CHAPTER 3: MATERIALS AND METHODS

3.1 LiDAR

Traditional remote sensing based on the rectification and geocorrection of air-photographs is limited by the ability of photographic techniques to identify significant landscape features only in appropriate conditions of land cover and lighting (Riley 1987; Wilson 1982). However, since many aspects of the geomorphology of riverine landscapes are represented by variations in the microtopography of river terrace and floodplain surfaces, surviving even in frequently cultivated areas, the ability to map this microtopography should produce an effective record of such features. LiDAR provides a means to accurately and rapidly map microtopography on a large scale.

LiDAR uses the properties of coherent laser light, coupled with precise kinematic positioning provided by a differential global positioning system (dGPS) and inertial attitude determination provided by an inertial measurement unit (IMU), to produce horizontally and vertically accurate elevation measurements. An aircraft mounted laser, most often a pulse laser working at rates in excess of 30 MHz, projects a coherent beam of light at the ground surface, the reflection of which is recorded by a sensitive receiver. Travel times for the pulse/reflection are used to calculate the distance from the laser to the reflecting object. To enable coverage of a broad swath beneath the moving aircraft is scanned by using rotating mirrors to direct the laser. The spatial resolution and scan swath width are determined by the frequency of the laser pulse and altitude of the aircraft at the time of survey. The dGPS provide detailed three-dimensional information on the location of the laser unit, while the IMU provide information on the pitch, roll and yaw of the aircraft. A complete LiDAR system comprises a scanning laser coupled with a dGPS and IMU linked through a computerised control, monitoring and recording unit. Post-survey processing of the simultaneously recorded laser, location and attitude data allows reconstruction of elevation values for the ground surface. Raw survey data in the form of a three dimensional point-cloud are projected to a local map datum, sorted, filtered and used to generate a regular grid of elevation values.

Typically the laser receiver is able to record multiple returns for a single pulse, allowing recording for example of a partial return from the top of a semi-opaque object such as a woodland canopy (usually referred to as a first-pulse (FP) return) and from the opaque ground beneath the canopy (a last-pulse (LP) return). Other information, such as the intensity (amplitude) of the reflection may also be recorded. Comparison of surfaces produced from FP and LP laser returns suggest that, at least in landscapes with moderate semi-opaque ground cover LiDAR is effective in penetrating vegetation to reveal the underlying land surface. Initial examination of laser intensity data suggests that there is a fall-off in the intensity of the reflected light that corresponds with landscape features such as palaeochannels.

Analysis of LiDAR elevation products has focused on examining the effectiveness of LiDAR elevation products for identifying significant topographical features of the terrace and floodplain, quantifying relative accuracy and absolute accuracy of LiDAR elevation products compared to elevation values recorded by field survey using dGPS, and analysis of the impact of varying resolutions of LiDAR elevation data on the DSM metrics and the ability to identify significant landscape detail.

3.2 IFSAR

Airborne radar uses radio waves to measure the distance between an aircraft mounted senor and the ground surface. Interferometry relies on picking up the returned radar signal using antennas at two different locations. Each antenna collects data independently, although the information they receive is almost identical, with little separation (parallax) between the two radar images. Instead the phase difference between the signals received by each of the two antennas is used as a basis for calculation changes in elevation. The results are enhanced by using processing techniques during data collection to generate a synthetic aperture of much greater size than the physical antenna used and so enhance resolution (Intermap 2003). Combining the principals of Synthetic Aperture Radar with Interferometry, Interferometric Synthetic Aperture Radar (IFSAR) is capable of producing both a radar image of the ground surface and calculating elevation changes to enable production of a digital surface model (DSM).

Intermap has undertaken IFSAR surveys of the entire of the UK. The results of the surveys are available as a commercial product in the form of 5m spatial resolution DSM with a vertical accuracy of between 0.5 and 1.0m and a 1.25m spatial resolution radar image. Analysis of the IFSAR products focused on investigating to what extent they were able to provide useful geoarchaeological information. The IFSAR DSM was imported into ArcGIS for visualisation and comparison with LiDAR and GPS derived elevation values. Elevation and derived slope frequency histograms were generated as well as basic DSM statistics

3.3 Aerial photography

Airborne remote sensing techniques have traditionally been employed to great effect in mapping the geomorphology and cultural archaeology of alluviated landscapes. Archaeologists have largely focused their attention on the comprehensive mapping of cropmarks and other features of the archaeological landscape revealed from the air (Riley 1980; Whimster 1989), and large areas of England have been comprehensively mapped as part of the National Mapping Programme undertaken by English Heritage (Bewley 2003). Aerial photographs have also been employed in mapping geomorphology in riverine landscapes, for example in extensive studies of the valleys of the rivers Trent (Baker 2003; Garton and Malone 1998) and Thames (Lambrick 1992; Robinson and Lambrick 1994) and in the alluvial landscapes of the Cambridgeshire and Lincolnshire Fens (Hall 1992; Hayes and Lane 1992). Such mapping of fluvial geomorphology provides a context for past cultural landscapes and assists in identifying topographical features of high archaeological potential (for example relict river channels) and isolating areas of past river erosion where little in the way of archaeological material might be expected to survive (cf Brown 1997). The systematic reconnaissance, mapping and classification of alluviated landscapes in this way has played a significant role in the strategic management of the geoarchaeological resource in the face of growing threats from aggregate extraction, housing and other development pressures (Bishop 2003). Within the present study examination of aerial photography focused on the mapping of significant landscape features, principally as a control (based on conventional techniques) for comparison to the various airborne and ground based remote sensing techniques tested.

The present study has focused on mapping landscape and geomorphological detail evident on vertical photographs. A cover search of all relevant photographs at the National Monuments Record collection (ref AP70673; appendix 1, the cover search results are annotated to indicate which photographs were viewed and reasons for selection or rejection) identified 83 oblique and 275 vertical photographs of the study area and its environs. In addition, a number of further photographs were identified and examined in the collections of Leicestershire County Council and Cambridge University.

All available photographs were viewed and selected prints digitised by scanning at 300dpi using an Epson Photoperfect 3780 desktop scanner for incorporation into the project Geographical Information System (GIS) developed using ESRI's ArcGIS 9. Air photographs were rectified and georeferenced to real world coordinates using the Georeferencing extension of ArcGIS 9 by matching significant landscape features with those seen on the Ordnance Survey mapping. Once rectified and georeferenced topographical features of the terrace and floodplain surface were digitised directly from the air-photographs within ArcGIS to produce GIS data comprising a set of polygons and polylines with attached attributes.

Transcription of features seen on air-photographs focused on elements of the natural landscape. No attempt was made to produce crop and soil mark mapping from oblique aerial photographs, or from those vertical photographs on which such evidence was to be seen, which work has already been comprehensively undertaken by others (see below). However the extent of both earthwork and crop/soilmark ridge and furrow was mapped (Figure 6) as this broadly reflects the different geomorphological units identified across the study area.

3.4 Materials and methods Ground Penetrating Radar

3.4.1 The Ground Penetrating Radar (GPR) and application in alluvial environments

Ground penetrating radar surveys use pulses of Electromagnetic (EM) radio waves directed down into the soil profile from a transmitting antenna, in order to investigate subterranean features. When discontinuities are encountered some of these radio waves are reflected back towards the surface, whilst other waves travel further down into the soil profile until they meet other discontinuities. At the surface a receiving antenna measures the reflected waves. By measuring the time taken between emission of the radar pulse and reception back at the antenna it is possible to measure the depth of a discontinuity in the soil profile. Within a floodplain context the boundaries between different geomorphological units will be seen as discontinuities, due to their different physical properties, e.g. clay and gravel.

Data is collected in GPR survey as single transects, through pulling the GPR over the ground and collecting data either continuously or at set intervals. These GPR transects are calibrated for changes in surface topography. The transects can be viewed singly to give a vertical profile of the section. Alternatively, several spatially referenced transects can be welded together to produce a solid cube. This cube can be sliced at set intervals producing plan views of the subsurface environment.

The process of estimating the depth of discontinuities within the soil profile is complicated by different dielectric constants found within different units. The electrical properties of a sedimentary unit effect the time taken for the radar pulse to travel through that unit. The dielectric permattivity is a property of an electrical insulating material (dielectric) equal to the ratio of the capacitance of a capacitor filled with the given material to the capacitance of the identical capacitor filled with air. The specific capacitance of a vacuum is Eo = 8.85×10^{-12} Farads per metre. The relative dielectric constant (Er) for air is 1 and is approximately 81 for fresh water (Radan User Manual Definition 2004, GSSI, 128).

Within an alluvial context the relative dielectric permittivity (RDP) of different sediment units is critical; which is the ability of a sediment to absorb, reflect and be permeated by, the radar pulse. If there is a significant change in RDP between two different geomorphological units, such as clay and gravel, then strong reflections will result at the interface of the two units. The GPR pulse will be dissipated by materials of high conductivity. Therefore, sediments with high clay and water contents cause rapid attenuation of the GPR signal and are often impenetrable to higher frequency antennas, such as a 200MHz antenna. Jol and Bristow (2003) revise GPR applications and practices for mapping sediments. One of their conclusions is that GPR is most effective in electrically resistive materials such as sand, gravel, peat and limestone but decreases in data quality are seen in highly conductive materials such as silt, clay and calcretes. Key factors that affect the RDP of an unconsolidated material can be listed as (mainly from Ekes and Friele 2003, 90):

- Pore size
- Sediment type
- Stratification
- Grain size
- Water content

It should be emphasised that although GPR survey can be used to identify and to some degree characterise sediment architecture, the mechanisms that affect the radar wave reflections are imprecisely understood. The reflection from an unconsolidated material will be a function of its water content below saturation levels; the water content itself being a function of the sediment properties (Van Dam *et al.* 2003, 257 – 273). If GPR survey is carried out over saturated sediments penetration will be limited.

In order to correctly calibrate the electric depth model created by the GPR it is important that the dielectric properties of the soil profile can be accurately estimated. This in practice is extremely difficult, as within alluvial environments any GPR transect is likely to cross a series of different geomorphological units, each having a different RDP. Therefore, a compromise has to be reached in the dielectric constant that is used. Within this project the dielectric constant of the soil was estimated through comparison with gouge core transects, which is a common method of calibration (for example see Bridge *at al.* 1998).

The gouge core transects allowed the depth of the alluvium overlying the terrace and modern floodplain gravels to be accurately measured across a whole GPR transect. The dielectric constant was then set, which identified the interface between the alluvium and the gravels at the same depth recorded by the gouge core transect. This represents a compromise on setting the dielectric constant as the calibration is taking place within an alluvium unit, not combining the average of the alluvium and gravel units. However, the gravels are impenetrable without powered coring equipment and thus the described compromise was reached through using gouge core data.

The identification of radar terminations is the basis for constructing a relative chronology for a sequence of sediment units (Bristow *et al*. 2005, 316*)*. Interfaces between different geomorphological units, e.g. a silty clay unit overlying a gravel unit, represent terminal events in either deposition or erosion processes and the start of subsequent processes. Although the ages of these sediment units cannot be ascertained without absolute dating methods, relative sequences can be constructed through studying the form of the interfaces seen. This has specific importance in geoarchaeological studies of alluvial environments where erosion and deposition by channels will have both destroyed and preserved the archaeological resource.

The heterogeneity of alluvial deposits allows discontinuities to be mapped and stratigraphies to be created. This property causes special considerations for GPR survey of alluvial environments. River floodplains are heterogeneous in both X, Y and Z dimensions. Upper terraces may have gravels close to the surface, with a thin covering of alluvium, whilst modern floodplains may have a considerable degree of alluvial deposition on gravels or bedrock. Palaeochannels may have high water contents, high clay contents, with organic rich pockets. Gravel architecture can vary radically between clast to matrix supported.

For GPR survey this can be problematic, in respect of data collection and real time amplification of signal. Consider two very different units that are surveyed within the same area, such as a gravel terrace and a palaeochannel with a fill of high clay content. The gravels in the terrace will have low absorption but high reflectance properties. Conversely, the palaeochannel will have low reflectance but high absorption properties, causing rapid attenuation of signal. In such cases, which are frequently encountered in alluvial environments, the different geomorphological units require a different amplification of signal. The amplification of the radar pulse is controlled through a gain applied to the signal. The level the GPR gain (amplification) is set at will be a compromise between obtaining good penetration in a series of different sediments and collecting clipped data, where the amplification of the signal has been too great and the minimum and maximum values are not realised. When considering alluvial stratigraphy it is often the contrast between different sediment units that is most important. Therefore, relative change and difference is as important for data collection within heterogeneous environments as absolute values.

3.4.2 GPR survey aims

The primary aim of the project is to produce a three dimensional model of the study area through combining the data resources of LiDAR, differential GPS survey, IFSAR and GPR, which can be used to create a chronostratigraphic model of the survey area and relate this to the archaeological resource (see chapter 9). In order to achieve this aim a series of GPR surveys were undertaken, to collect data on the subsurface stratigraphy of the floodplain. The subsurface stratigraphy can be used to:

a) Classify different geomorphological units.
b) Produce relative chronologies of different geomorphological units.
c) Use factors a) and b) as a guide to the potential palaeoecological and geoarchaeological resources of different sedimentary units.

In order to achieve this overall aim it was necessary to undertake GPR survey in a variety of locations within the study area. The following objectives were set for the GPR survey:

A. Development of a GPR field methodology to map large scale. geomorphological units within river floodplains.
B. Three-dimensional GPR survey of at least one area of terrace 2.
C. Three-dimensional GPR survey of at least one area of terrace 1.
D. Three-dimensional GPR survey of at least one area of the modern floodplain.
E. Integration of these data sets with the LiDAR.

In addition to these aims the GPR surveys experimented with a series of data collection parameters, in order to develop optimal survey parameters for floodplain investigation. Experimentation was made with linear and grid plan methods of data capture, different transect intervals and antenna frequencies.

3.4.3 GPR transect and grid plan data capture

When developing a field strategy, the aims and objectives of the data collection need to be considered and offset against the type and volume of data required. When considering using a GPR survey to assess floodplain stratigraphy there are a series of key issues relating to data capture. Primarily, are two-dimensional transects sufficient for data collection or is three-dimensional grid plan survey required?

A two dimensional transect will give a section view of the sediment stratigraphy. Different sediment units are identifiable as areas of different reflectance and absorbance. The spatial dimensions of any geomorphological features are not identified, although it is often possible to obtain these through other means, e.g. field based mapping. A data grid will allow a model to be produced in three dimensions. Variation can be seen between and within different sediment units on both XY and Z axes. The extent of some individual features can also be mapped (e.g. terrace islands).

Within a three-dimensional grid plan survey other issues need to be addressed relating to field methodology. Primarily, the transect spacing will determine the level of data resolution within a survey and the degree of interpolation between data points. Secondly, the size of the survey grids combined with the transect spacing will influence the data resolution and subsequent interpretation. The difference in data capture between transects and grids also has implications for the amount of time spent ‘in the field’, with grid surveys taking considerably longer in staking out, data collection and data processing/interpretation.

3.4.4 Choice of survey areas

Areas were selected for GPR survey that had good LiDAR results and showed geomorphological variation, i.e. palaeochannels, gravels bars, etc. However, the presence of some arable crops meant that it was not possible to survey in some fields. Also ploughed fields, when combined with heavy rainfall, meant that other fields were unavailable for survey (fieldwork was conducted in November 2004, January and February 2005). Thus the GPR fieldwork was a compromise between areas of interest and areas of access.

3.4.5 Transect spacing

The GPR investigations were undertaken on a geomorphological scale, characterising major geomorphological units in both spatial and temporal dimensions. To this end the surveys needed to cover large areas, whilst maintaining a good level of data resolution within the survey area. In order to develop the field methodology, transect intervals of 1m, 5m, 10m and 20m were experimented with. A minimum of fifteen transects were collected per grid survey, with the ideal standard being twenty transects or greater per survey area.

3.4.6 Grid sizes

The grid sizes varied, dependant on the aims of each survey, the transect interval and the size of the field being surveyed. Table 3.1 gives the sizes of each survey, whilst the location of each survey is shown in Figure 3.1. The selection of a survey area is subjective and all surveys aimed to collect a representative sample of the features being studied.

3.4.7 GPR configuration

Two antenna frequencies were employed in the project, being 400MHz and 200MHz. The system employed was a GSSI SIR3000 unit, collecting data using both a hand held trigger on time-based collection and also with a survey wheel (Fig. 3.2). The SIR 3000 has only one fixed antenna so CMP (common mid point analysis) was not applicable and coring transects were used for data calibration. Data was collected using 512 samples/scan, with 16 bits per sample at 64 scans per second. Field filters were set at three times the antenna frequency for the IIR vertical high pass (600MHz) and one quarter of the antenna frequency for the IIR low pass (50MHz).

Calibration of the signal amplification was made on terrace gravels, which were expected to have the highest reflectance values within the survey area. Experimentation was made to find noisy areas (such as gravels close to the surface) for calibration. The signal amplification, controlled by the number of gain points used, varied between individual transects and grid plan surveys. On individual transects 5 gain points were used to maximise penetration, although data clipping sometimes occurred when using such high gain settings. In contrast the grid plan surveys used lower gain settings, to prevent data clipping. However, this reduced the effective GPR penetration. Between 2 and 4 gain points were used on the grid surveys, varying on a survey by survey basis.

Survey name	**Size**	**Transect spacing**	**Antenna frequency (MHz)**	**Core data**
MFT1	225m	N/a	200	Gouge core 10m intervals
MFG1	125m x 225m	5m, 10m and 20m	200	Gouge core 10m intervals
MFG2	40m x 25m	1m	400	Gouge core 10m intervals
T1T1	395m length	N/a	200	Gouge core 10m intervals
T1QT	69m length	N/a	200	No but section drawn
T1T2	100m length	N/a	200	Yes gouge core
T1G1	155m x 100m	5m	200	Yes gouge core
T1G2	155m x 35m	5m	200	No
T1G3	125m x 240m	5m	200	No
T2T1	335m	N/a	200	Yes gouge core transect 10m intervals
T2G1	95m x 170m	5m	200	No

Tab 3.1: The GPR surveys.

Fig 3.2: The GPR survey about to start on the modern floodplain, using a 200MHz antenna.

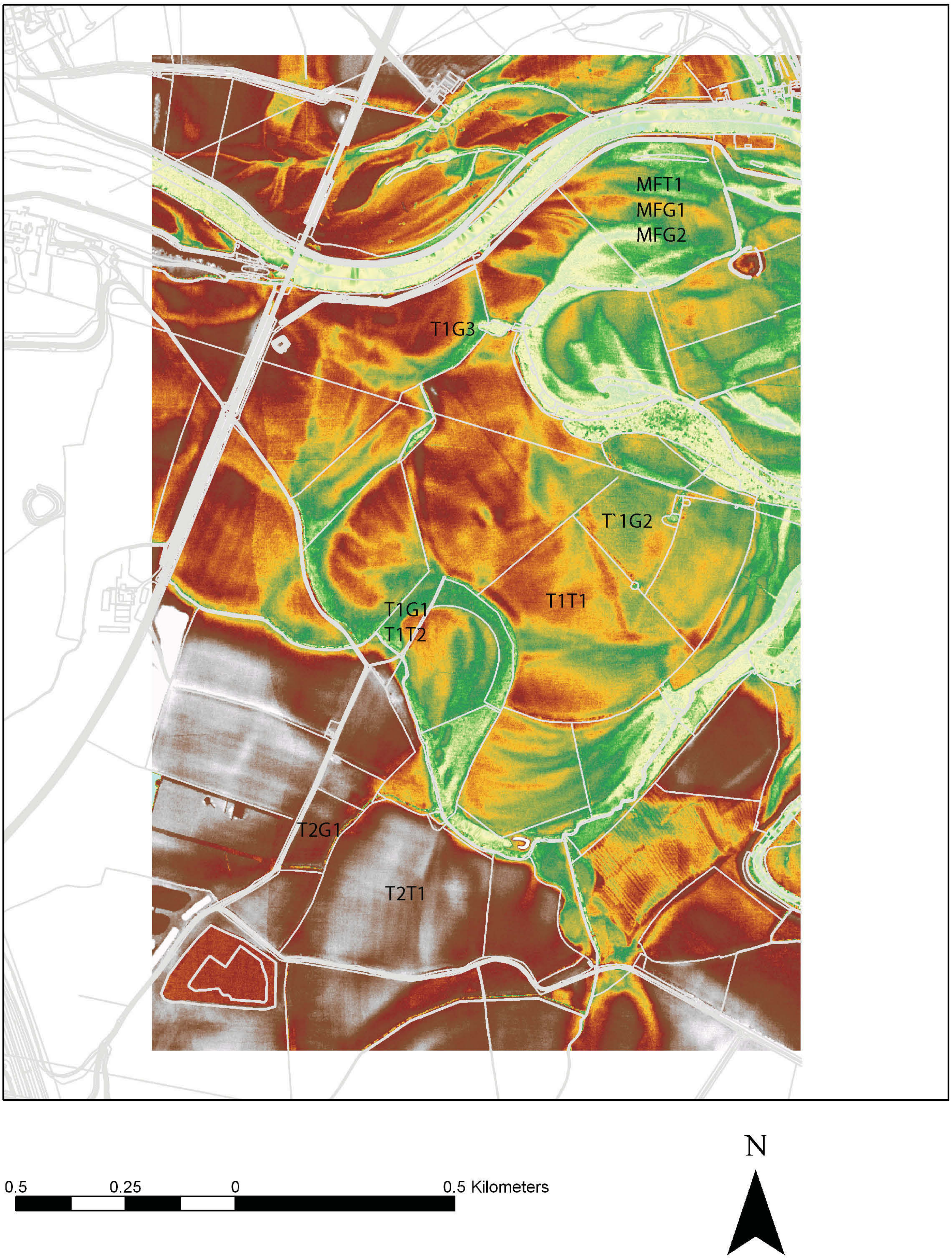

Fig 3.1: The GPR survey areas within the overall study area.

3.4.8 Field survey

All survey areas were staked out using differential GPS survey. Some of the GPR transects were collected through time based collection whereby, markers where set out at 5m intervals, with a hand held trigger being used to mark each survey point. Most transects were collected using a survey wheel, with markers were placed at 50m intervals and using with ranging rods for straight alignment. The location of all transects was recorded with the differential GPS, as where key features such as field junctions for external reference. Topographic data for GPR surface normalisation was collected at 5m intervals using the differential GPS in some surveys but in others using the last pulse DTM values from the LiDAR data.

3.4.9 GPR processing

The processing of the data followed a prescribed route, developed through experimentation with GPR data collected on alluvial deposits. Data processing is subjective. The aim of the processing steps undertaken in this project was to set the correct time zero, correct for hyperbola reflections via migration, remove background noise and increase/decrease gains to provide good contrast in the data. This is a simple processing sequence that can bring out good quality results in alluvial data sets.

For each set of survey data time zero was set through the first positive peak seen within GPR section. Migrations were undertaken through a variable velocity migration. A series of hyperboles were selected in the GPR diagram, coming from a variety of depths and sediment units. A graph was made of the relative velocity curve, taking into account the size of the parabolas combined with the depth of the parabolas, allowing changes in the velocity of the radar pulse through the profile to be calibrated. Normally several different graphs were experimented with in each survey until a satisfactory result was obtained.

Background removal filters were used to 'clean' the data, along with some application of vertical high pass and vertical low pass filters. Deconvolution filters were generally not used. Deconvalution filters have the ability to remove 'ringing', multiple reflectors caused through wave diffraction in low absorption/high reflectance environments. However, deconvolution also has the ability to remove real data, which is interpreted as the effect of multiple reflections, such as some of the reflections seen within the gravel units. In general areas of ringing were seen in the palaeochannel fills that had high water tables and high clay contents. In such cases the data was removed from the display, as the ringing appeared as data below the actual depth of penetration.

3.5 Transect coring

In order to aid interpretation of the GPR and LiDAR data and provide separate stratigraphic data, gouge core transects were undertaken on some GPR transects. Gouge core sampling was undertaken at 10m intervals along specific GPR transects. The gouge core had a 2cm diameter. The depth of each unit was recorded with a description of its composition before impenetrable gravel was encountered. In addition to the gouge sampling, a section of exposed quarry was recorded with a GPR transect being conducted along the top of the section. The quarry section allowed the comparison of a GPR transect against a drawn and photographed section. The drawn section sampled at 2.5m intervals. This provided a second means of GPR depth calibration.

3.6 Geomorphological mapping

A geomorphological map was constructed of the study area through using field based mapping and recording onto 1:10, 000 maps.

3.7 Data archive and query

ArcGIS provided the primary database for the project. ArcGIS is a Geographical Information System (GIS), which is used for the storage and exploration of data, linking together aspects of geomorphology and archaeology, in spatial and chronological dimensions. The investigation of an area of cultural landscape requires the collection of data from a range of sources involving both field based and desk based research. These strands of information are then placed together within a GIS, allowing relationships between variables to be visualised and explored.

A GIS is a spatially referenced database. Each variable can have a large number of attributes (categories) stored with it, giving a description of that variable. Data can be stored either as point data (e.g. an archaeological site), line data (e.g. a river) or as a vector (e.g. an area of river terrace). These data can then displayed and queried as a series of layers.

The following data were entered into the ArcGIS database:

I) Geomorphological maps, which were adapted through on screen digitisation
II) Geology maps supplied through the BGS
III) LiDAR intensity, DSM and DTM models
IV) IFSAR DSM and DTM models
V) Co-ordinates of the fieldwork survey areas
VI) Depth sliced GPR data
VII) 1:10000 OS maps
VIII) Digitised SMR data
IX) Bore hole locations
X) Rectified aerial photographs of the study area

3.8 Integration of Remote sensed and ground based prospection methods

ArcGIS provided the primary means of integrating the various data sources, particularly the GPR depth slices with the remote sensed LiDAR data. ArcScene was also employed to allow the layering of GPR and LiDAR data in a quasi-3D environment, permitting direct visual comparison between the data types.