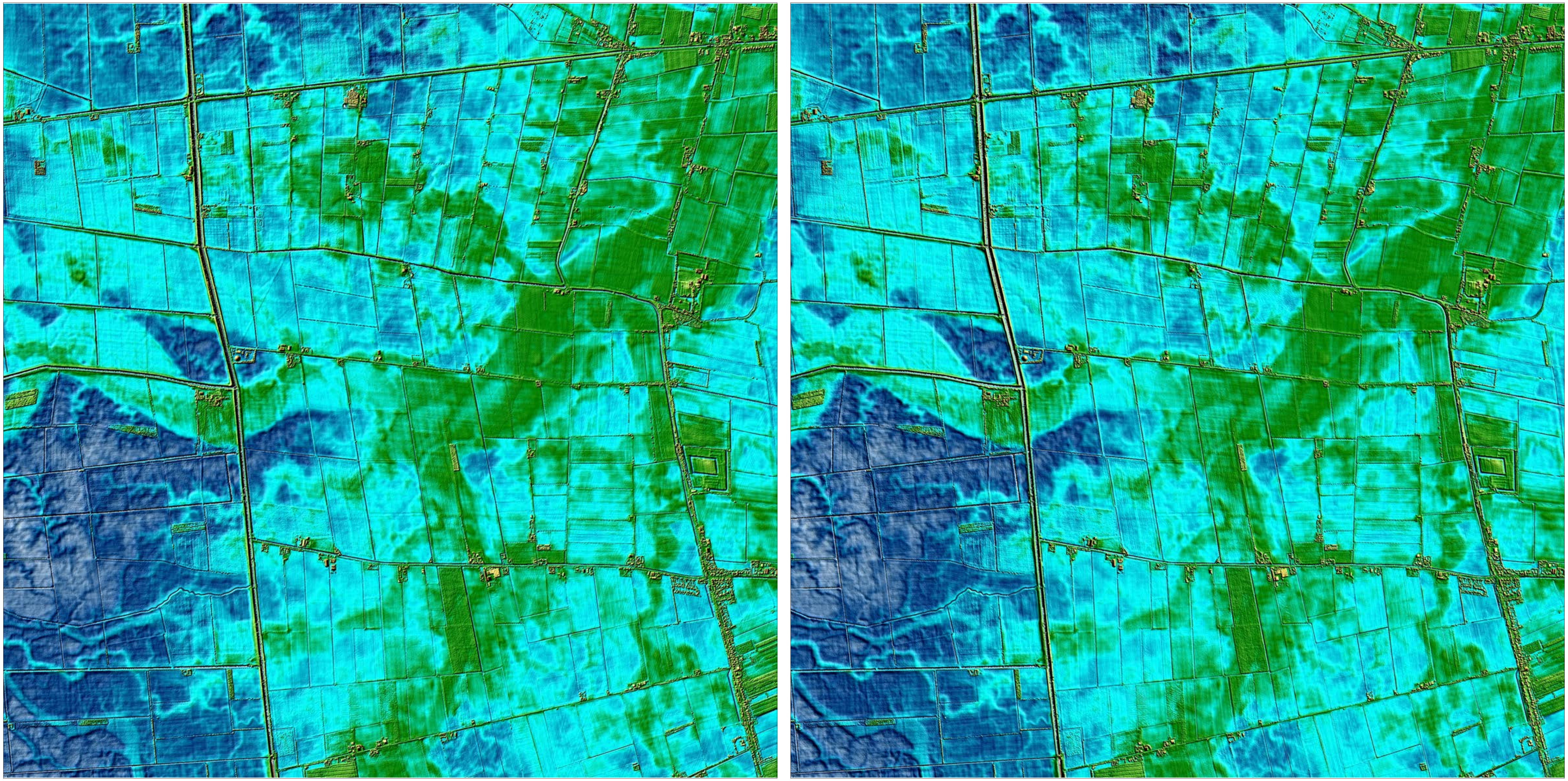
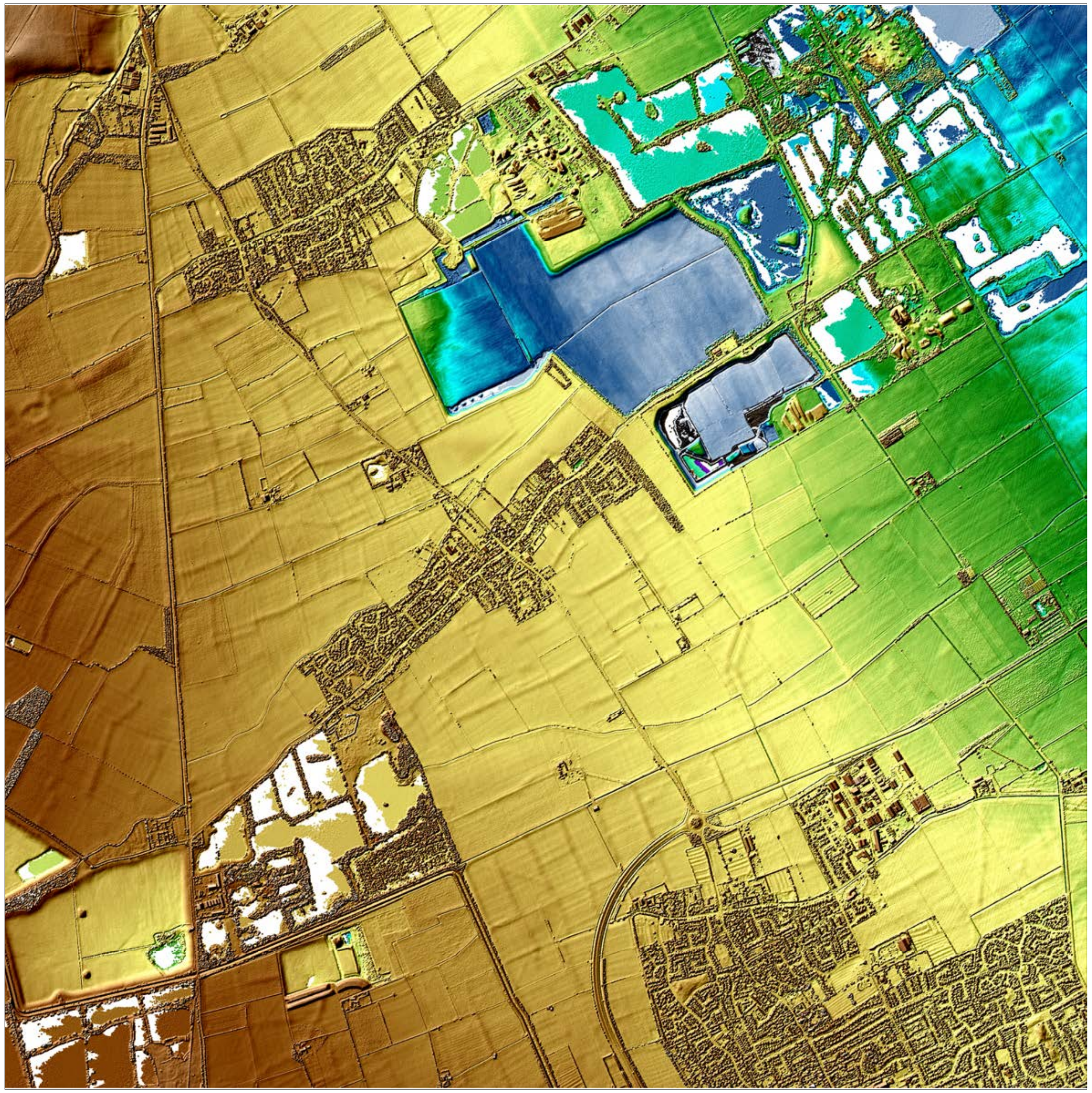


Figure 4 TF12NE Pinchbeck Fen: 'sunlight' from northwest (left); northeast (right) (1:25 000)



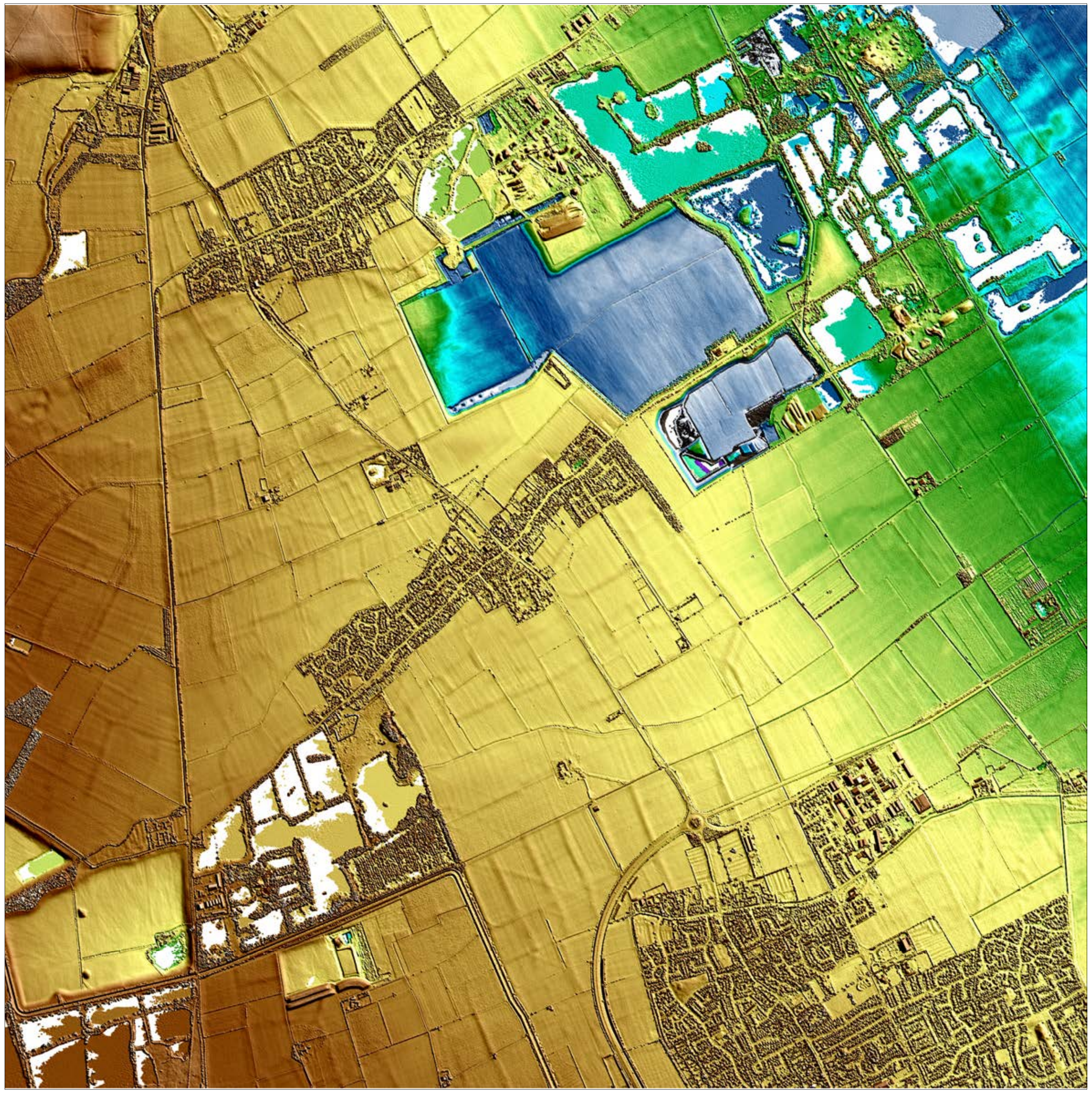


Figure 5 TF11SW Baston and Langtoft: 'sunlight' from northwest (left); northeast (right) (1:25 000)

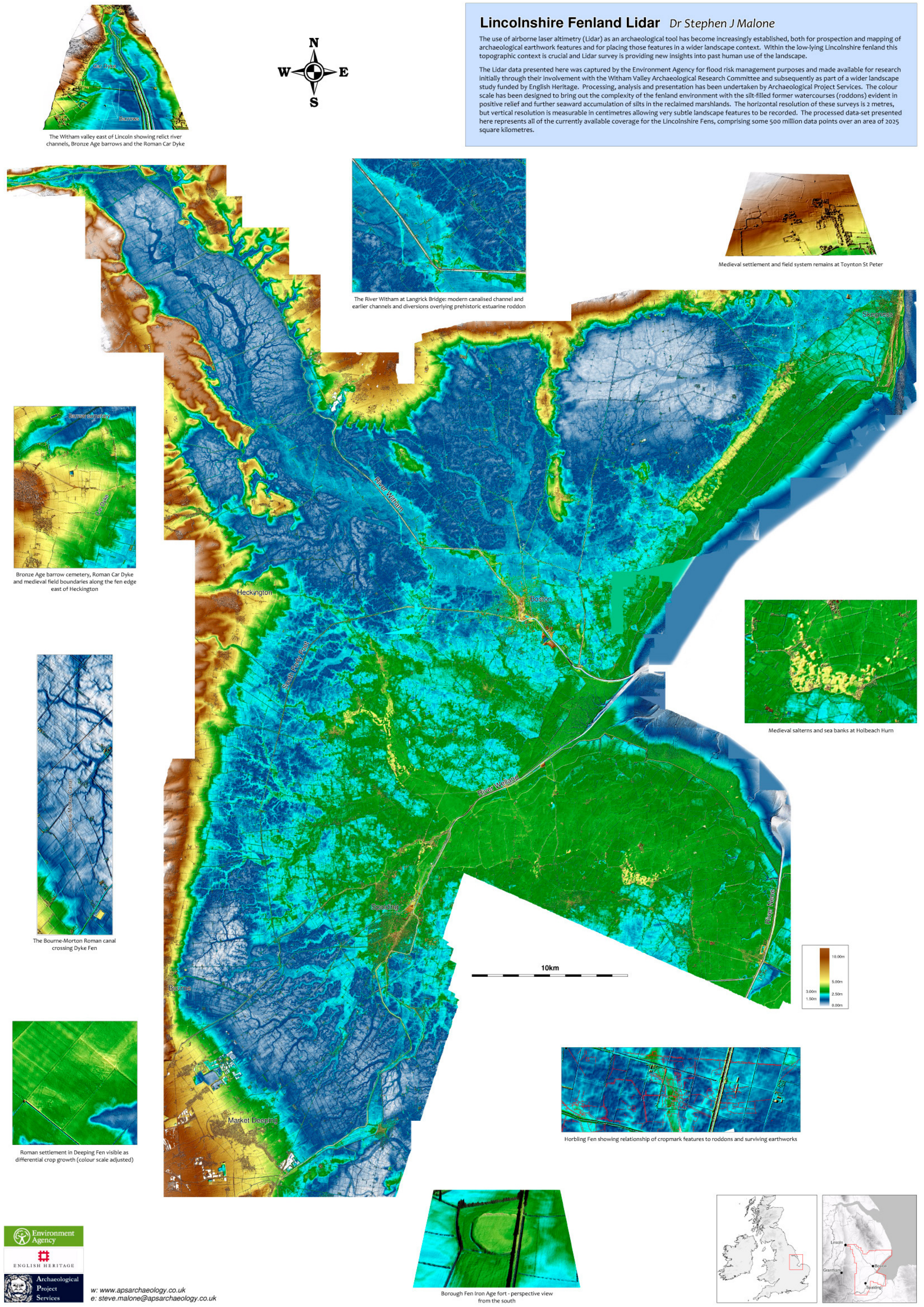


Figure 6 Poster design for dissemination of survey results

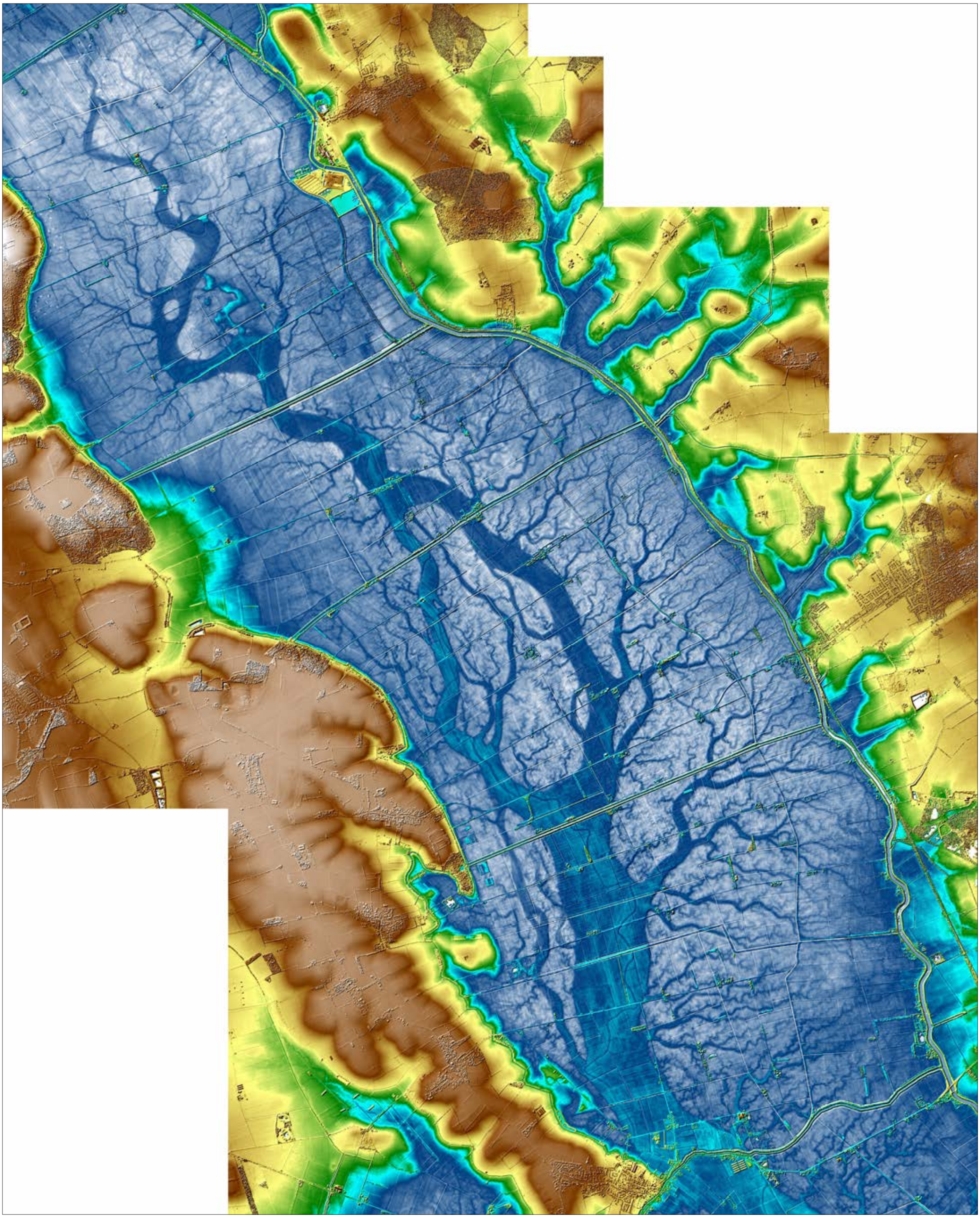


Figure 7 Roddon system of prehistoric estuarine and salt-marsh channels in the Witham Valley

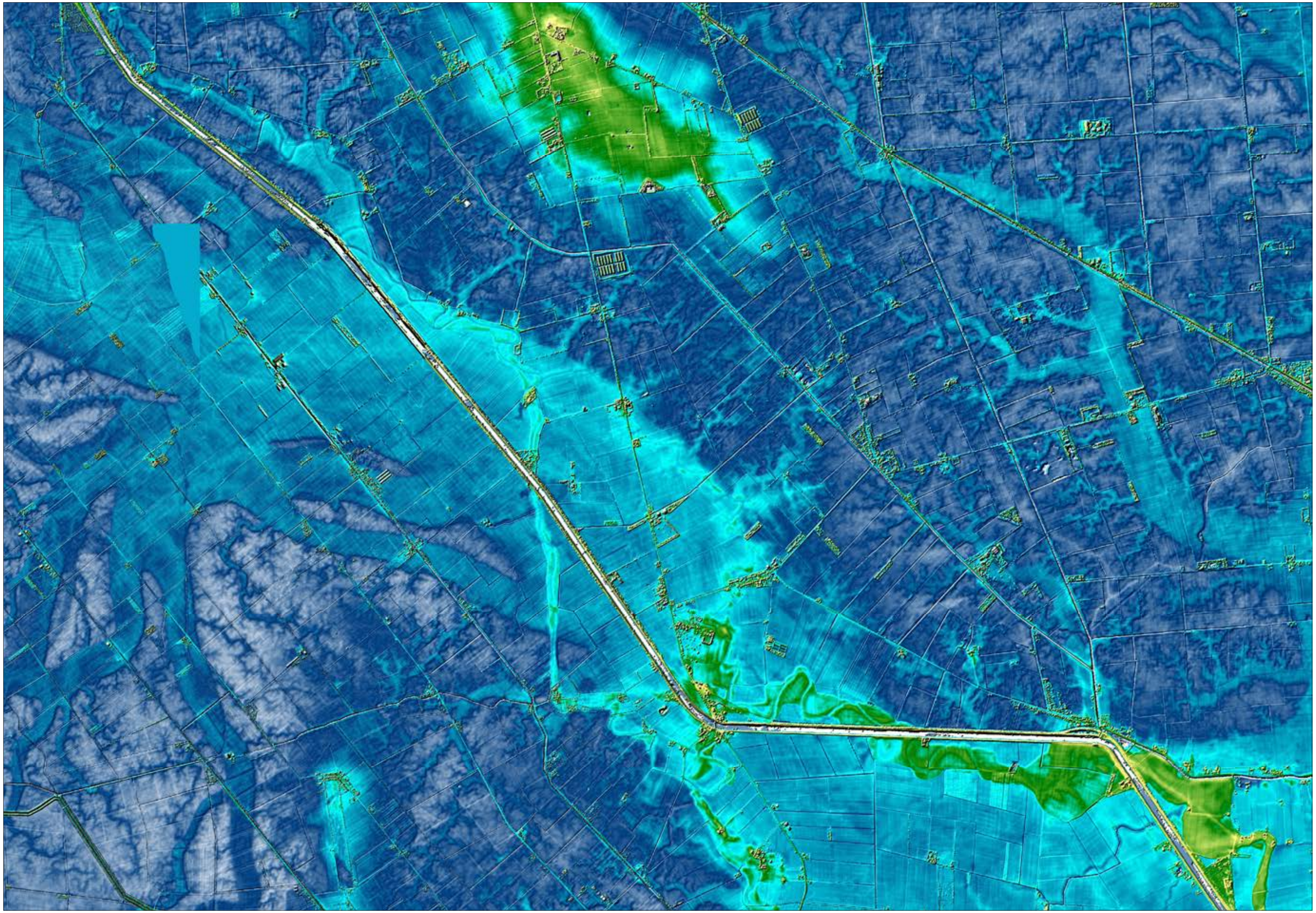


Figure 8 The River Witham at Langrick Bridge: modern canalised channel and earlier channels and diversions overlying prehistoric estuarine roddon (1:50 000)

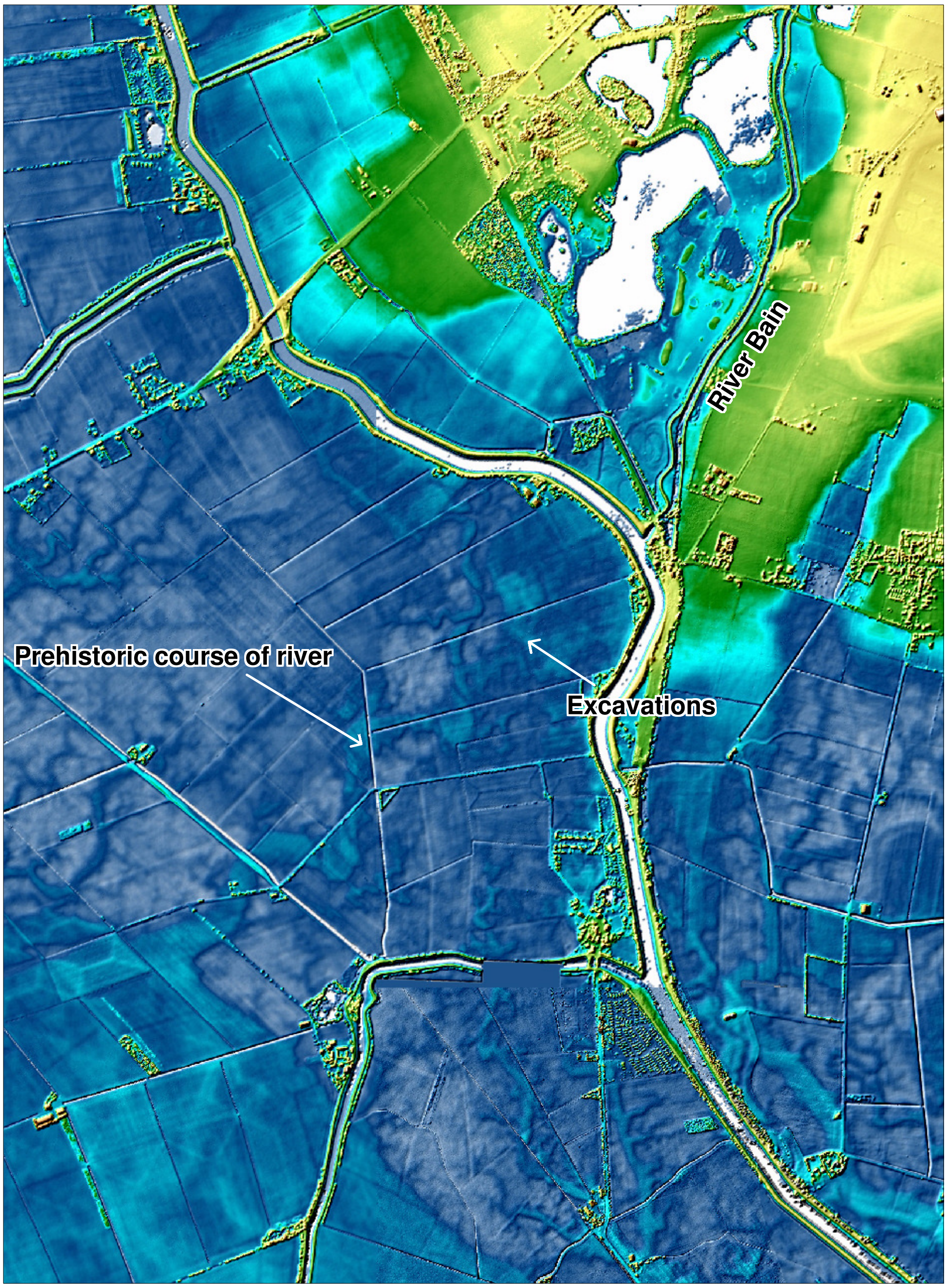


Figure 9 Dogdyke and the River Bain (1:25 000)

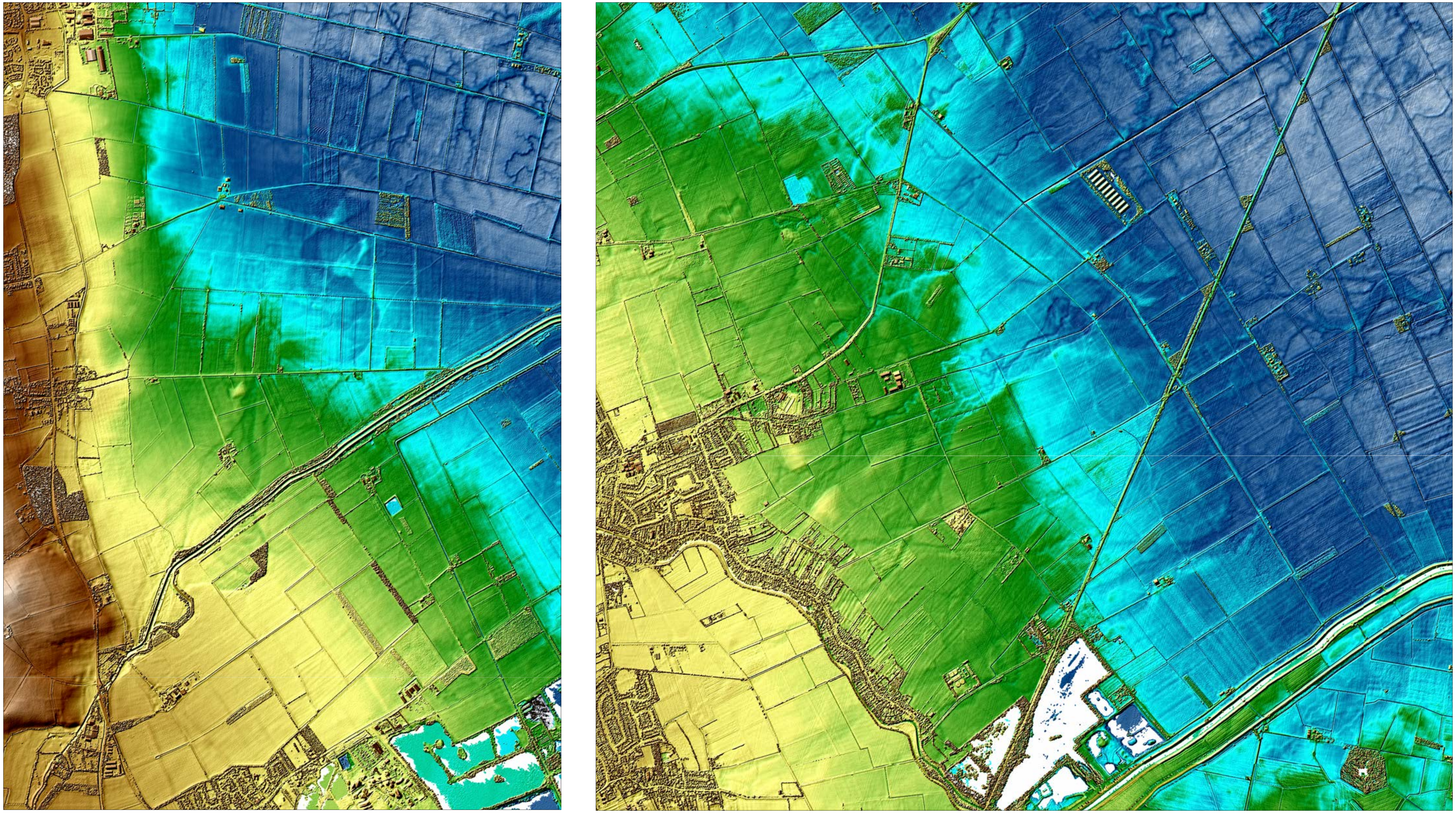
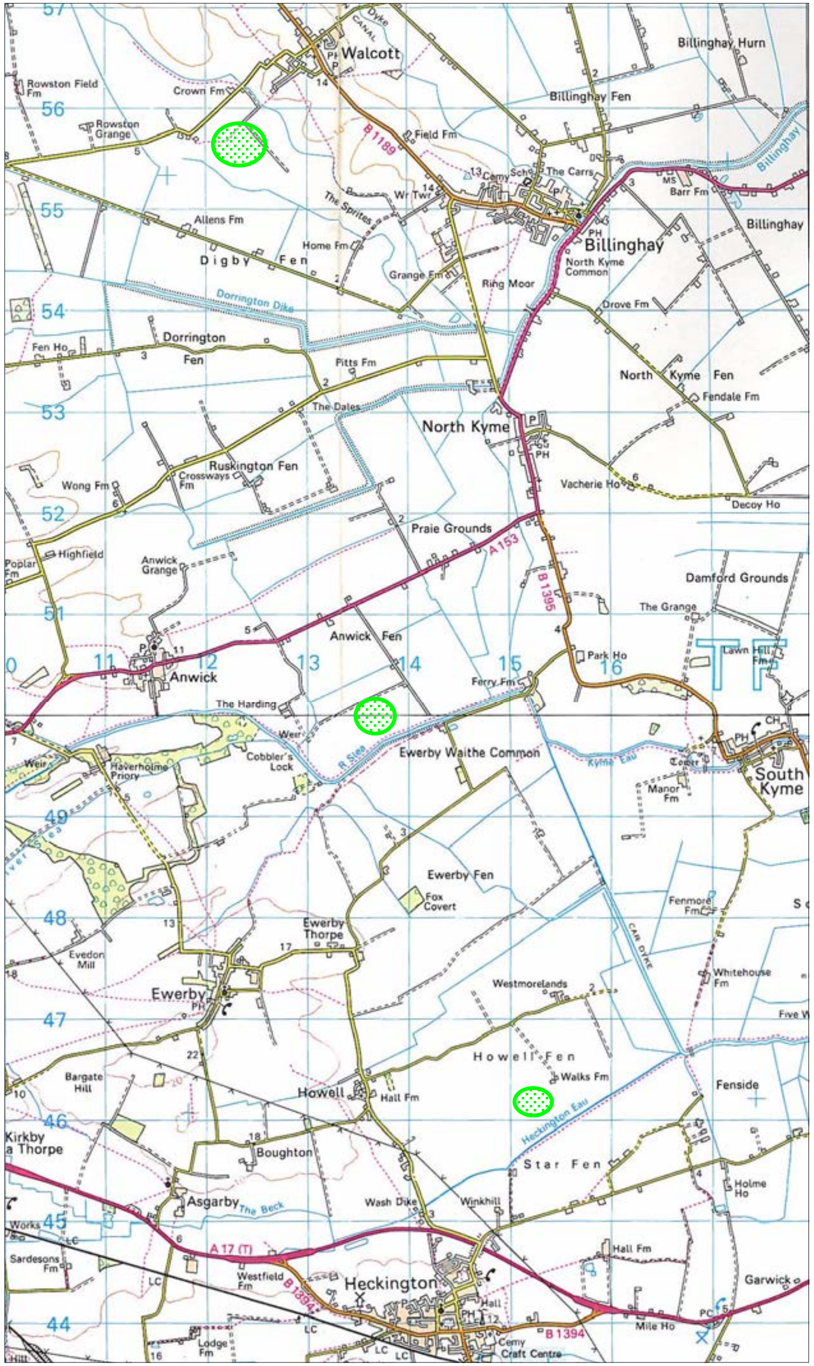


Figure 10 Fen-edge drainage: River Glen (left); River Welland (right) (1:25 000)



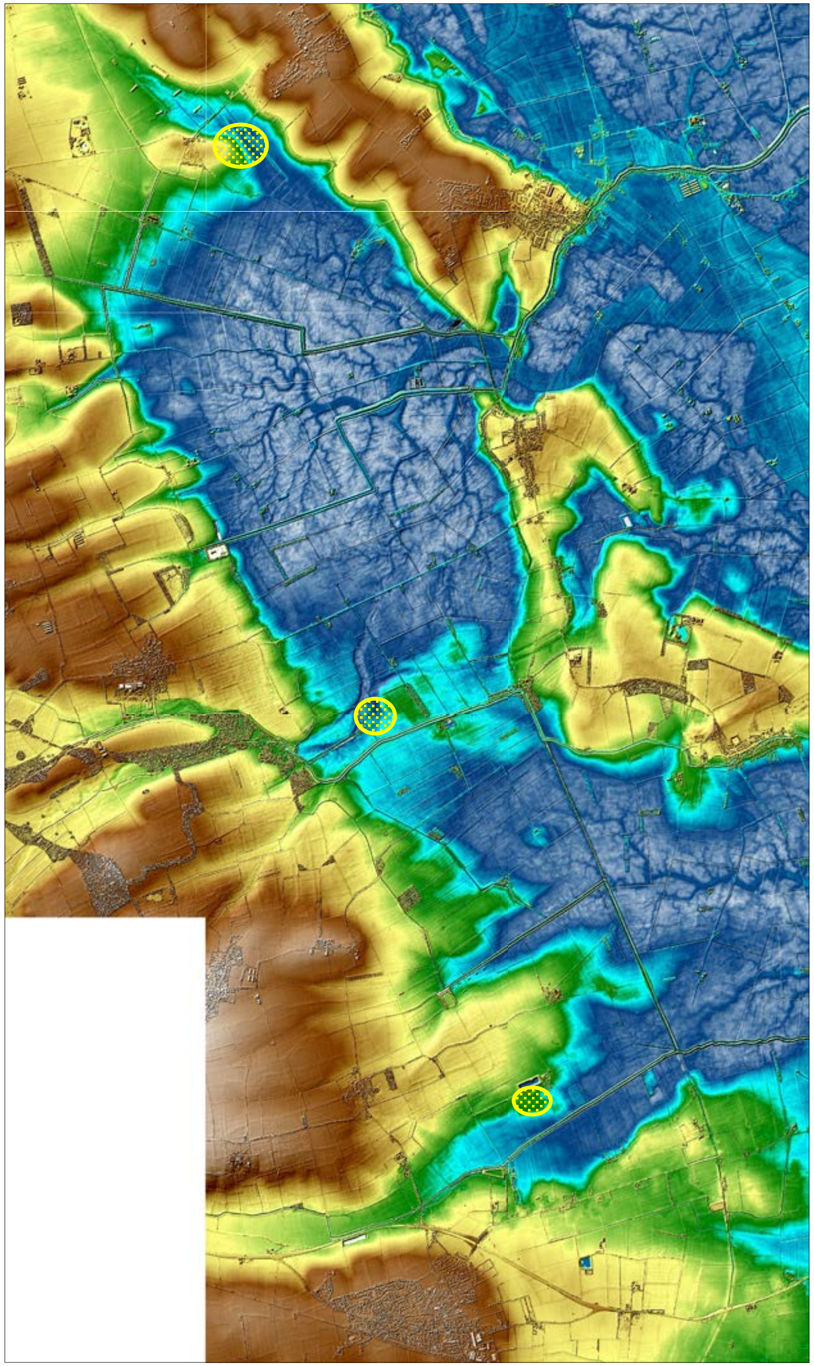


Figure 11 Fen-edge barrow cemeteries in landscape context

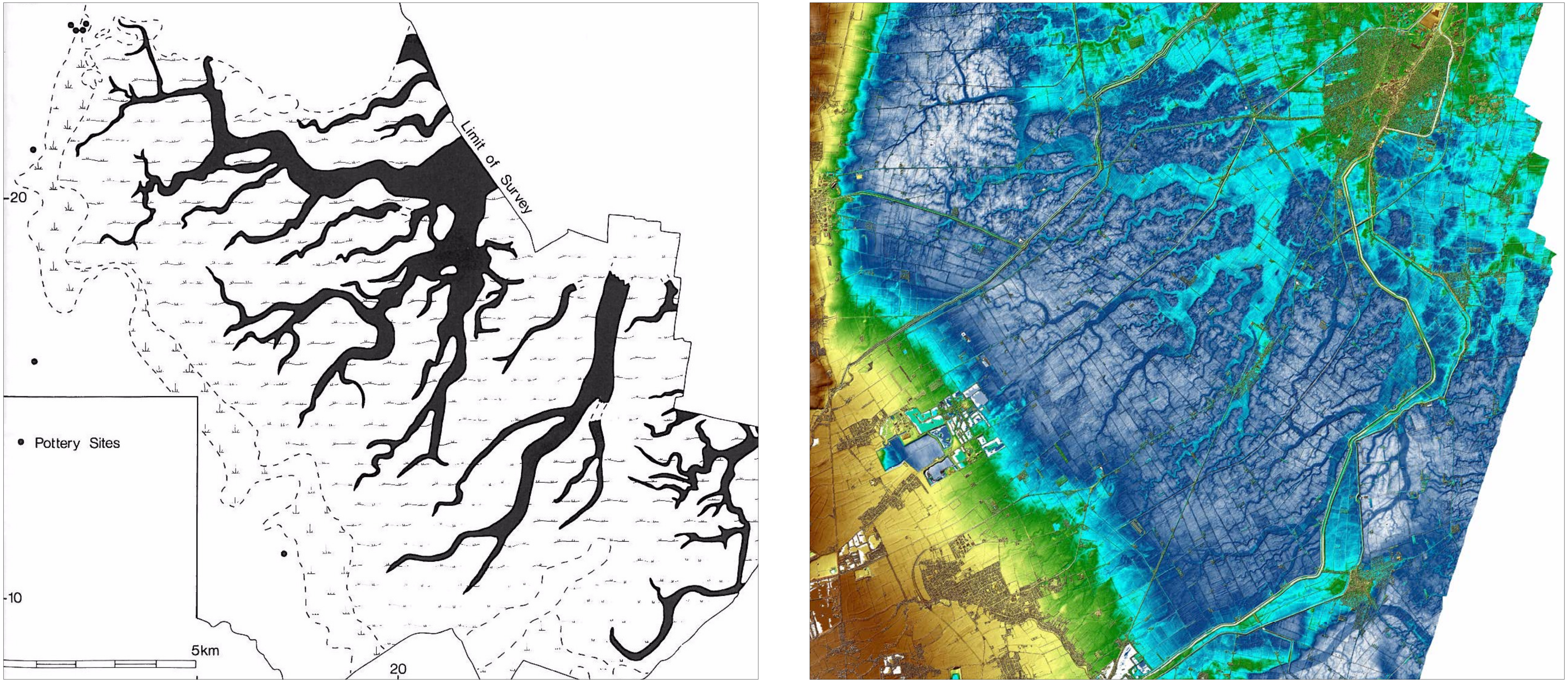


Figure 12 Fenland Project plot of Roddons in Deeping Fen in comparison to Lidar plot (1:100 000)

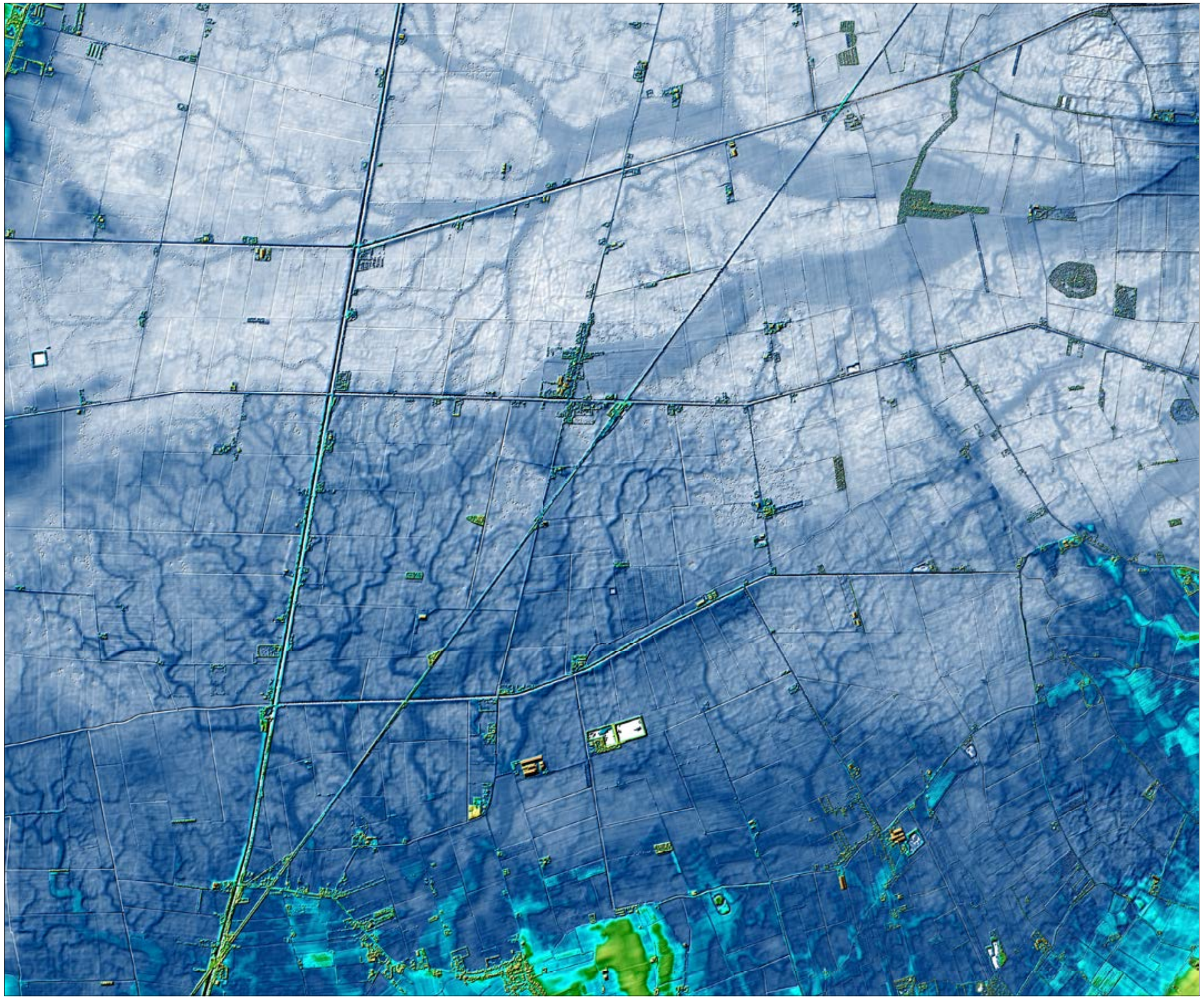
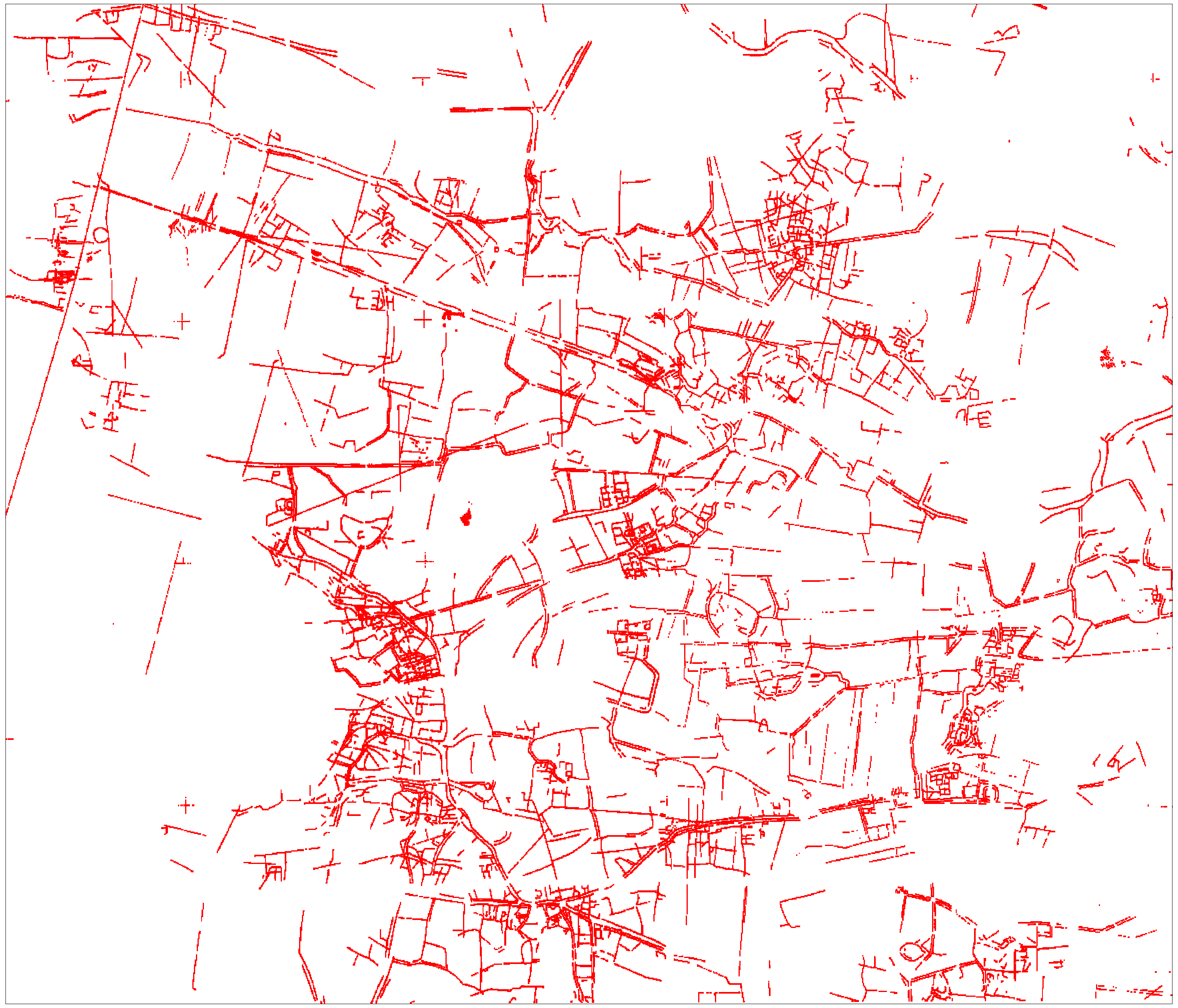


Figure 13 North-South drainage on the southern edge of East Fen overlying earlier West-East drainage pattern (1:50 000)



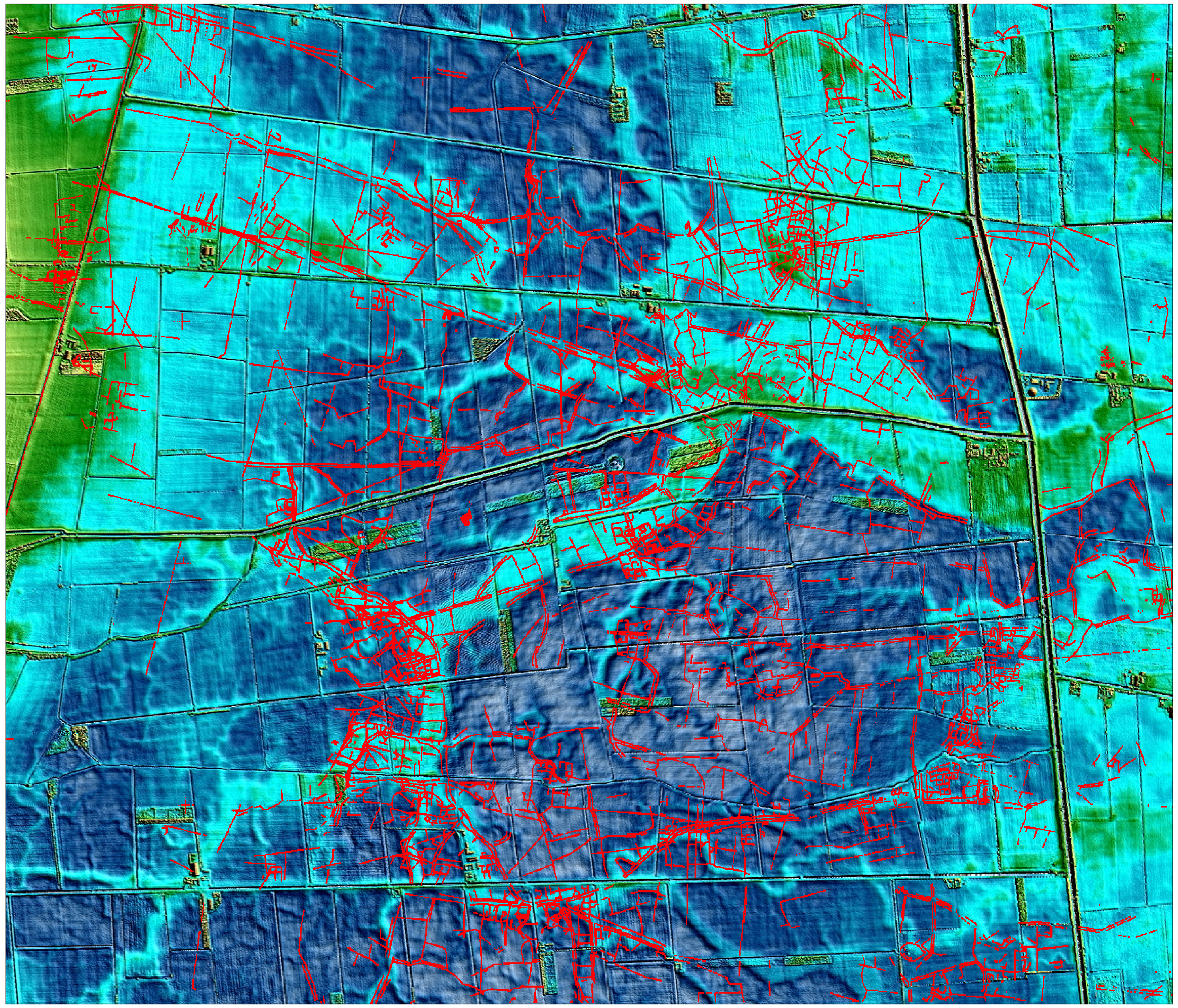


Figure 14 Rippingale Fen: NMP air-photo mapping overlaid on Lidar plot (1:25 000)

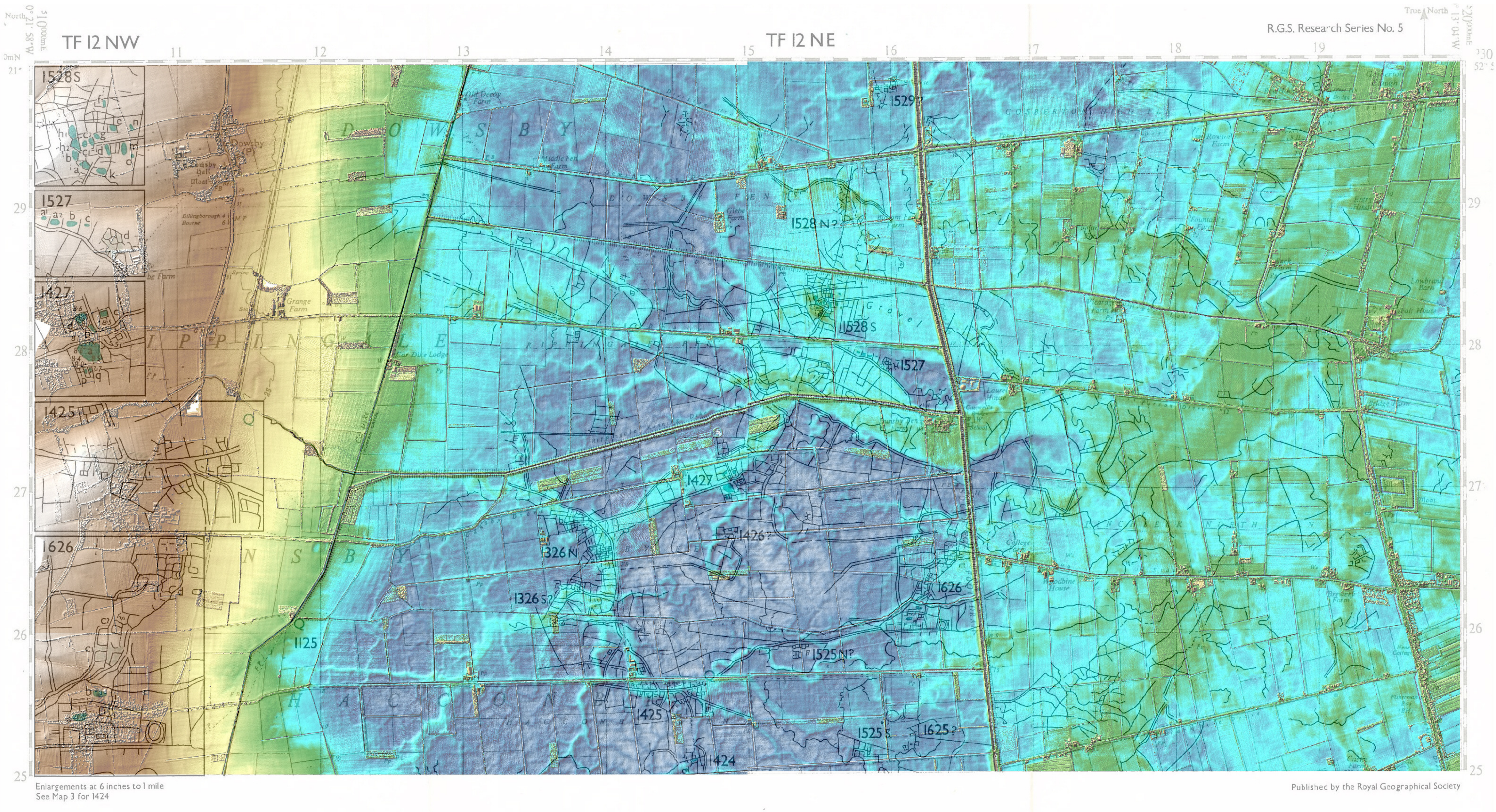


Figure 15 Fenland in Roman Times mapping overlaid on Lidar plot (1:25 000)

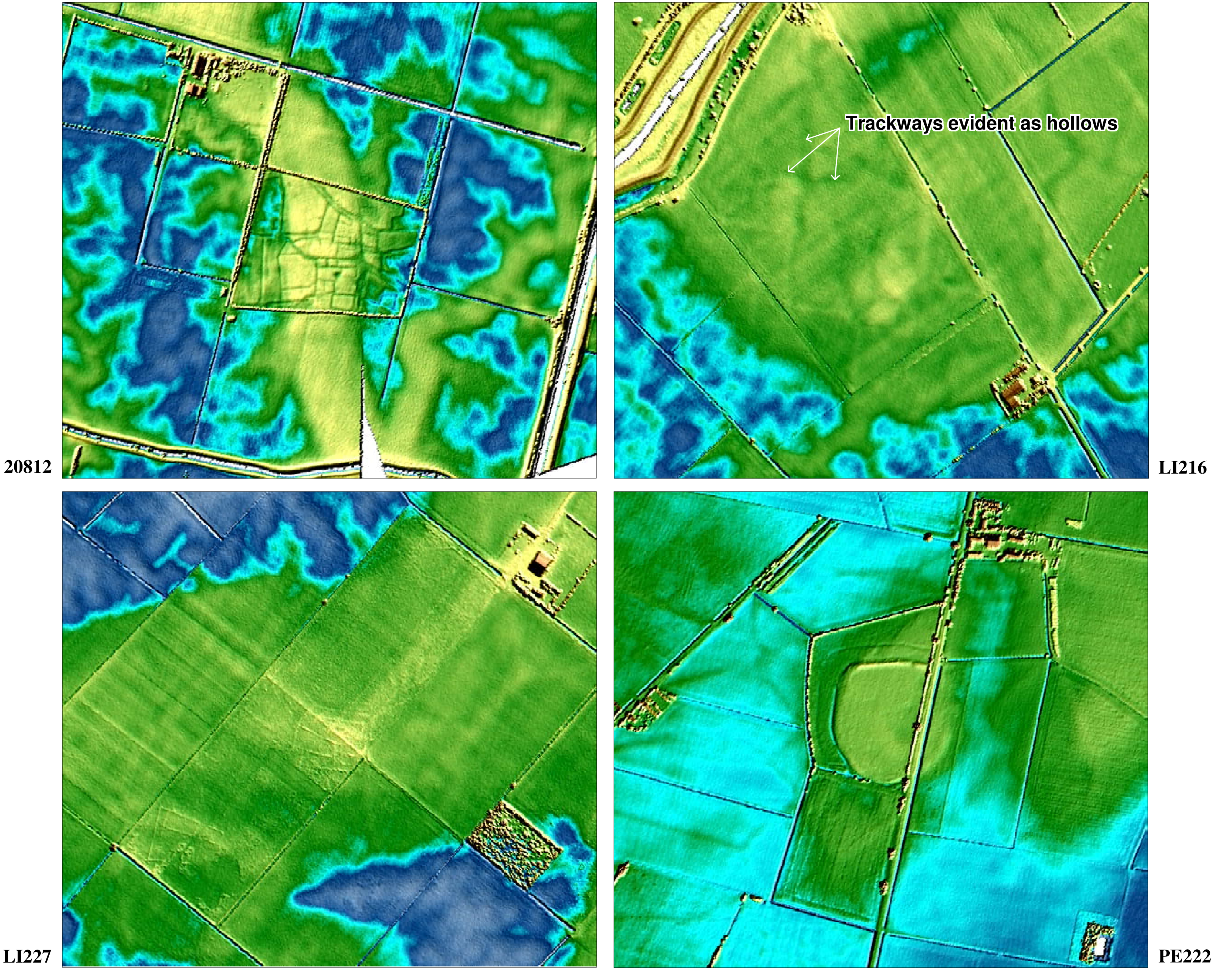


Figure 16 Fen settlement (colour scales adjusted for emphasis) (1:10 000)

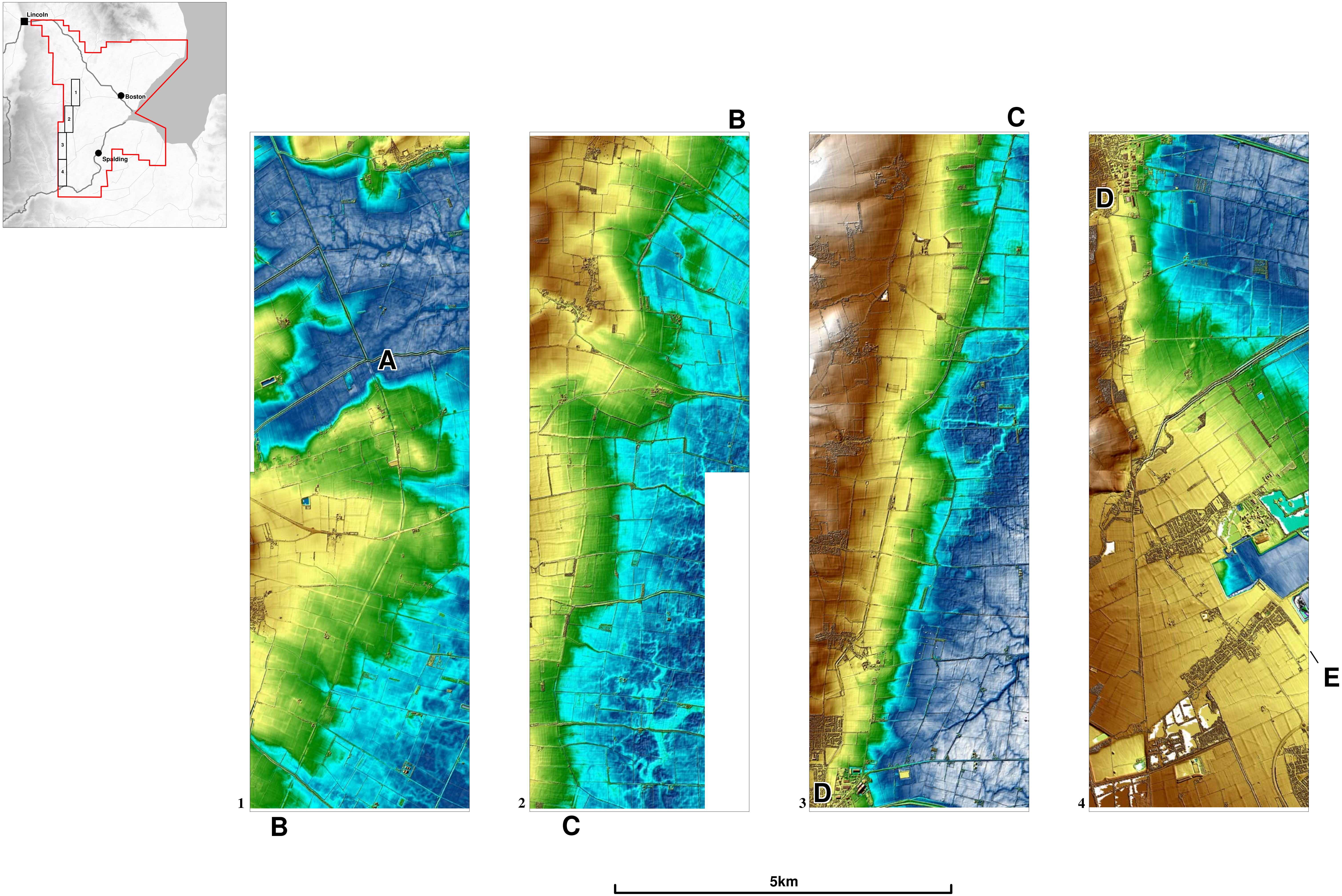


Figure 17 The Car Dyke (1:50 000)

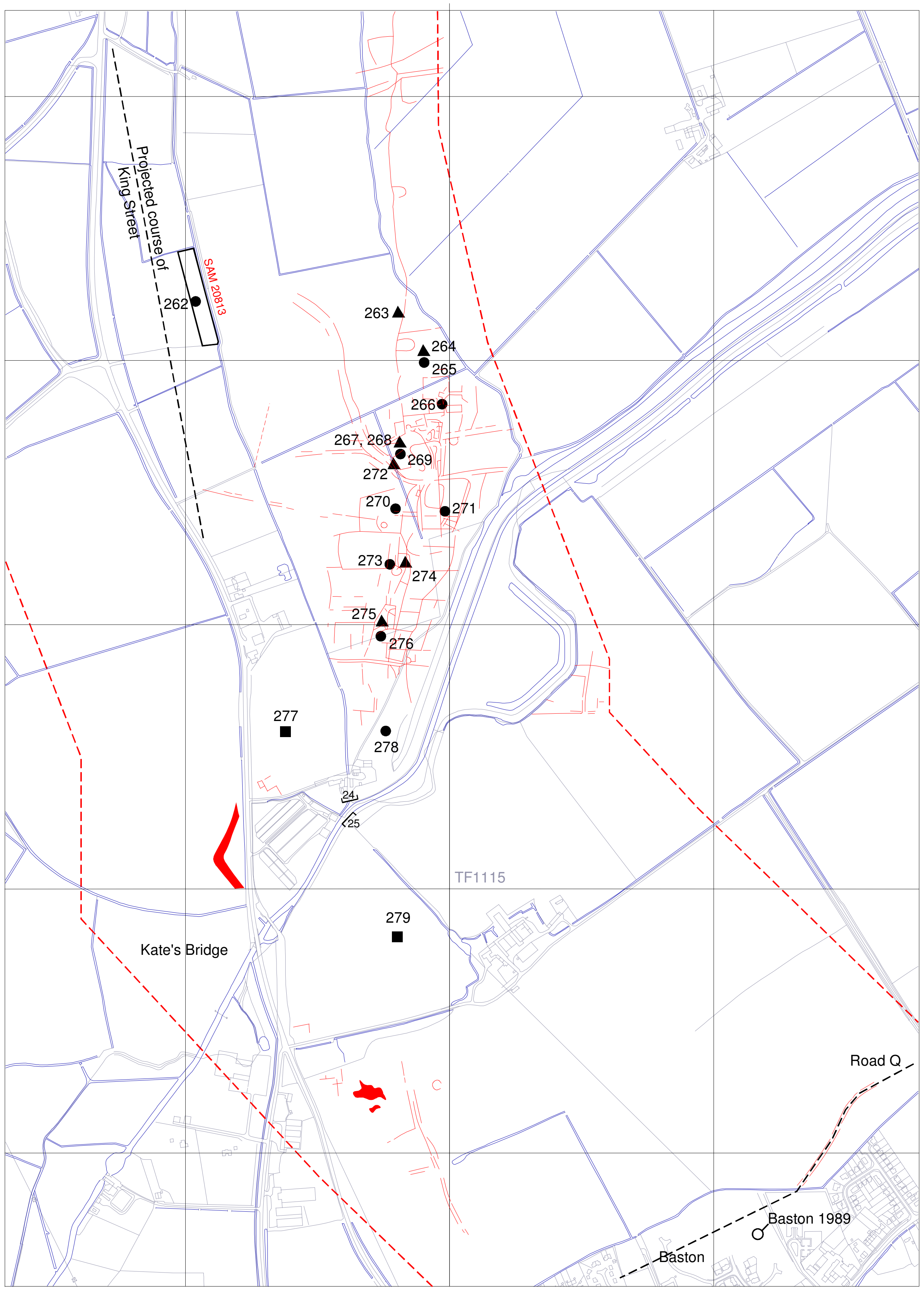


Figure 18 The Car Dyke: Thurlby to Baston (after Simmons and Cope-Faulkner 2004, fig. 63) with Lidar plot (1:10 000)

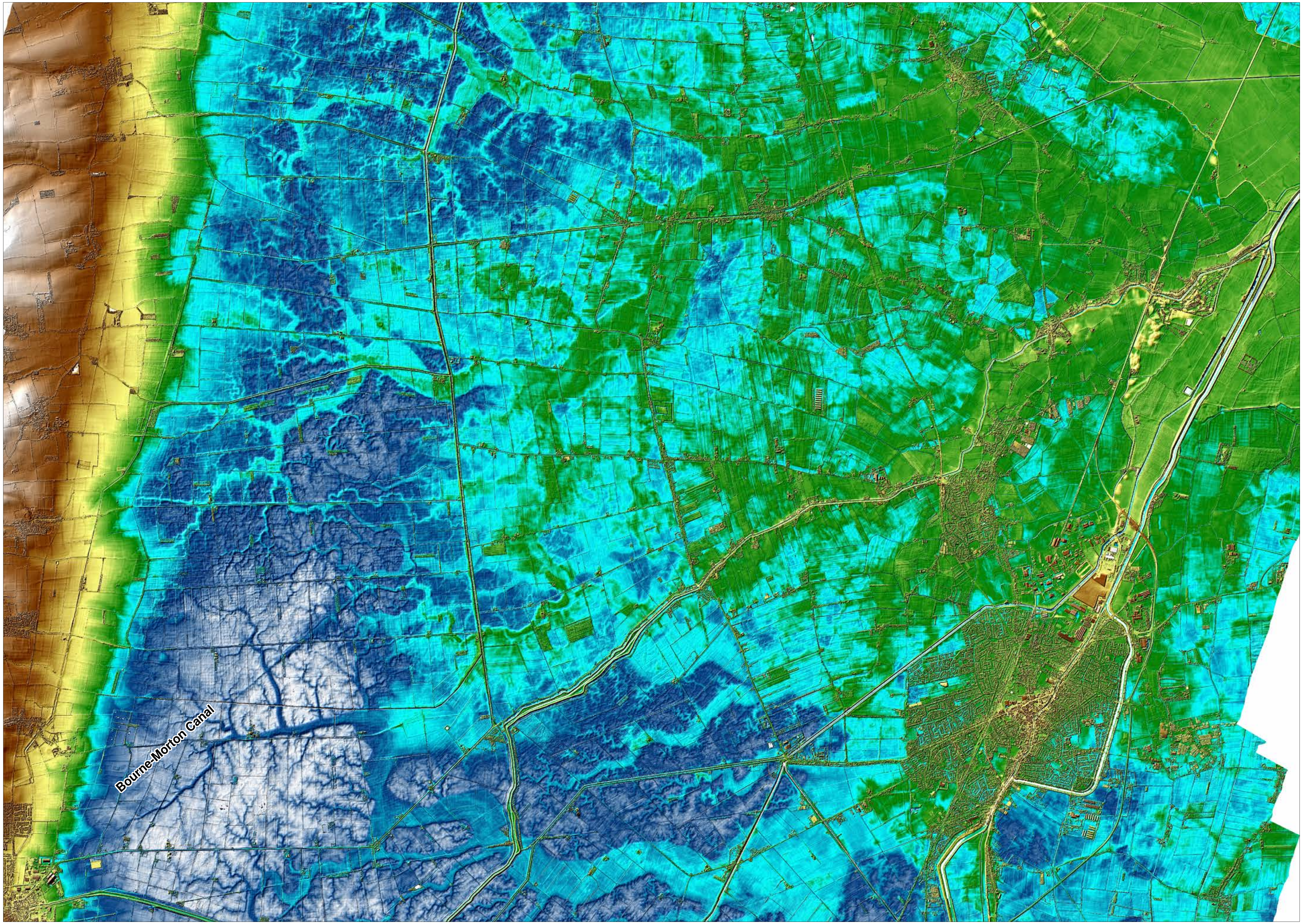


Figure 19 Bourne-Morton Canal and seaward channels (1:50 000)

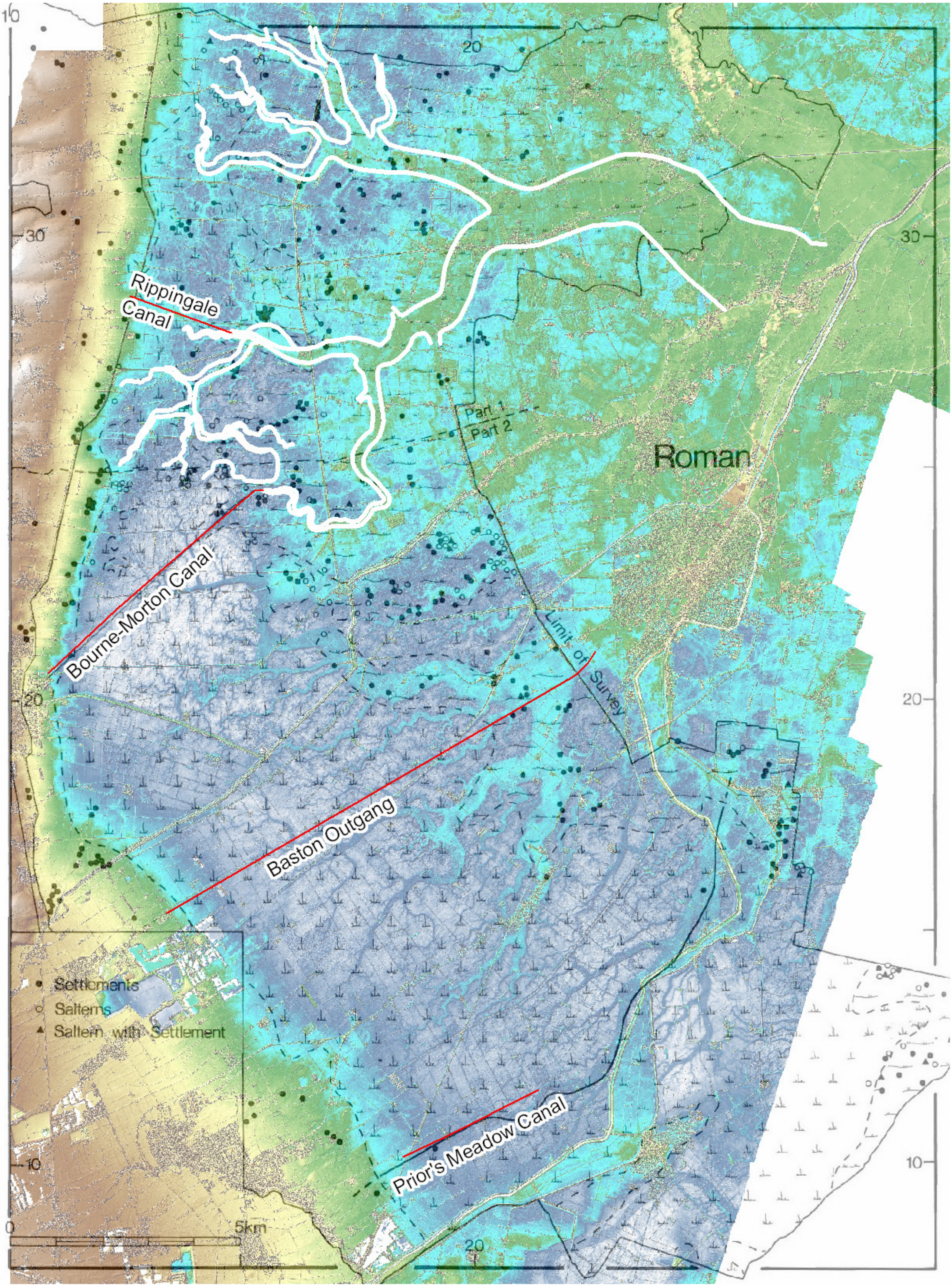
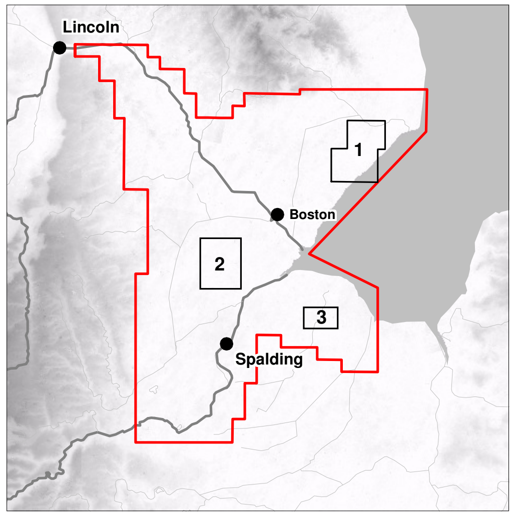
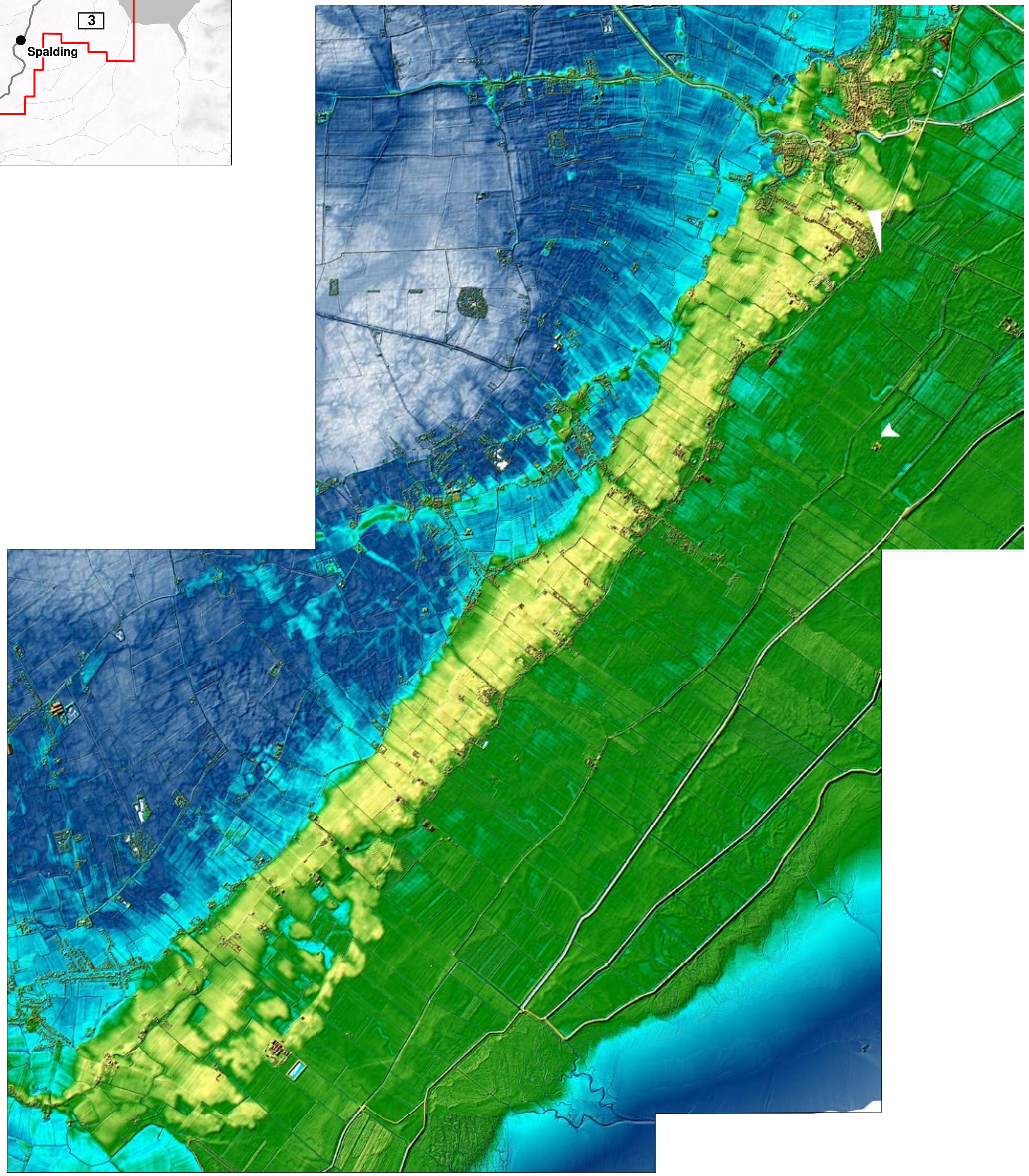
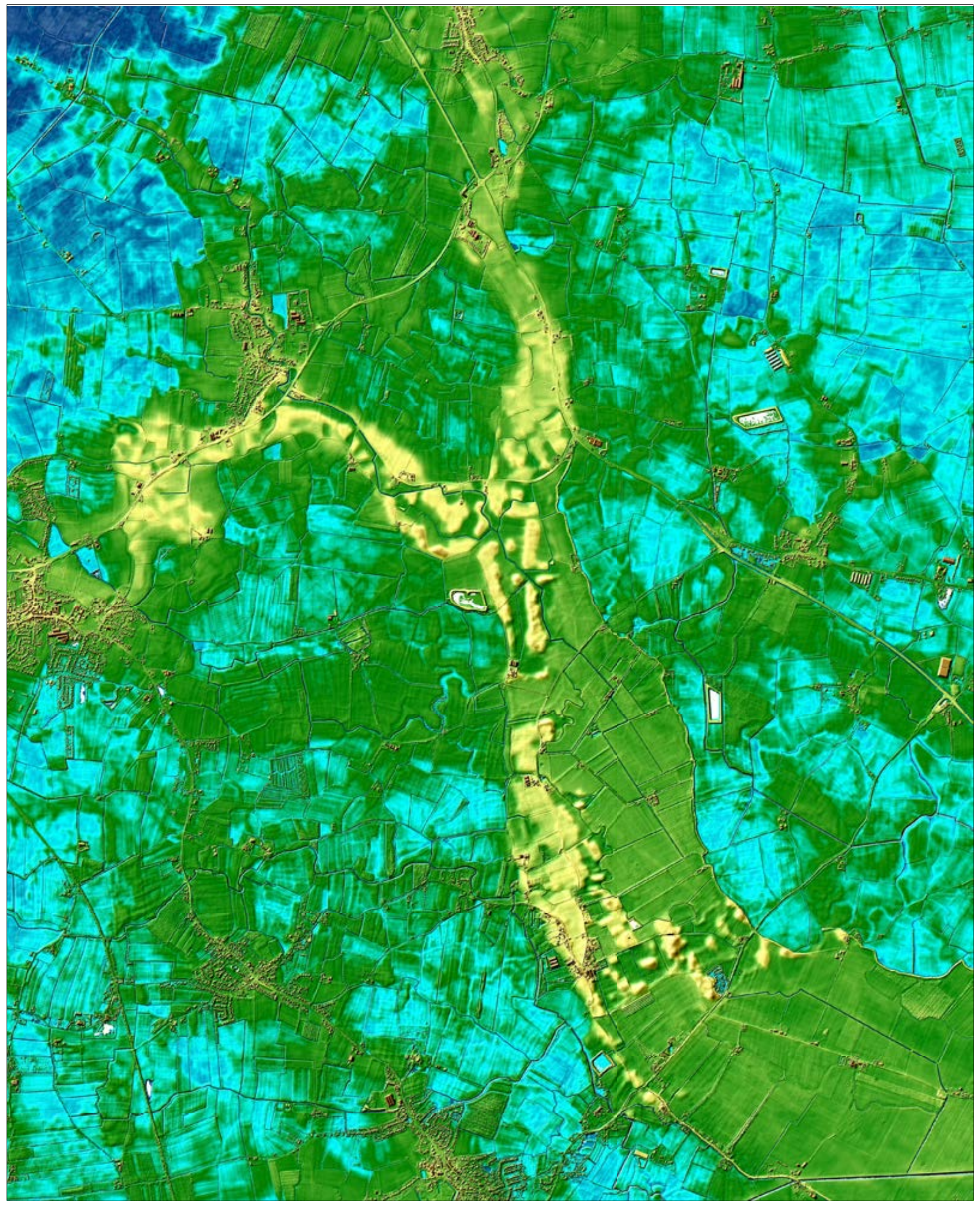


Figure 20 Eastward communications from the fen edge (1:100 000)





1 Friskney and Wrangle Tofts

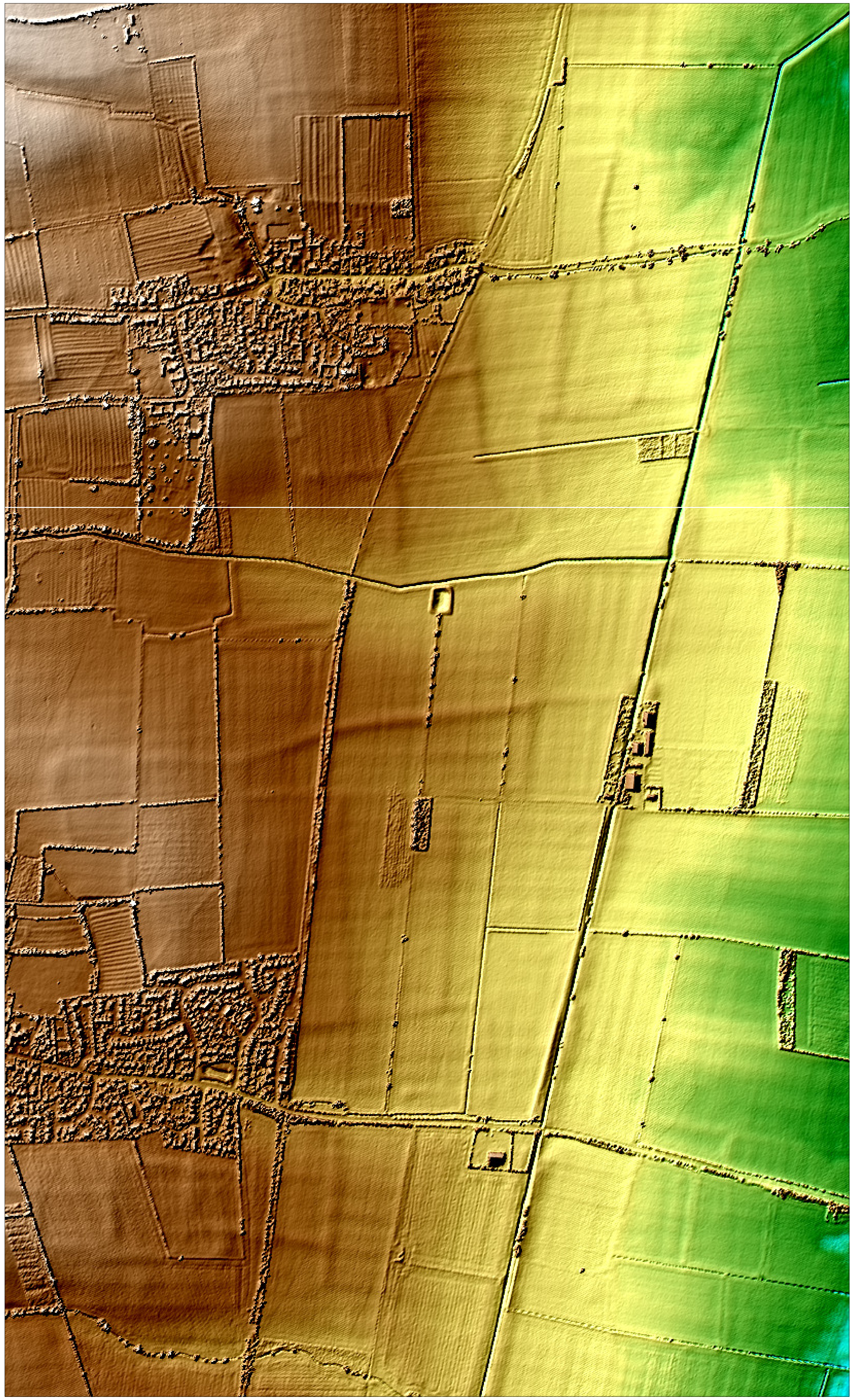


2 Bicker Haven

3 Holbeach Hurn

5km

Figure 21 Medieval salterns (1:50 000)



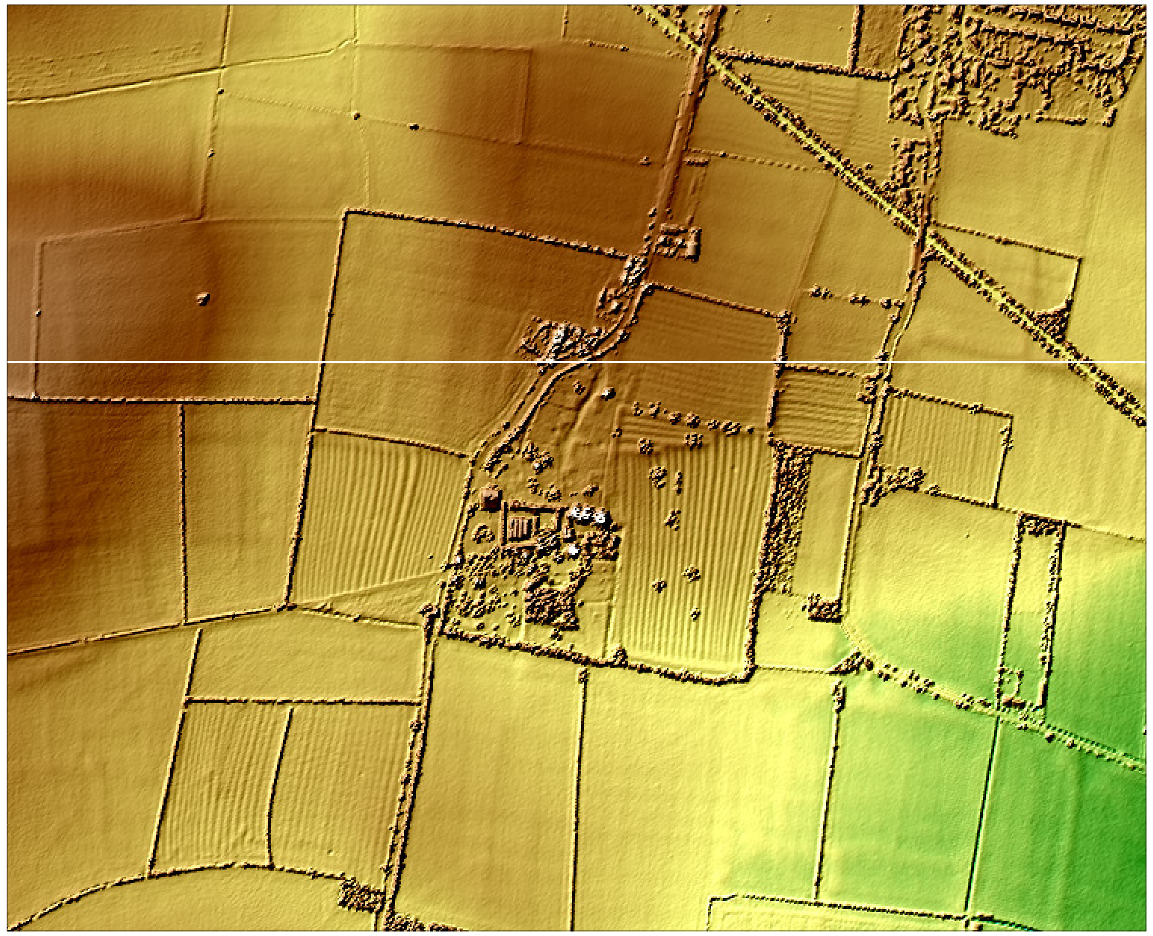


Figure 22 Medieval earthworks on the fen-edge uplands: Morton and Haconby (left); Thorpe Latimer (right) (1:10 000)

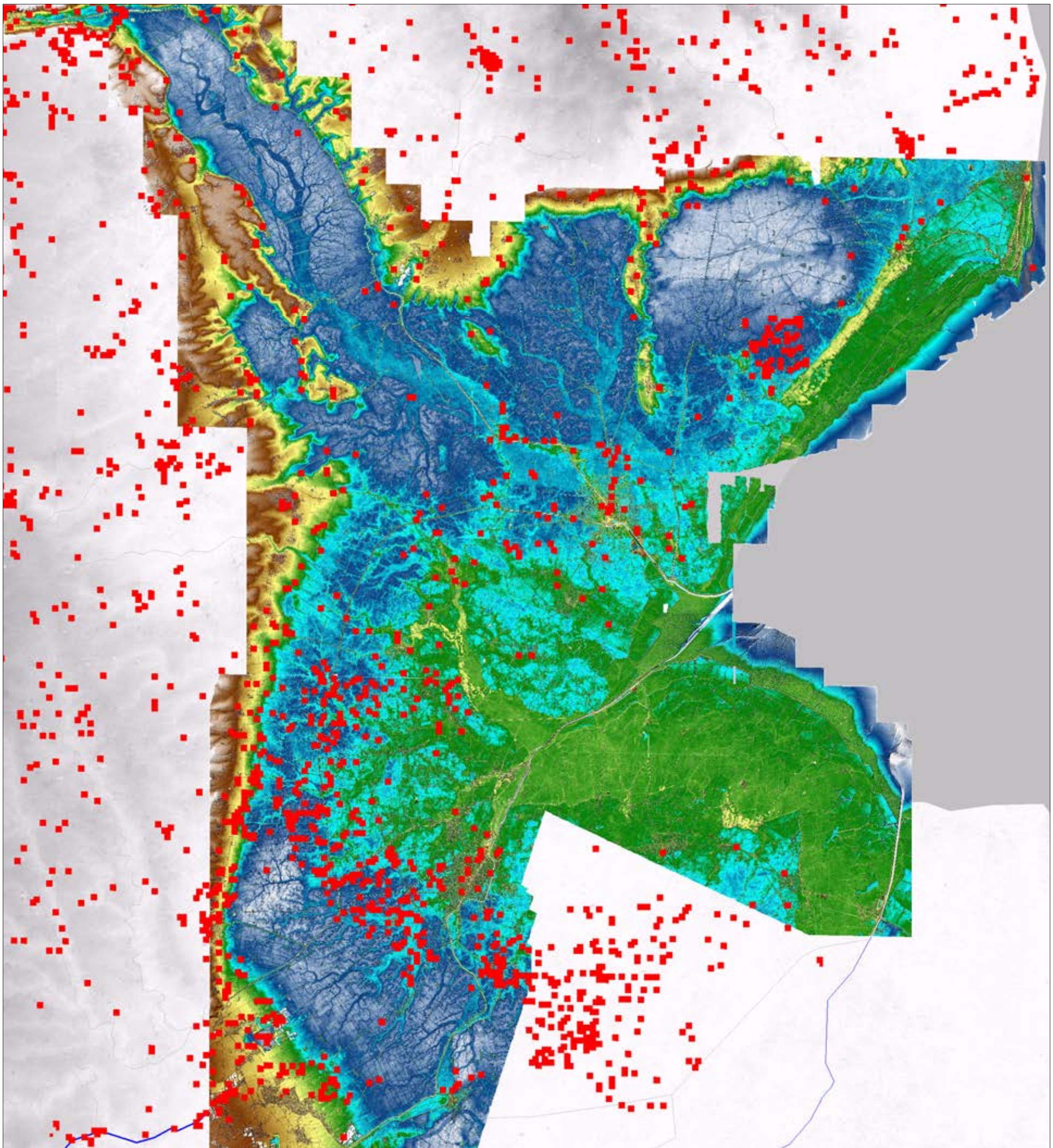


Figure 23 Lincolnshire HER Roman period records overlaid on Lidar plot

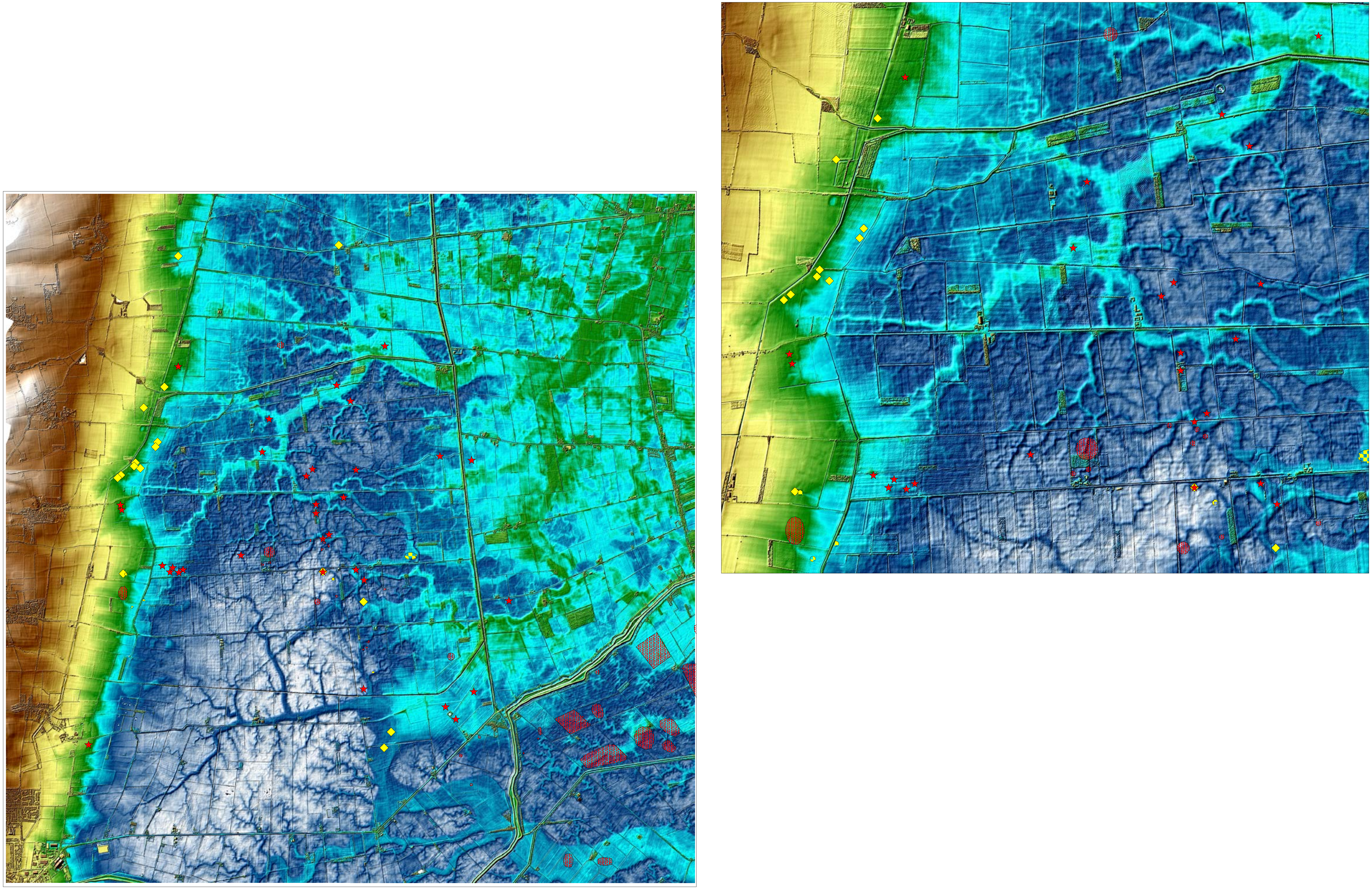


Figure 24 TF12: Iron Age (yellow) and Roman (red) salterns recorded in the HER in relation to extinct creek systems (1:50 000; detail 1:25 000)

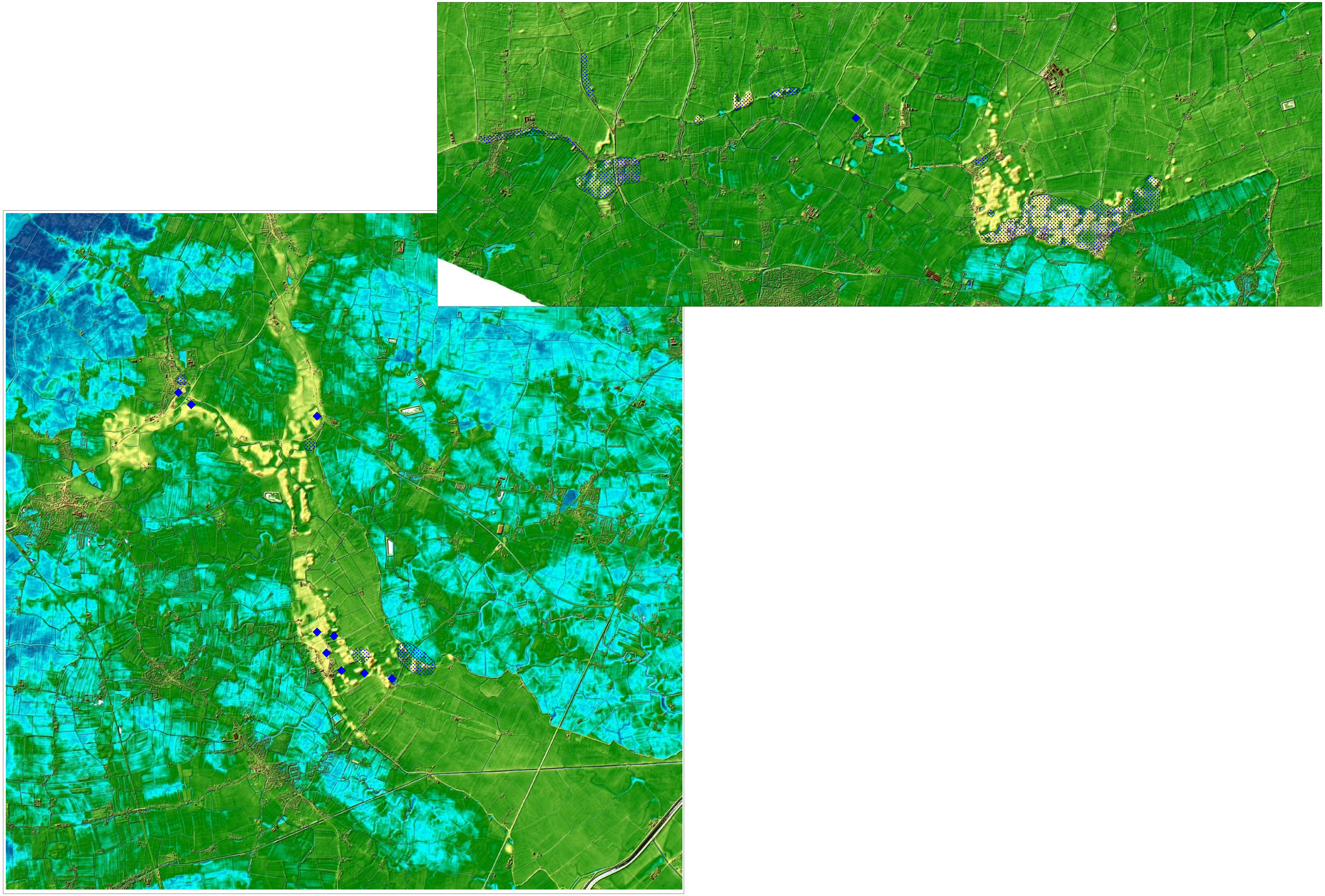


Figure 25 Medieval salterns recorded in HER overlaid on Lidar plot: TF23 (lower left); Sacacen's Head and Holbeach Hurn (upper right) (1:50 000)

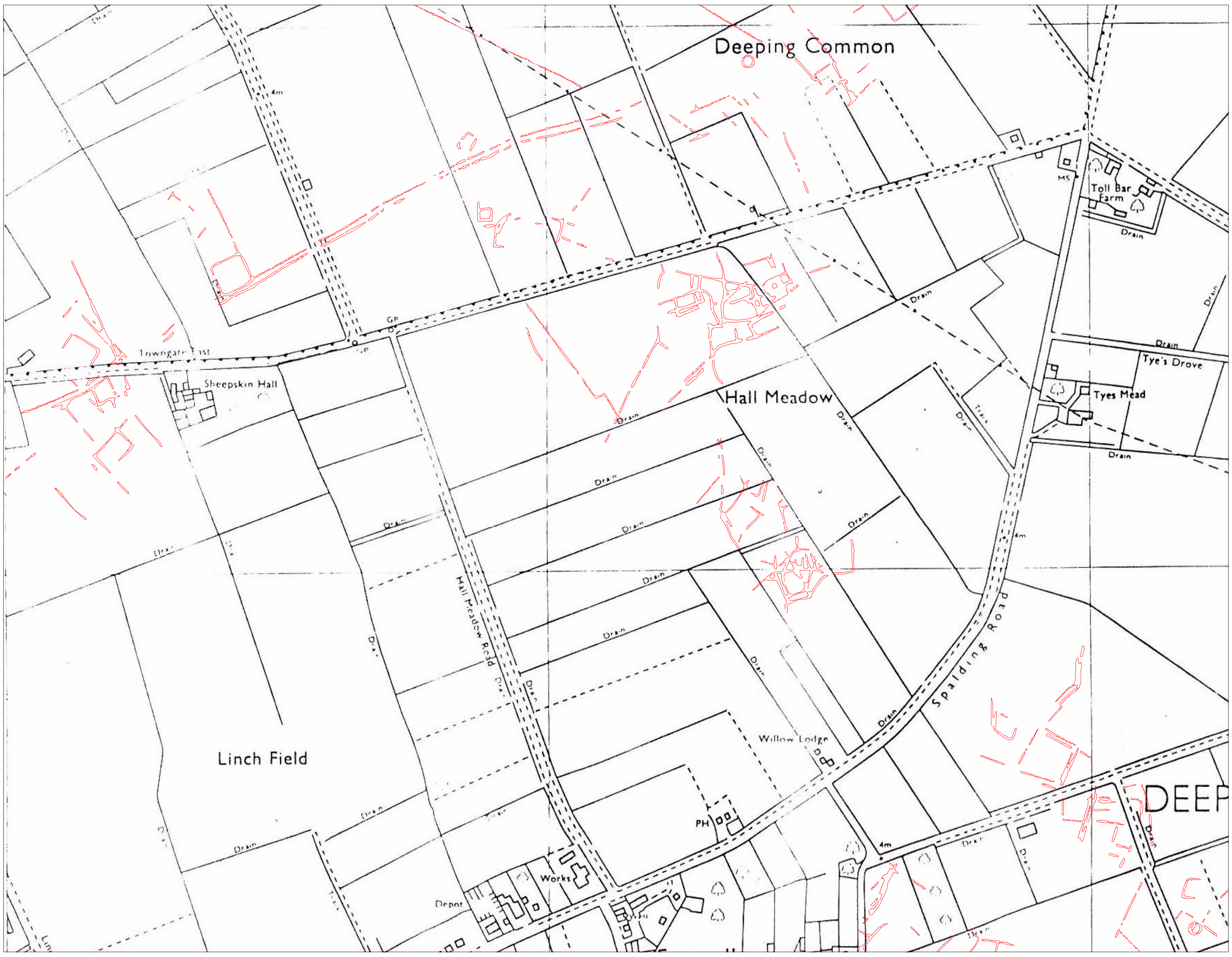


Figure 26 TF11SE Cropmarks on the fen-edge: NMP plot overlain on Lidar (1:10 000)