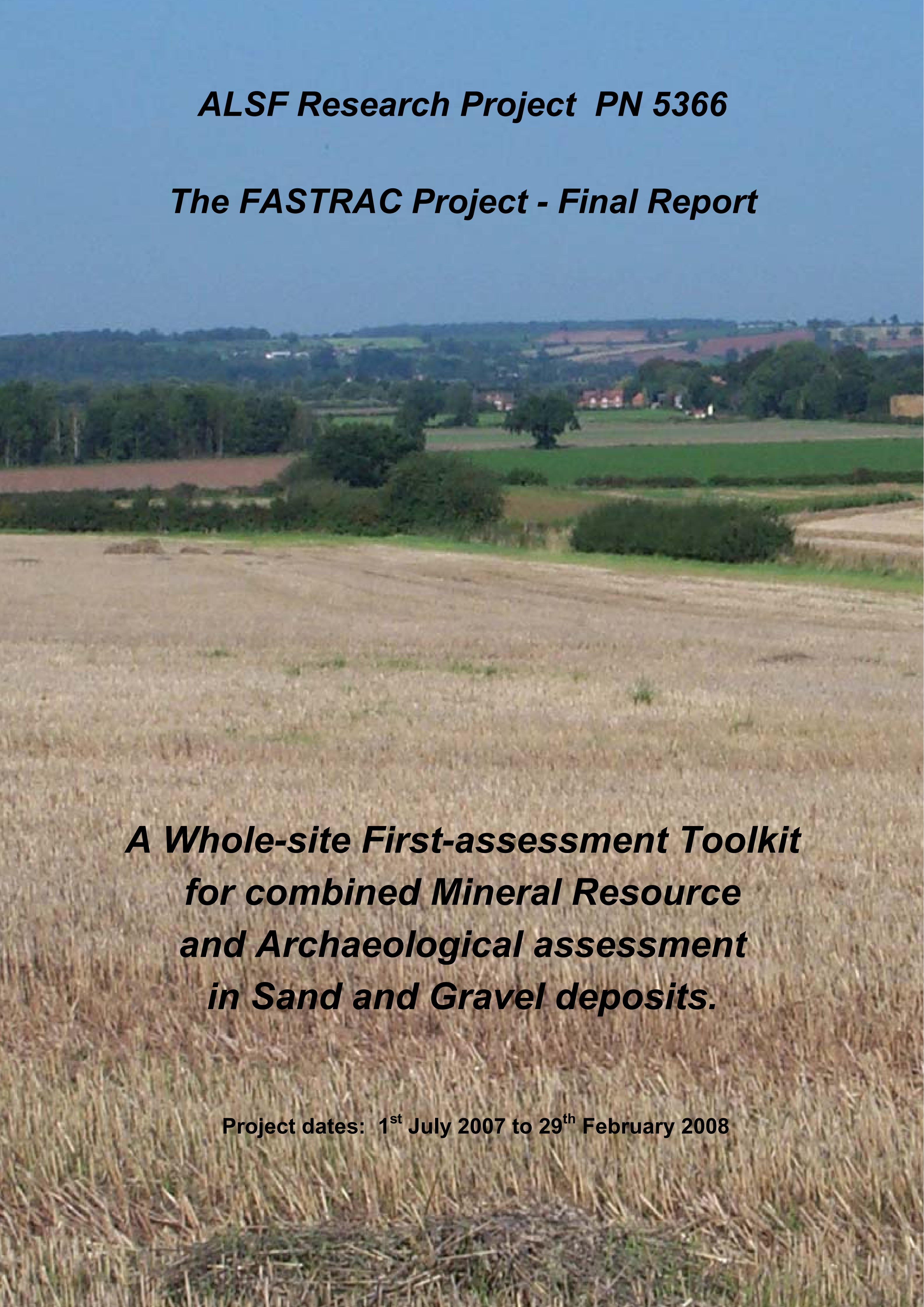
ALSF Research Project PN 5366

The FASTRAC Project - Final Report



A Whole-site First-assessment Toolkit for combined Mineral Resource and Archaeological assessment in Sand and Gravel deposits.

Project dates: 1st July 2007 to 29th February 2008

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Final Report

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Project dates: 1st July 2007 to 29th February 2008

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A Whole-site First-assessment Toolkit for combined Mineral Resource and Archaeological assessment in Sand and Gravel deposits.

Executive Summary

This project addresses ALSF core objective *"developing the capacity to manage aggregate extraction landscapes in the future"*, by developing site-assessment methodology.

Ground investigations are essential components of site assessment for both mineral resources, and archaeological remains. The techniques used for both mineral and archaeological assessment are often similar. Since investigations for both purposes must be performed in areas of potential mineral resource, and there is considerable overlap between them, there are potential benefits to mineral operators, heritage protection, and the planning process, in developing a systematic integrated approach to these investigations. It is important to remember that both mineral deposit and archaeology occupy essentially the same physical space, broadly defined as the soil layer. The project has been timely in relation to the very recent emergence of commercial availability of both airborne, and ground geophysical high resolution survey methods. The project team have the combined expertise in the separate new methodologies and data integration. They also have experience of the current practice in extractive industry, heritage protection and planning to assess critically the value of the information gained using the proposed methods.

We have studied two example sites, at Sturton-le-Steeple and Shelford, both in the Trent valley. Both sites combine the presence of a known aggregate resource with known archaeological remains, as well as being part of a populated and worked landscape, with issues such as soil quality, hydrogeology and bio-diversity to be considered.

We have compiled a separate GIS project for each site, combining pre-existing data with new airborne and surface surveys (Chapter 3). Airborne techniques such as Lidar and hyperspectral imagery provide high spatial resolution data (typical 1m or better) for an entire site, extending to hundreds or thousands of metres, and its even broader landscape setting (Chapter 5). Our case studies have demonstrated that such data are applicable in both archaeological (Chapter 4) and mineral prospection (Chapter 6) as well as in developing mitigation strategies (i.e. resource impact assessment). The ability to scan large areas in this way and select areas for searches using geophysical techniques provides a natural hierarchy of methodology. One aim of prospection is to classify the landscape on multiple scales. This project has demonstrated (Chapter 9) the potential to better-define boundaries of mineral deposits and to define areas of prospectivity for both recent and ancient history (Chapter 7).

Confidence in interpretation may be divided into two primary aspects, spatial accuracy, and characterisation. Chapter 8 provides some good examples of the difficulty of establishing reliable locations for some data, particularly using oblique aerial photographs. The benefit of using multiple complementary surveys, all located with DGPS is well demonstrated. Characterisation refers to relating observed variation in a survey parameter to specific physical properties of the ground. Such an ability to uniquely characterise volumes of the subsurface from remote sensing data and geophysical data is still a research objective rather than an established reality. However the systematic integration of precise survey data, which forms the core of this project, is the key to future advances in this area.

If the whole-site assessment methodology is to become a practical tool, it must be cost-effective within the operating constraints of current aggregate extraction. An essential, and attractive feature of the method is that it decreases risk throughout the assessment and development process. Not only will the increased information facilitate the planning process, but the extensive database will be augmented as production develops (Chapter 10), and provide a useful site management tool throughout the life of a quarry.

Contents

1 Introduction to the FASTRAC Project........ 1-1

1.1 Rationale for the project........ 1-1

1.2 The Participants........ 1-5

1.3 Methodology........ 1-5

1.4 Resources and programming........ 1-5

1.5 Publication and Presentation........ 1-8

1.6 Archive deposition........ 1-8

2 Literature Review........ 2-1

2.1 Site Assessment overview........ 2-1

2.2 Archaeological site assessment methods........ 2-1

2.3 Airborne Remote Sensing........ 2-3

2.4 Applications of Geophysical methods to site assessment........ 2-5

2.5 Sand & Gravel Deposit Evaluation........ 2-6

2.6 Hydrogeology and Hydrology........ 2-9

2.7 Land and Soil........ 2-10

3 DATA COMPILATION........ 3-1

3.1 Airborne Laser Scanning (Lidar)........ 3-1

3.2 Airborne Multispectral Remote Sensing........ 3-3

3.3 GEEP........ 3-9

3.4 English Heritage CART System........ 3-12

3.5 BGS SHELFORD DATA........ 3-13

3.6 SHELFORD AND STURTON AIR PHOTOGRAPHIC DATA........ 3-17

3.7 BOREHOLE DATA........ 3-19

3.8 RESOURCE ESTIMATION........ 3-19

3.9 Software preparation........ 3-24

3.10 HISTORIC AND MODERN MAPPING DATA FOR STURTON........ 3-24

4 Case Study – High Resolution Geophysics........ 4-1

4.1 Rationale for High-resolution surveys........ 4-1

4.2 Technological developments........ 4-1

4.3 The English Heritage CART System........ 4-2

4.4 The GEEP system........ 4-4

5 Sturton: mapping the terrace-floodplain interface……………………………………..5-1

5.1 Introduction…………………………………………………………………… 5-1

5.2 GEEP Surveys…………………………………………………………………5-2

5.3 Airborne Lidar………………………………………………………………… 5-2

5.4 Hyperspectral Data…………………………………………………………… 5-8

5.5 Conclusions: effectiveness of geophysical and remote sensing surveys….5-16

6 Case Study – Shelford Mineral Assessment………………………………………….. 6-1

6.1 Borehole data………………………………………………………………… 6-1

6.2 The Brett Sand & Gravel investigation……………………………………….. 6-3

6.3 Variogram Analysis of particle size data……………………………………… 6-3

6.4 Quality Mapping……………………………………………………………… 6-8

6.5 Benefit of whole site geophysical and remotely sensed data to……………6-18 mineral assessments

7 Case Study – Mineral and Archaeology relationships……………………………….. 7-1

7.1 Introduction…………………………………………………………………… 7-1

7.2 Investigation of Deposit Boundaries, Palaeolandscape and…………………7-1 Associated Archaeological Features.

7.3 Investigation of Deposit Heterogeneity, Quality,………………………………7-5 Palaeo-landscape and Associated Archaeological Features.

7.4 Conclusions……………………………………………………………………7-10

8 Comparison of Methods for locating Archaeological Features - Shelford………… 8-1

8.1 Introduction…………………………………………………………………… 8-1

8.2 Magnetometer survey……………………………………………………….... 8-1

8.3 The Air Photographic Record …………………………………………………..8-6

8.4 Correlations between NMP and FASTRAC cropmark plots………………...8-11

8.5 Airborne Remote Sensing……………………………………………………8-11

8.6 Correlations between results of different methods…………………………..8-17

9 Case Study – Classification of areas……………………………………………………9-1

9.1 Landscape Classification……………………………………………………..9-1

9.2 Building a Landscape Classification Model………………………………….. 9-1

9.3 Conclusions……………………………………………………………………9-6

10 Project Outcomes & Conclusions…………………………………………………10-1
10.1 Hierarchy in areal coverage & resolution……………………………………..10-1
10.2 Spatial sampling………………………………………………………………10-2
10.3 Classification…………………………………………………………………..10-2
10.4 Confidence in Interpretation…………………………………………………10-3
10.5 The costs, and feasibility of whole-site assessment…………………………10-3
10.6 Recommendations for Further Research……………………………………..10-5

11 Acknowledgements……………………………………………………………………11-1
11.1 The FASTRAC Team…………………………………………………………...11-1
11.2 FASTRAC Associated contributors…………………………………………11-1
11.3 Shelford Field Site……………………………………………………………11-3
11.4 Sturton Field Site……………………………………………………………...11-3

12 References……………………………………………………………………………..12-1
12.1 References: Archaeological site assessment………………………………..12-1
12.2 References: Airborne remote sensing………………………………………..12-2
12.3 References: Geophysics………………………………………………………12-4
12.4 References: Mineral Assessment……………………………………………..12-7
12.5 References: Hydrogeology……………………………………………………12-8
12.6 References: Land and Soils…………………………………………………12-8

Appendices

1 Data Sources
1.1....Ordnance Survey Base Mapping data……………………………………………...1
1.2 ...BGS Shelford Data…………………………………………………………………1
1.3 Air Photograph Coversearches: Shelford And Sturton Study ……………………2

2 GIS Database 1
2.1... Software requirements…………………………………………………………...1
2.2.... Database structure…………………………………………………………………1
2.3.... Indemnity Statement……………………………………………………………….4

3 GIS database on DVD 1
4 Project Outputs, presentations and publications 1
5 Air Photograph Listings……………………………………………………………………1

1 Introduction to the FASTRAC Project

1.1 Rationale for the project

Ground investigations are essential components of site assessment for both potential mineral resources, and to test for the presence of archaeological remains. The purpose in either case is to determine physical properties of the sub-surface and thus characterize the sub-surface materials so that both mineral resources and archaeological features can be identified. In the variability, heterogeneity and complexity of subsurface structures it is rarely possible to identify unambiguously a particular target. Comprehensive survey early in the exploration sequence is concerned primarily with excluding areas which are not of interest, reducing risk of failing to find relevant features, and identifying a small number of key locations for intensive, usually invasive and more expensive, follow-up investigation.

The techniques used for both mineral and archaeological assessment are often similar, comprising airborne remote sensing image analysis, ground-based geophysical survey and invasive ground investigation (drilling or trenching). Since investigations for both purposes must be performed in areas of potential mineral resource, and there is considerable overlap between them, there are potential benefits to mineral operators, heritage protection, and the planning process, in developing a systematic integrated approach to these investigations.

In usual practice these investigations are dealt with as separate issues, with different methodologies being used by different contractors at different times. Mineral industry geologists would typically rely mainly on a drilling campaign to sample an aggregate resource, while when an archaeological assessment is required for a planning application, a trenching investigation may be used. Either may be assisted by remote-sensing analysis or geophysics. This can often lead to duplication of effort, particularly for the acquisition of geophysical survey data. It also has the effect of reinforcing divisions between the two rather different areas of expertise employed, and the attitudes of the interest groups involved.

It is important to remember that both mineral deposit and archaeology occupy essentially the same physical space, broadly defined as the soil layer. The interactions between solid geology, the derived soil layer, the archaeology and the hydrogeology are all important in both understanding the details of the site, and considering its exploitation or protection.

1.1.1 Reasons for the project

This aim addresses ALSF core objective *"developing the capacity to manage aggregate extraction landscapes in the future",* and contributes to each of the following ALSF objectives

- research to enhance the understanding of the scale and character of the historic environment in current or likely future aggregate producing areas in order to provide the baseline information necessary for effective future management.
- methodological and technical research to improve predictive, evaluation and mitigation tools in order to promote and advance maximum information gain and cost effectiveness which will benefit both the extraction industry and the historic environment.
- dissemination and assimilation of ALSF funded and other related work to stakeholder groups

The aims of this project are also strongly supported by major players in the aggregates industry. Tarmac and Hanson have supported previous work by Hill and Jeffrey (MIST project "WARMIT"), and Lafarge are supporting this project.

Some objectives of this project also align with interests of the Soils Programme of the British Geological Survey, and the output of the case studies from the chosen sites will benefit the continuing work of the Trent Valley GeoArchaeology group.

The project is timely in relation to the very recent emergence of commercial availability of both the airborne and ground geophysics high resolution survey methods. The project team have the combined expertise in the separate new methodologies and data integration. They also have experience of the current practice in extractive industry, heritage protection and planning to assess critically the value of the information gained using the proposed methods.

Research design

The aim of this project is to combine a range of rapidly acquired data sets including Lidar, multi- and hyper-spectral imaging and ground based geophysical methods for integration using GIS systems and/or sophisticated 3D imaging techniques to provide a powerful and rapid methodology for site evaluation. Combining all the available data in one large data resource, *data-fusion* , with suitable methods for interrogation and visualizing the data volume allows the interrelationships between data to be understood so that maximum information is derived. It is envisaged that this will allow for both the modeling and estimation of the mineral resource together with an initial evaluation of the likely archaeological features.

In addition, more sophisticated 3D imaging techniques, for example Ground Penetrating Radar (GPR) and Electrical Resistance Tomography (ERT), can be subsequently included to enhance the data model, with the location of these investigations guided by the results from the rapidly acquired whole-site toolkit. No attempt will be made to collect such complex and more expensive datasets within the current project, although previously existing results will be included where possible.

1.1.2 Project objectives

1. Perform a literature review of the subject areas relevant to the core aims, the application of remote sensing (in the broadest sense) techniques to the evaluation of both aggregate resources and archaeological remains
2. Acquire Lidar and hyperspectral data for the two case-study field sites, either from database (Shelford) or by commissioned survey (Sturton-le-Steeple), and process the data for entry to a GIS database.
3. Obtain precise, densely-sampled field geophysical data using a novel multi-sensor system over the two test sites and process this for entry to a GIS database
4. Obtain control data to verify the multi-sensor surveys by a combination of (i)duplicate survey using established geophysical survey techniques, (ii) resistivity imaging surveys in particular targeted locations (iii) boreholes for direct sampling.
5. Collate all relevant existing data for each site, and the newly acquired data into one GIS database for each site.
6. Interpret the datasets, using both the power of the GIS system and other tools as necessary, e.g. geostatistical analysis of the aggregate deposit data, considering the three specific (but overlapping) objectives: archaeology, mineral resource and soils & Hydrogeology.
7. Analyze the contribution of each dataset to the interpretation objectives, and examine the cross-links between each of the datasets and the interpretation objectives.
8. Define and document the benefits and costs of whole-site comprehensive assessment for the test sites examined.
9. Draw conclusions concerning the value of such assessment if applied to a wider range of sites. In particular consider whether the overall reduction in risk (uncertainty

in the presence or extent/quality of either mineral resource or archaeological remains) is justified by the cost of the exercise.

10. Archive the data resulting from the project in an accessible location and format.
11. Promulgate the results of the project in an appropriate variety of formats including a project report, academic research journal articles covering both the archaeological and the mineral industry, and general interest information for other interested professions (e.g. planners) and the public.

These objectives will be achieved through the involvement of the project partners in the series of tasks illustrated in the GANTT chart in Figure 1.1.

1.1.3 Choice of Field Sites

To illustrate the application of this methodology, two separate field sites have been chosen. The criteria used to control choice of site are:

- Existence of a known aggregate deposit, with confirmed archaeological remains in the near-surface.
- Location spanning the river-terrace and alluvial floodplain, permitting assessment of the effectiveness of the applied techniques in these different landscape zones. Particular interest is focused upon the problem of tracking terrace-edge archaeological sites into alluvial zones (as at Sturton below) and identifying at an early stage sub-alluvial cultural remains with high potential costs to the quarry company.
- Access to all previous data for the site including drilling data defining the aggregate deposit and archaeological assessments.
- Access to the land for any necessary follow-up surveys, such as the multi-sensor geophysics.
- The proposed work should not in any way compromise existing or prospective archaeological Schemes of Treatment developed according to the guidelines of PPG15 and 16. A clear separation between this research project and any requirements of the development process through PPG15/16 must also be demonstrated for potential study areas.
- Linkage with existing mineral resource, geological or archaeological projects which would provide synergy with this project.
- Minimum logistical difficulties with access to sites to reduce unnecessary costs (confined sites to mainland UK, preferably England).

As a result, the project design has identified two sites which satisfy all these criteria most closely. One member of the project team will assume the data collation responsibility for each of the selected sites. The sites are described below.

Shelford, Nottinghamshire

Shelford village lies approximately 5 miles east of the city of Nottingham on the terraces of the river Trent. The field site lies just to the east of the village immediately before the road bridge at Gunthrope, which carries the A6097. The site lies within the bounds of a designated area (2km by 0.75Km north/south orientated catena centred around grid reference 467300,342695) developed by the British Geological Survey over the past two years to investigate the applicability of a variety of methodologies to spatially model the soil geology continuum. The site was specifically selected to be representative of a lowland alluvial soilscape and over the past two years the geology and pedology has been remapped at a spatial resolution of 1:10000. An extensive programme of invasive investigations has supported this mapping. This includes auguring, trial pitting, drilling of fully cored boreholes and geophysics (ERT, micro-seismic, GPR and two temporally discrete galvanic resistivity surveys by Geocarta ARP@). The BGS currently has access to Environment Agency LIDAR data for the site.

We will use this information to provide a more focussed investigation (covering approximately 50 hectares) of the site to evaluate (a) the sand gravel resources at the site (previously investigated by the Crown Estates) and (b) its archaeological heritage, which was specifically excluded from BGS investigations due to the presence of a scheduled monument designated under the Ancient Monuments and Archaeological Areas Act 1979 (c. 46). There is no planning approval for extraction at this site, and no current actions to develop such plans.

In terms of geology and potential aggregate resources the site is underlain by between 0.5 to 1m of soil and up to 6 metres of Holocene and Pleistocene sand and gravel deposits, which in turn overlay bedrock (Mercia Mudstone). Geophysical surveys and drilling have shown the deposit to have been formed by a variety of alluvial processes and unsurprisingly areas of predominantly fine-grained and coarse-grained materials have been identified and mapped. Current groundwater levels are typically between 1 and 1.5 m below ground level. An area immediately to the west of the site is being considered for flood protection.

In terms of archaeological heritage the site contains a scheduled monument with Early Bronze Age and Neolithic features (Revill, S.,1974) along with a wide variety of cropmarks indicative of long-term habitation. The site includes the remains of a 15th century Priory (Austin canons) and manor that was garrisoned during the English civil war.

It is the consortiums view that the existence of, and access to excellent contextual data, together with partially explored archaeological and resource significance, current goodwill between members of this consortium and landowners / tenants and proximity to universities and institutes participating in the consortium makes this site perfect for investigating the concept of Whole-site First-assessment Toolkit.

Sturton-le-Steeple, Nottinghamshire.

An area of some 112 ha lying immediately north of the Romano-British town of *Segelocum* (Littleborough) formed the focus of a desk-based assessment by Challis (1999) and a programme of fieldwalking, geophysical prospection, auger survey and evaluation trenching by Elliott (2004) on behalf of Lafarge Aggregates Ltd. The area is in active development and subject to a planning application due to be heard during 2007. Extraction of the mineral under part of the case-study area is likely, but beyond the time duration of this project. The area comprises a low sand and gravel terrace, flanked on its eastern side by a broad alluvial floodplain incorporating at least two small sand and gravel 'islands'. The evaluations revealed a major Late Neolithic to Iron Age palaeochannel running north-south adjacent to the eastern edge of the terrace, part of a Late Bronze Age post alignment and extensive evidence for Romano-British activity, but comparatively few traces of post-Roman activity

Important evidence for Late Bronze Age activity was provided by the discovery of part of a post alignment recorded adjacent to a low gravel 'island' within the floodplain. This may represent part of a timber trackway and raises the possibility of further significant cultural and palaeoenvironmental remains of Neolithic or Bronze Age date buried beneath alluvium.

Romano-British activity is represented by three large multi-phased Romano-British ditched enclosure complexes surviving along the terrace-edge. Features include ditches, gullies, pits, postholes, a possible stone oven and stone post-pads for at least one structure, while waterlogged deposits containing Romano-British material were observed at each site to run into the floodplain. The sites yielded a rich collection of artefacts, including 2098 pottery sherds. Other finds include quernstones and slag, suggesting some limited cereal processing and metal working, while imported pottery and glass hint at the market influence of the nearby Roman town at *Segelocum*. Pollen, charred plants, waterlogged plant remains and insects obtained from feature fills and from deposits running into the floodplain indicate a high potential for study of the contemporary environment and agricultural economy. Another focus of Romano-British activity was identified on a low gravel island within the floodplain. The top of the gravel island appeared to have been denuded of archaeological features, but deposits containing Romano-British pottery survived at the island's edge and dipped into the palaeochannel and floodplain. Evidence for significant post-Roman activity is slight.

1.2 The Participants

The project team (Table 1.1), has brought together an appropriately wide range of expertise to address the various facets of the research. This work builds on a range of previous research projects involving members of this project team (see Chapter 2) which demonstrate the range of interest in this project area, and the synergy within the project team. The combination of archaeologists, geologists, geographers, geophysicists, and industry in the form of an aggregate company and a survey support company also shows the broad enthusiasm for the objectives of the project across the range of interests involved in this work. The industrial members of the project team will also support the project financially in terms of contribution in kind.

1.3 Methodology

As stated above the main aim of this project is to provide a clear evidence base for the effectiveness of remote-sensing data (including geophysics) in detecting and delineating both mineral deposits and overlying archaeological remains. Part of the effectiveness of these methods is the broad spatial coverage available with these methods as opposed to the limited sampling necessarily involved in trial pitting or drilling. The full value of this comprehensive areal coverage can only be realised by combining the data in advanced GIS systems. The full investigation of the power of such analysis is beyond the limited time duration of this project, but is an area which the project team intend to develop in the future.

For the purposes of this project we will build a comprehensive database for each of the two test sites. This database will include all the conventional data already in use in this application area, but augmented by new and evolving techniques. The ideal dataset will typically comprise the range of data types described in Chapter 3. It is an important aspect of this study that many of these data are readily available in digital form from verified databases. An essential part of this project is to incorporate new data to be collected using the novel techniques which are described in Chapter 3.

1.4 Resources and programming

1.4.1 Staffing and equipment

All work will be carried out by the project team as shown in Table 1.1, or sub-contracted but managed by them. Within the time limits of this project there is insufficient time to recruit and train new staff. Datasets will be purchased and processed, and software licenses where appropriate. Field investigations will be carried out to deploy the latest survey techniques at the two trial sites.

The data fusion operations will involve considerable resources both for manpower and computing facilities. The project team will also need to meet and work together. Formal project meetings will be held at key points in the project at Leicester (Figure 1.1), but meetings between subgroups of the project team will be more frequent.

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Table 1.1. Participants in the project.

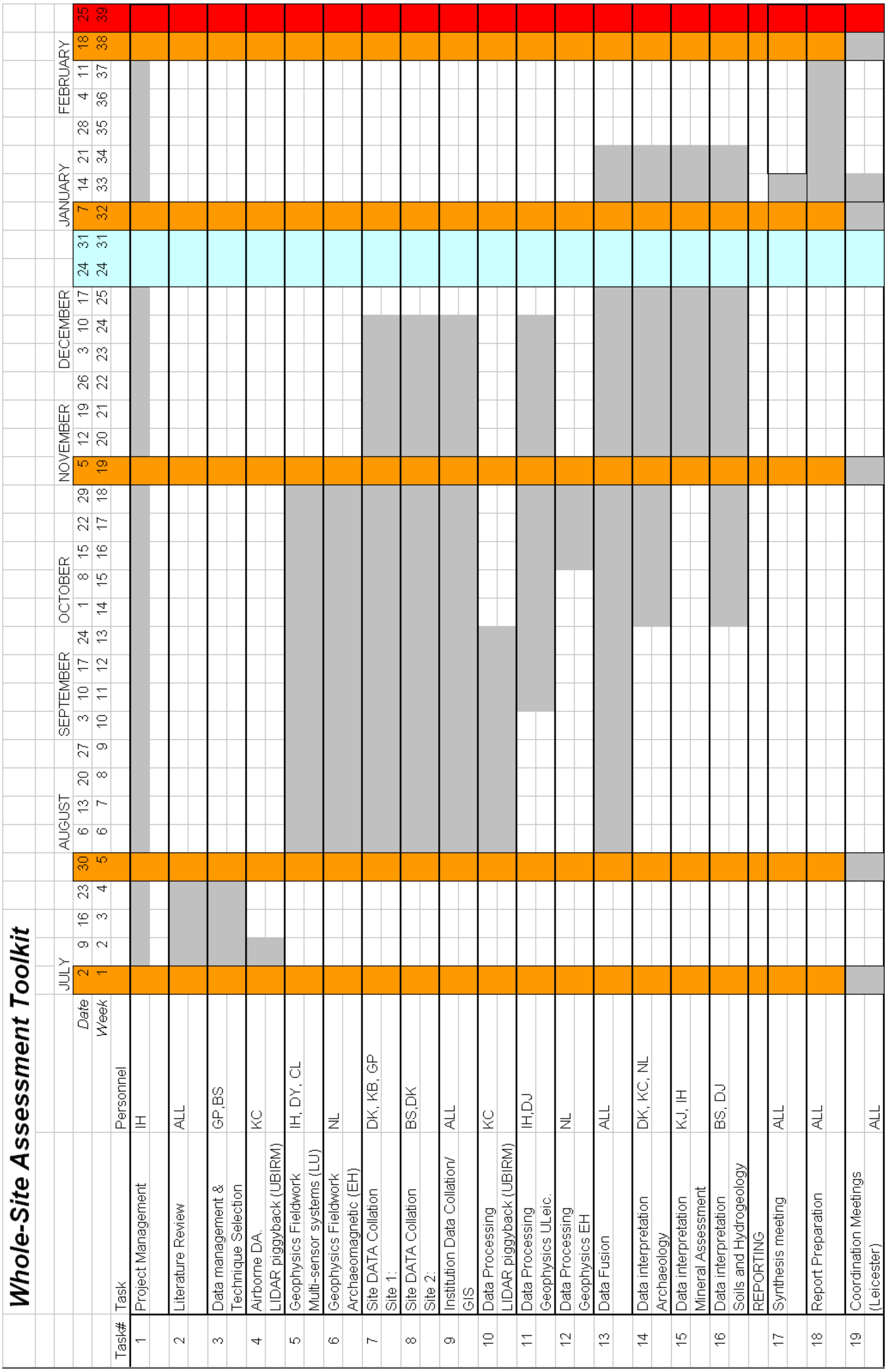


Figure 1.1 GANTT chart for the individual tasks in the FASTRAC project

1.4.2 Timetable

The schedule for this project is shown in the GANTT chart (Figure 1.1). This relates the timing of each of the individual tasks to each other and the overall timescale. Key benchmarks in the progress of the project are marked by project team meetings which divide the project into 4 logical sections:

1.5 Publication and Presentation

We will demonstrate that performing a whole-site integrated first-assessment early in the consideration of a site will be likely to provide significant cost savings for the mineral operator, heritage protection, and the planning authorities, arising from:

- Earlier data availability in the process, and common data volume encouraging a more collegiate and less combative process between developer and heritage protection.
- Better soil management, aggregate deposit assessment and archaeological evaluation
- Reduced environmental impact of intrusive investigations.
- The experience gained in this project informing the development of evidence-based best practice in this area.
- The data will be entered on the ALSF section of the Archaeology Data Service (ADS) and OASIS (Online Access to the Index of Archaeological Investigations) if necessary.

A primary publication target will be a project synthesis paper in *Archaeological Prospection*. A second paper presenting the detail of the two case studies in terms of archaeological results would ideally serve as a companion paper in the same journal. The project results concentrating on the mineral assessment will also be submitted to the journal Applied Earth Science (formerly Transactions of the Institute of Minerals and Mining IMM section B).

Presentations of results by project partners will be coordinated as the project progresses. Initially it is intended that Ian Hill will give a presentation on the themes of the project at the European Association of Archaeologists meeting at Zadar in September 2007.

1.6 Archive deposition

Project results will be disseminated through a detailed project report, and publication in relevant academic journals spanning the range of industry, geology and geophysics, and archaeology (see section 1.5).

The published report will also be accessible by the general public, and a suitably simplified synopsis of it could be incorporated on the HELM website (http://www.helm.org.uk/)

The data will be prepared to meet the standards and specifications suggested by Schmidt (2002), and will be submitted to the ALSF section of the Archaeology Data Service (ADS) and OASIS (Online Access to the Index of Archaeological Investigations) if necessary. Both of these can be found at http://ads.ahds.ac.uk/

Copies of the project report and all original data will be lodged on the public archive facility at Leicester University.

2 Literature Review

2.1 Site Assessment overview

The exploration, evaluation and exploitation of aggregate resources both within the United Kingdom and Internationally is more than simply a matter of identifying a source of suitable material. In England Mineral Policy Statements (Minerals Policy Statement 1, Planning and Minerals, 2006) set out high-level policies governing the exploration and exploitation of mineral resources (including aggregates), which include the need for an assessment of the impacts of any development on people and the environment. Guidance provided to minerals planning authorities (Planning and Minerals: Practice Guide, 2006) outlines the following areas as being the principal impacts of mineral workings and the environments on which they may have an effect:

Principal Impacts: noise; dust/air quality; blasting/vibration/fly rock; mineral waste; visual intrusion into the local setting and the wider landscape; traffic; land instability; landscape character

Environments potentially impacted: archaeological and heritage features; groundwater; surface water; internationally or nationally designated, protected or sensitive species and plant and wildlife habitats; nationally protected geological and geomorphological features.

As a consequence of these policies and guidance information pertaining to these impacts and environments must be collated, assessed and submitted in the process of developing any application involving the extraction of minerals. This literature review consequently focuses on areas in which geophysical and remote-sensing (satellite or airborne spectral imagery) techniques can be applied to further the developers and regulators ability to provide an accurate assessment and valid planning application.

2.2 Archaeological site assessment methods

The first step in determining the archaeological and historic potential of areas identified as potential aggregates extraction sites is the preparation of an archaeological desk-based assessment aimed at summarising current knowledge of the proposed quarry. This should provide the foundation for assessment of the requirements for further fieldwork and facilitate selection of the most appropriate techniques for identifying archaeological and historic features and safeguarding or recording these in advance of development. The range of potential techniques should be carefully assessed and selected in close liaison with planning archaeologists, the quarry company and other interested parties and should be chosen so as to minimise damage to the cultural resource.

Useful guidance on the range of appropriate techniques, methodologies and required standards for archaeological fieldwork is provided in *Standards and Guidance* documents published the Institute of Field Archaeologists (IFA). It is recommended that all fieldwork be carried out according to the procedures specified in the following IFA documents, which include reference to techniques listed in this section:

- *Standard and Guidance for archaeological desk-based assessments* (Oct 1994; revised Sept 1999 and Sept 2001)
- *Standard and Guidance for archaeological field evaluation* (Oct 1994; revised Sept 1999 and Sept 2001)
- *Standard and Guidance for archaeological excavation* (Sept 1995; revised Sept 1999 and Sept 2001)

- *Standard and Guidance for the archaeological investigation and recording of standing buildings or structures* (Sept 1996; revised Sept 1999 and Sept 2001)
- *Standard and Guidance for the collection, documentation, conservation and research of archaeological materials* (Sept 2001)

Other valuable guidance documents for assessment of the cultural resource have been prepared by English Heritage. These documents, which include discussion of fieldwalking (English Heritage 2006), metal detecting (*ibid.*) and geoarchaeological assessment techniques (English Heritage 2004), are listed below alongside other key works.

A basic distinction may be drawn between non-intrusive and intrusive methods of assessing the cultural resource. It is recommended that non-intrusive or minimally intrusive techniques such as air photographic survey or field scanning be used wherever possible, ensuring adherence to the principle of preservation *in situ* expounded in *Planning Policy Guidelines* 15 and 16. It should be emphasised, however, that ultimately only more intrusive work such as evaluation trenching may yield sufficient information to characterise accurately the threatened archaeological resource and permit formulation of an effective mitigation strategy. As noted below, however, the effective targeting of evaluation trenches hinges upon information acquired during many of the other surveys listed in this section and upon remote sensing technologies discussed elsewhere in this report.

2.2.1 Desk-based assessment

The desk-based assessment should provide an up to date assessment of current knowledge of the cultural resource, and as a minimum should include the following information sources:

- Search of Historic Environment Records (HERs) maintained by the appropriate administrative authority and of NMR site records.
- Collection and assessment of all available documentation and all available maps of the area (Ordnance Survey, Enclosure maps, Tithe maps, etc)
- Search of published and grey literature
- Examination of available oblique and vertical air photographs, with the aim of identifying and plotting cropmarks, soilmarks, earthworks, *etc.*
- Walkover survey: walkover of proposed development area to locate preserved earthworks (ridge and furrow, *etc*), standing buildings/structures, palaeochannels, *etc.*
- Collection and analysis of extant borehole records

2.2.2 Non-intrusive fieldwork

Subsequent fieldwork, guided by the results of the desk-based assessment, could include:

- Geochemical analyses: e.g soil phosphorous survey to locate, delimit and interpret archaeological sites (Craddock *et al* 1985).
- Field scanning: walkover of fields observing and mapping finds distributions but not collecting material.
- Detailed surveys of identified earthwork sites.
- Surveys of standing buildings/structures threatened by development.
- Plans of palaeochannels and other fluvial features surviving as visible features on the floodplain and river terraces (permitting better identification of areas liable to preserve significant organic deposits and cultural remains such as burnt mounds).

2.2.3 Minimally intrusive fieldwork

Included in this category are several techniques that may diminish or bias the preserved archaeological resource but that by comparison with test-pitting or excavation have limited destructive impact upon archaeological features and deposits. In addition, from the cost perspective such techniques may yield significant information on the archaeological and palaeoenvironmental potential of proposed development areas at a fraction of the cost of more extensive excavation.

- Surface artefact collection by systematic fieldwalking (ideally along transects no less than 10m apart, ensuring thereby that significant Upper Palaeolithic or Mesolithic sites characterised by small low-density lithic scatters do not elude discovery).
- Metal detector survey of ploughzone, with selective collection of metal artefacts
- Coring (commercial drilling rigs, power augers and hand augers): systematic coring of development areas to elucidate the sub-surface stratigraphy and topography of floodplain and terrace zones threatened by quarrying; organic samples for radiometric dating and for palaeoenvironmental assessment to be obtained from palaeochannels and buried land surfaces.

2.2.4 Other intrusive techniques

Information on the preserved archaeological resource may often be obtainable only by more intrusive excavation techniques, ranging from manually dug test-pits to large-scale open-area machine-stripping accompanied by targeted manual excavation. Any one or a combination of the following evaluation techniques may be employed depending upon the nature of the archaeological resource and the questions posed during evaluation:

- Manually excavated test pits: pits of variable size (commonly 1m x 1m), dug down through topsoil and subsoil to a maximum safe depth of 1.2m to establish primarily the density of lithics, pottery and other artefacts; to be located at spacings appropriate to the questions posed by evaluation (e.g. Trent Valley Mesolithic activity foci unlikely to be located by test-pit spacings of over 10m).
- Machine-excavated test-pits: to establish sub-ploughsoil stratigraphy and to prospect for buried organic deposits relating to palaeochannels or old land surfaces; at least one side to be manually cleaned, recorded and sampled for palaeoenvironmental and/or dating evidence if appropriate organic deposits are revealed. Depth and size variable, but deep machine pits with stepped/battered sides will leave a large destructive footprint.
- Hand-excavated or machine-stripped and manually excavated evaluation trenches, employed for investigating cropmarks, geophysical anomalies *etc.* and for investigating apparently blank areas between known archaeological sites; size and spacing to be determined by consultation with planning authorities.

The effectiveness of trial-trenching and test-pitting strategies hinges upon the information acquired during less intrusive evaluation work, the results of which should enable more effective targeting of excavations. Trial trenches can miss important archaeological remains and unless very closely spaced can underestimate significantly the buried archaeological resource (e.g. Walker and Challis 2004); this important but very costly tool should therefore be used in conjunction with combinations of the other techniques listed in this section and the remote sensing methodologies discussed elsewhere in this report.

2.3 Airborne Remote Sensing

Archaeological remote sensing encompasses a broad range of techniques from conventional aerial photography, passive and active airborne and satellite remote sensing to ground based geophysical surveys (Challis and Howard 2006). Cropmarks formed on well-drained river terraces and other sand

and gravel deposits formed amongst the earliest archaeological phenomena recorded by remote sensing, through the medium of aerial photography. The history of aerial archaeology is well documented (Bewley 2003; Riley, 1987; Wilson, 1982) and need not be repeated here. The systematic recording and transcription of archaeological cropmarks to landscape-wide maps has formed one of the key activities of archaeologists working in alluvial environments over the past 30 years (eg. Whimster, 1989). Rather more recently, archaeologists have become increasingly aware of the importance of the environmental and geo-archaeology of alluvial landscapes and have utilised conventional aerial photography to investigate and systematically map the natural landforms such as palaeochannels frequently preserved on valley floors, which provide a context for cultural activities (Garton and Malone 1998; Howard et al 2001; Baker 2007).

2.3.1 Lidar

Airborne Lidar has gradually assumed a place as part of the toolkit of remote sensing techniques available to archaeologists interested in the historic landscape. Published applications around the world include broad landscape studies (Barnes 2003; Bewley et al 2005; Bofinger et al 2006; Harmon et al 2006; Powlesland et al 2006; Shell and Roughley 2004), geoarchaeological mapping and prospection (Challis 2005; Challis 2006; Charlton et al 2003), investigation of the potential for Lidar to detect upstanding archaeological remains beneath the vegetation canopy (Deveraux et al 2005; Doneus and Briese 2006; Risbol et al 2006; Sittler and Schellberg 2006) and applications using Lidar intensity images (Challis et al 2006; Carey et al 2006). Although the potential offered by Lidar to contribute to the compilation and refinement of records of the historic environment has been broadly recognised (Holden et al 2002; Bewley 2003; Crutchley 2006) systematic use in this domain is in its infancy.

2.3.2 Airborne Multispectral and Hyperspectral Remote Sensing

To date, with the exception of Powlesland's work in the former peat filled lake basin of the Vale of Pickering (an environment radically different to the alluvial landscape of the Trent Valley, which is more characteristic of other river systems), airborne multispectral and hyperspectral remote sensing has received little attention for archaeological prospection in alluvial landscapes (Challis and Howard 2006). Studies to date have been dominated by use of the Daedalus Airborne Thematic Mapper 1268 (ATM) a multispectral instrument recording spectral reflectance and infrared radiation in 11 discrete bands ranging in wavelength from visible blue to thermal infrared (0.42 – 13.0μm). Reflectance is recorded on an 8-bit digital scale (image pixel values from 0-255) at a typical spatial resolution of 2m. The Compact Airborne Spectrographic Imager (CASI) has also seen some use in the UK. The CASI-2 instrument operated by NERC is a highly configurable hyperspectral scanner capable of recording spectral reflectance in up to 288 spectral channels at varying spatial resolution. In the archive data held by NERC the instrument has been operated in default mode (12 bands 0.43-0.875μm) with reflectance recorded on a 12-bit digital scale (image pixel values 0-4096) with a spatial resolution of 1m.

The potential of such instruments for archaeological and geoarchaeological studies has been mooted for some while (eg Allsop 1992) and work in the former lake basin of the Vale of Pickering and on Salisbury Plain (Powlesland 1997 and 2006; Barnes 2003) has demonstrated some success, although data were not subject to a comprehensive suite of analytical techniques such as the calculation of vegetation indices or multivariate analysis. Several studies have also considered uses of ATM and CASI data in other landscape types (eg Rowlands 2007 in the Mediterranean; Winterbotton 2006 in the Scottish Islands) and for non-archaeological purposes (eg Davidson and Watson 1995, Harris *et al*, 2006, Rainey *et al*, 2003). There are extensive published applications of the analysis of multispectral and hyperspectral airborne remote sensing that comprise studies of soil or vegetation properties that are directly analogous to those undertaken by archaeologists' (eg Ben-Dor et al 2002; Harris et al in press; Liu et al 2003; Rainey et al 2003).

Existing research documents use of a number of analytical techniques for use on ATM, CASI and similar remotely sensed data including false colour composites, thermal analysis, generation of vegetation indices and automatic image classification. **False colour composites** are produced by mapping different band combinations to the three colour channels of a computer graphics system. This will allow, for example, production of composite focused on reflectance in particular parts of the spectrum such as the near infrared where discrimination of variations in vegetation character or soils (enhancing visibility of crop and soil marks) may be greater (Winterbottom and Dawson, 2005). **Thermal images**, based on analysis of the emitted thermal band (11) of ATM imagery has proven particularly effective at identifying variations in the land surface representing underlying archaeological features (Rowlands and Sarris, 2007; Winterbottom and Dawson 2005; Ben-Dor, *et al*, 2001).

Vegetation Indices such as the Normalised Difference of Vegetation Index (NDVI), Enhanced NDVI and Soil Adjusted Difference of Vegetation Index (SDVI) use mathematical formula to express particular vegetation parameters as expressed by spectral reflectance, for example NDVI is an index of variations in green vegetation vigour. These techniques has proven effective at enhancing archaeological features such as cropmarks revealed by vegetation changes (Vining and Wiseman, 2007; Lasaponara and Masini, 2007; Winterbottom and Dawson, 2005) and a variety of indices will be calculated for the study areas. **Image classification** techniques rely upon the ability of computer analysis of the spectral data contained within multispectral images to identify homogenous clusters of pixels with distinctive spectral characteristics. Classification may be fully automatic (unsupervised), or based on a user intervention (supervised), for example to "train" a classification programme to locate areas with a particular spectral signature based on previous visual examination of the data, or on ground truth data. In general automatic classification techniques have performed poorly when applied to remotely sensed images for archaeological purposes, often because the spectral characteristics of archaeological objects are not sufficiently distinct from background data (Rowlands and Sarris, 2007; De Laet *et al*, 2007). Object-oriented approaches, where a two stage analysis first identifies spectrally homogenous areas within an image and then attempts a classification of these area, has proven somewhat more effective, but is still problematic (Rowlands and Sarris, 2007; Benz *et al,* 2004).

2.4 Applications of Geophysical methods to site assessment

2.4.1 Archaeogeophysics:

A wide range of geophysical methodologies have been applied to the location of subsurface archaeological remains and an extensive literature covers the history and specific adaptation of these techniques for this use (e.g. Clark 1990; Scollar *et al.* 1990; Aspinall 1992; Gaffney and Gater 2003; Linford 2006). As might be expected, the majority of successful techniques target the very near surface to a depth of approximately 1m where, for the majority of sites in the UK, evidence for archaeological activity is likely to be found. Under these conditions dense, sub-metre sample intervals allow geophysical anomalies due to archaeological features to be described in great detail enhancing the interpretation of the resulting data sets (e.g. Schmidt and Marshall 1995).

As with any form of geophysical prospection the principal requirement is the ability of a particular technique to distinguish an indicative physical contrast between the archaeological features under investigation and the host medium. Given the wide range of physical materials comprising archaeological remains and the complex processes of site formation and post-depositional alteration, this can often present a considerable challenge under typical field conditions. Variations in target conductivity due, for example, to the presence of buried masonry building remains often present a suitable target for earth resistance (e.g. Clark 1990), electromagnetic (e.g. Cole *et al.* 1995) and ground penetrating radar techniques (e.g. Linford 2004). It may also be possible to use magnetic survey to detect weakly magnetic masonry within a host soil of higher magnetic susceptibility (e.g. Gaffney *et al.* 2000). However, the association between occupation activity and the enhancement of the magnetic properties of geologically suitable soils (e.g. Linford 2005) provides the necessary physical contrast that justifies magnetic survey as the most widely used prospection technique by far for archaeological prospection in the UK.

More recent developments in archaeological prospection have seen the development of magnetic instrumentation to both increase the rate of data acquisition in the field (e.g. Bartington and Chapman 2004) and deploy high-sensitivity measurements at dense sample intervals for the identification of very subtle anomalies (e.g. Linford *et al.* 2007). Continued advances have also been made in the adaptation of towed earth resistance measurement systems (e.g. Dabas *et al.* 2000; Walker *et al.* 2005) and the integration of navigational/positional data with GPR instruments (e.g. Leckebusch 2005) to increase the applicability of these two techniques to much wider area landscape surveys (e.g. Neubauer *et al.* 2002).

Of more specific interest to the current project is the application of geophysical methodology to archaeological site evaluation (e.g. English Heritage 1995; Gaffney *et al.* 2002), where the choice of both techniques and sampling methodologies may be compromised by the scale of the site under investigation. This has often led to the adoption of more indicative geophysical techniques, such as topsoil magnetic susceptibility measurement (e.g. Clark 1983) and magnetic scanning, to identify areas of likely archaeological activity for limited follow-up coverage with detailed, recorded survey. Under suitable conditions such an approach can prove effective, although, weakly magnetic features and distributions of discrete, non-linear anomalies can be easily missed, particularly over large sites where variations in local geology and soils would be expected.

Particular problems may be encountered over lower lying, floodplain sites where significant deposits of alluvial material may impede the identification of archaeological activity through remote sensing (e.g. Clark 1992; Weston 2001; Challis and Howard 2006). This is often due to a combination of factors including an increased depth of overburden, which will reduce the magnitude of anomalies detectable at the surface, and the potential for floodplain sites to offer less favourable conditions for the processes of magnetic enhancement related to occupation activity (e.g. Linford 1994; Weston 2004). Ironically, such water-logged conditions generally result in very good conditions for the preservation of organic remains and the presence of alluvial overburden can also offer an enhanced degree of protection to archaeological sites from damage due to mechanised ploughing.

In the context of the current study two major problems are apparent when considering the archaeological evaluation of proposed aggregate extraction sites, namely the very large areas of land involved and the floodplain location for many of these projects. The potential scale of the evaluations would normally favour the use of rapidly deployed indicative techniques, followed by the use of detailed geophysical survey over a selected sub-sample of the site. Such an approach, using different levels of detail of geophysical evaluation, is well established (e.g. Gaffney *et al.* 2002), although some variation in the success of even recorded surveys compared to the underlying archaeological remains revealed on excavation is often encountered (e.g. Linford and David 2001). Of greater concern, however, are the often poor geophysical conditions presented over floodplain sites where indicative techniques, such as topsoil magnetic susceptibility and magnetic scanning, are most highly compromised and significant archaeological activity may only be revealed through invasive investigation. This may lead to the requirement for large scale evaluation through randomly sampled trial trenching, or the potential delay to an ongoing development to allow for the recording of unanticipated archaeological remains.

One potential resolution to this problem is development of very rapid means for acquiring detailed survey data, preferably utilising multiple geophysical techniques and arrays of individual sensors. The purpose of the current research is to further investigate the application of these systems in comparison to both other means of site evaluation and sampled areas of conventional geophysical acquisition.

2.5 Sand & Gravel Deposit Evaluation

Sand & gravel land search in England typically involves use of published geological data derived from BGS mapping and Mineral Assessment Report Series. However most large aggregate companies also have a major archive of geological information based on decades of exploration and site investigation. The use of computer systems based on integrating geological and planning data is also being developed by the BGS mainly for public authority and planning policy use (Coleman 1998). This is also being supplemented by environmental asset maps but these are generally on a scale that is too large for effective individual site consideration (Coleman 1998). More integrated studies are have been used to define potential site areas (Crimes et. al. 1994) and in certain localities satellite imagery has been used for large scale river system assessment (Petch 1990)

Site investigations are usually undertaken using drilling techniques such as flight auger drilling, shell & auger, reverse circulation and more recently sonic drilling although care is required in comparing the results produced from different techniques (ADICT & Dixon 1988). Sites are usually drilled on variable grid patterns with spacings around 100m (Smith & Collis 1993, Annals 1991). These are frequently supplemented by trial pits for recovery of both bulk samples for processing and to assess the coarsest ('oversize') fraction which may not be recovered or is comminuted during drilling, and which may require crushing or a modified extraction method.

The samples recovered are graded to give particle size distributions that, with appropriate correction to simulate processing, can be compared with specifications for potentially saleable products. This is undertaken using a set of standard sieves on which EU product specifications are based however some British Standard or customer specific criteria may also still be used requiring other sieve fractions to be assessed (Smith & Collis 1993). These grading tests are supplemented by a smaller number of samples that are described in standard format and assessed for a range of physical and application specific tests such as crushing, sulphate durability, shape etc (for example British Standards Institution 1975 et seq, European Committee for Standardisation 2002a,b,c)

Where the material is to be used for concrete aggregate it will be incorporated in concrete mixes and strength assessed. The detailed petrography will also be described to evaluate potential for Alkali Silica reactivity and associated problems. Similarly sands for use in asphalt will be incorporated into a Marshall asphalt design trial to assess bitumen demand in contrast to existing asphalt sands (Pike 1990).

Important to planning the potential quarry design is the presence and level of the water table. This is recorded in boreholes at the time of drilling but monitored long term by installation of piezometers which are dipped on a regular basis to assess the fluctuations in water table through the seasons.

While the drilling aims to define the geometry and approximate volume (and hence tonnage) of the deposits, the samples are used to assess the potential usability of the material in aggregate applications. There are significant issues relating to sand & gravel deposit evaluation based upon trends in the type of deposit being explored for and permitted, and the influences of increasing corporate governance requirements and internationalization of the industry (Jeffrey 2007).

Historically sites were relatively simple, particularly in England, relying on river gravels and fluvio-glacial deposits. In many areas the cleanest and most easily exploited deposits are either exhausted or for planning reasons are no longer available. The more complex glacial and associated deposits are increasingly being used. Here the lateral continuity of the aggregate bodies is much more variable, and the internal lithological units comprising the bodies are also much more variable and less laterally continuous. In this case the need for more detailed spatial sampling of the deposits during exploration is clear. The typical industry approach to evaluation does not always recognise this and geostatistical analysis of drilling results has been used to suggest additional drilling may be needed (Jeffrey et. al 2004b, Jeffrey et. al. 2005). Geostatistics is not widely used in deposit evaluation due to this reason and the only marginal difference in using kriging to define deposits size (Arthur 1994, Hack 2005).

Extraction of economic deposits has been widely planned based on the variability indicated by these boreholes, particularly on differences in gravel, sand and silt contents. Rules of thumb are frequently used to assess, when split into a coarser concreting sand, and finer asphalts or mortar sand, what gradings and proportions of each will be produced. Planning of the site based more on the variability of the deposits match to the desired product has been developed in more recent MIST projects (Jeffrey et al 2004a).

2.5.1 Mineral Assessment geophysics

Application of geophysical methods in the aggregate mineral industries to exploration for and evaluation of sand and gravel deposits has been restricted. A principal limitation on this have been the combination of cost of geophysical surveys relative to trial-pits or drilling for such shallow deposits, combined with the perceived added value of recovering actual samples of the material through physical sampling. Secondly, the traditional policy of drilling on a regular grid pattern has been shown to provide reliable and robust estimates of the overall physical volume of deposits (Wardrop, 1999). There has also been considerable scepticism in the industry about the ability of geophysical techniques to provide useful constraints on the lithological variation within deposits.

Geophysical techniques offer a possibility of providing close spatial sampling in a non-invasive way, and may be viable commercially if they are cost-efficient. Recent advances in use of multi-sensor geophysical surveying techniques (e.g. Hill 2004a, 2004b, Jeffrey et al 2005) have explored these possibilities by carrying out surveys over known mineral deposits with such multi-sensor platforms, with positive results. It is clear that geophysical techniques can respond to the lateral variation in such complex sand and gravel deposits, but there are a range of separate lithological factors which can influence the geophysical response and it is unclear how well the observed geophysical anomalies can be resolved into separate lithological factors which are important to aggregate planning and extraction. Apart from the purely geometrical factors such a depth of burial, thickness of deposit and lateral continuity, the lithological factors such as dominant grain size, grain size distribution, clay content, water saturation are difficult to isolate from the geophysical response.

Electrical conductivity is a prime geophysical parameter which is related to several of the lithological parameters listed above. Resistivity in particular has been used to resolve variations between boreholes and on deposit margins (e.g Reynolds, 1997, Kearey et al, 2002). Modern methods of resistivity imaging and their interpretation in terms of conductivity cross-sections (Loke, 1996a) are a powerful tool in determining bulk conductivity properties of the sub-surface. There is however a difficulty in the time and cost involved in carrying out a detailed grid of survey lines.

EM methods are attractive because of their speed and recent work has focussed on rapid methods of undertaking surveys at high resolution across large parts of the deposit as an aid to interpretation of drilling results (Hill 2004a, Jeffrey et al 2005). Hill (2004a) has shown that producing conductivity maps from EM survey data can be rapid and precise, and that such maps can be derived for several different depths of penetration into the ground, providing effective depth-slice images of the subsurface structure. Such images were also shown to be directly compatible with resistivity imaging profiles conducted across the same test deposit. The weakness of such EM survey data is in the difficulty of having uniformly accurate calibration of the EM data values from different equipment systems necessary to conduct surveys at different depths. Without such calibration, combination of the data into integrated quantitative modelling of the sub-surface is problematic.

There is a logical argument for using geophysical surveys as a replacement for grid drilling, with drilling reserved for targeted holes to prove the geophysically defined variability. Some drilling however is always going to be required to provide material for detailed sieving and performance trials and the potential of geophysics to be an accurate predictor of aggregate quality beyond simple clay and silt levels is still in its infancy.

2.6 Hydrogeology and Hydrology.

The hydrogeology and hydrology of a prospective aggregate extraction site has a profound impact on both the planning case submitted to the regulator (i.e. via its impacts on water quality and quantity, groundwater quality, archaeological preservation and restorative options) and the developer (i.e. methodologies of site operation and economics of site development). An assessment typically follows a tiered approach of a desk study followed by increasingly intrusive investigations, numerical modelling and monitoring. Because of the dynamic nature of the water cycle investigations require (a) an assessment of the impact of the primary extraction but also of the potential impact, (b) the fate of process fluids and (c) the prediction of the longer term suitability and sustainability of any proposed site restoration plan. All of these investigations require the development of a conceptual model of the site along with associated numerical predictive hydrological and hydrogeological models. The accuracy of these models is often difficult to ascertain until development has started and as a consequence the opportunity of providing addition information from geophysical and remote-sensing methodologies should be beneficial to the development of a more robust planning application.

Desk Study

One of the major aims of the desk study phase is to define baseline conditions and the spatial distribution of hydrological and geological features of the proposed site and its local environs. Information typically collated includes data at a variety of scales (local and site specific) from the Ordinance Survey, Meteorological Office, British Geological Survey and the Environment Agency (e.g. hydrological features, geology, groundwater spatial data and levels, groundwater and surface water abstraction consents, surface water discharge consents and vulnerability assessments etc). From this data a preliminary conceptual model of the site will be developed highlighting knowledge gaps and associated strategies for reducing them in subsequent phases of the study.

Intrusive Study

Baseline information collected during the desk study will be augmented by numerical and observational data collected during other intrusive resource assessment and development activities (e.g. borehole drilling and associated geological and hydrogeological assessments) and ongoing resource exploitation and restoration planning (e.g. need for washing and other treatment, drainage, landscaping etc.). On the basis of this data the preliminary conceptual model will be revised and numerical models developed to predict the developments impact on local hydrogeological and hydrogeological environments (i.e. water balances, impacts and risk assessments).

Case studies and methodologies associated with the development of hydrogeological and hydrological methodologies associated with mineral assessment include:

Reducing the Effects of Surface Mineral Workings on the Water Environment. Report prepare for the DETR by Symonds Travers Morgan,1998.

Hydrology of Mineral Workings. Effects on Nature Conservation, (Guidelines and Technical Annexe). Report prepared for English Nature by MRM Partnership, March 1994.

Sustainable Urban Drainage Systems – Best Practice Manual. CIRIA. Report C523, 2001.

Sustainable Urban Drainage Systems – Design Manual for England and Wales. CIRIA Report C522, 2000.

2.6.1 Opportunity for incorporating additional information from geophysics and remote sensing

a) Baseline Data

In England where good quality mapping exists at scales below 1:10K improvements in the quality of baseline data are most likely to occur through the use of ground-based rather than airborne remote sensing. In respect of airborne investigations aimed at enhancing the developer's knowledge of the hydrological characteristics of prospective site the techniques offering perhaps the greatest potential include airborne EM for aquifer characterisation (e.g. Reference – BGS) and LIDAR for hydrological features and landscape, although a wide range of other techniques may be applicable in the longer term (Robinson et al., 2006).

b) Data from Intrusive Studies. Because of the need for numerical data for input into predictive modelling, and the inherent difficulty (and thence costs) of hydrologically modelling complex (both temporally and spatially) alluvial environments much of the data collected in typical planning applications relates to the relatively simplistic modelling of fluid levels and fluxes by dipping, gauging and automated sampling of surface and groundwater. Of the wide range of available techniques those most suitable for assisting in hydrological investigations must either (a) be able to provide a detectable contrast between the aquifer host material and the water table (b) be able to provide data relating to the hydrological properties of the aquifer and/or unsaturated zone and (c) be able to provide temporal information. These needs are best met by ground based geophysical surveys and installations (Robinson et al., 2006).

2.7 Land and Soil

Soil is a fundamental part of England's landscape and is increasingly valued as a finite resource in need of protection (DEFRA 2004; European Union, 2006). In addition the Rural White Paper (2000), Our Countryside – the future, made clear that planning decisions should consider the overall value of the land in deciding what countryside should have the greater protection. Thus when determining minerals planning applications the agricultural quality of the land should be considered together with other sustainability considerations (e.g. wildlife; geodiversity; the quality and character of the landscape; its amenity or historic interest), and the feasibility of reclamation or restoration to a standard required to secure an appropriate after-use.

To date the most commonly used form of assessment incorporated into mineral planning applications is that encompassed within guidelines contained in the Agricultural Land Classification of England and Wales (MAFF, 1988). This system provides a framework for classifying land according to the extent to which its physical or chemical characteristics impose long-term limitations on agricultural use and as such requires information on the climate (temperature and rainfall), site factors (gradient, micro-relief and flood risk) and soil (texture, structure, depth and stoniness). However, this classification only covers the potential agricultural use of the land and does not take into account the aspirations of maintaining multifunctional as encompassed by developing policies on soil (DEFRA, 2004). It is also worthy of note that in many alluvial sand and gravel deposits in England the depth of soil is shallow and that in many cases exploitable material may exist very close (<30cm) to the surface.

2.7.1 Opportunity for incorporating additional information from geophysics and remote sensing

The use of geophysics and remote sensing to determine land and soil quality dates right back to development of these techniques and has been applied successfully for many years. However, none of these techniques is universally applicable for the determination of soil type (REF Lawley – MAFF) or soil properties and costs remain relatively high (Robinson et al., 2006). There now exists a broadening interest in this area of research (Slater et al., 2006; Lawley et al., 2007) as the concepts of soil multi-functionality and sustainability, and climate change has led to interest in the derivation of soil properties and function rather than traditional soil mapping and applied in England.

Application of remotely sensed techniques such as airborne spectral imagery based on near surface properties of the soil and landscape offer some degree of information on soil texture and moisture content and have been used extensively in the digital mapping of soils (Scull et al, 2003). LIDAR can provide information on micro-relief, which can be used to refine the agricultural land classification scheme. However all of these techniques are sensitive to the presence of crops and trees in the landscape.

Ground based geophysical techniques again offer considerable promise in terms of determining soil properties however, the depth of investigation of such techniques often bypass thin soils and there is a need for careful planning if information on both the upper most layers and deeper sand and gravel resources are to be evaluated simultaneously.

3 DATA COMPILATION

3.1 Airborne Laser Scanning (Lidar)

General Introduction

Airborne Lidar has gradually assumed a place as part of the toolkit of remote sensing techniques available to archaeologists interested in landscape studies. The present study uses both 2m spatial resolution elevation data acquired from the Environment Agency (EA) and 1m spatial resolution elevation data collected for the project team by Infoterra. Analysis of Lidar elevation data, in the form of colour shaded and relief shaded elevation models, is rapidly able to reveal geoarchaeological and geomorphological detail, such as terrace and palaeochannel geometry, often with greater effectiveness than conventional aerial photography (Challis 2006). Examination of Lidar intensity data (available for the Infoterra collected data, but not from EA) offers the potential to reveal additional geoarchaeological detail and to remotely determine aspects of soil and sediment character (Challis et al 2006).

The Lidar Principle

Airborne laser scanning 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 kHz, 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 area a 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. Typically the 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 backscattered laser pulse may also be recorded.

Backscattered laser intensity measurements do not form a part of the standard data product supplied by EA. The Lidar system used by EA, NERC and many UK-based commercial Lidar providers (an Optech Airborne Laser Terrain Mapper) operates in the near infra-red (NIR: 1047nm) and so backscattered intensity is in-effect a record of the reflectance of earth surface materials at this wavelength.

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. A detailed technical discussion of Lidar may be found in Wehr and Lohr (1999) and Baltsavias (1999), details of the system used in the present study are contained in Optech 2003.

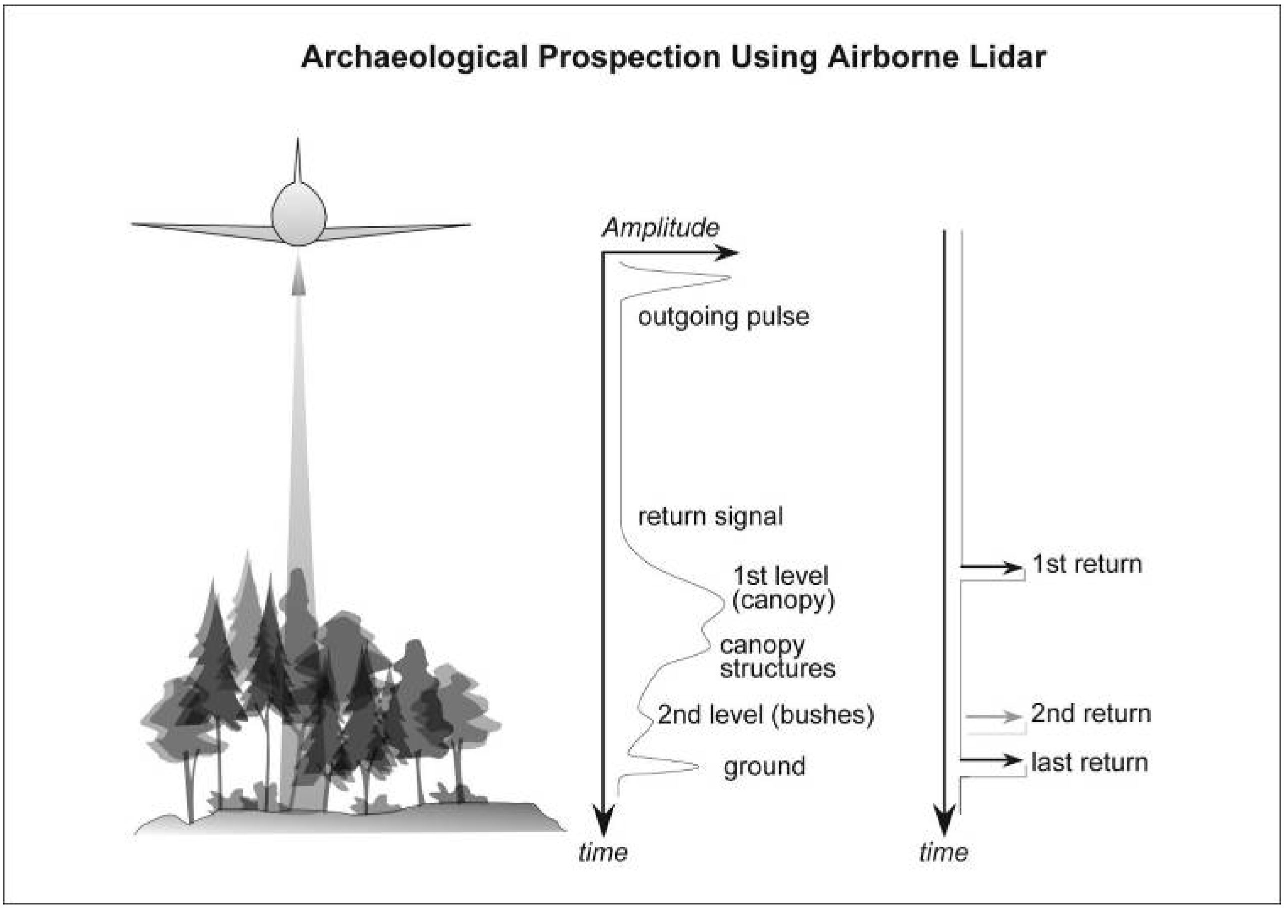


Figure 3.1. The airborne Lidar principle. Archaeological analysis makes use of both the elevation values and the intensity (amplitude) of each returned pulse.

Instrument Used

The Lidar data used in the present study were supplied by the Environment Agency (Shelford) and Infoterra (Sturton-le-Steeple). The EA Lidar data were collected by a flight comprising part of the Agency's airborne remote sensing programme using an Airborne Laser Terrain Mapper (ALTM) the Optech ALTM 2033 Lidar which is able to record two returns (first and last) for each laser pulse, typically collecting 0.5 points/m^2 (Brown et al 2003). EA data are processed to WGS84 projection, transformed to British National Grid and a regular grid with elevation values in OSGB36 datum, generated from the raw point-could.

Data Processing

Lidar data from EA were supplied in 2km square tiles with a 2m grid resolution in ESRI ASCII grid format. The EA data product comprises a single return without access to separate FP, LP or intensity data. In the present study EA data were used by importing the individual 2km square grid tiles into ESRI's ArcGIS geographical information system and merging them to form larger grids representing the entire of each river reach studied, to allow comparison with other relevant data.

Infoterra data was collected by a single flight, again flown using an Optech ALTM 2033 Lidar recording two returns (first and last). The Infoterra data was supplied as point cloud xyzi data in LAS format for first and last pulse returns processed to WGS84 datum. The point clouds were processed using Applied Imagery's Quick terrain modeller software to generate first and last pulse digital surface models at 1m spatial resolution, and 8-bit greyscale images derived from first and last pulse intensity values.

The DSM and intensity images were further processed using Erdas Imagine 9 by reprojecting to British National Grid and converting ellipsoidal elevation values to orthographic values based on Ordnance Datum.

Analytical Techniques

The Lidar DSM were imported into a geographical information system (GIS) developed using ESRI ArcGIS 9.2 to allow direct comparison with digital HER data and digitised, geocorrected aerial photography. Visual interpretation of the Lidar data was based on the examination of shaded relief images generated within ArcGIS to identify anthropogenic features. Shading was calculated from four different azimuths, northwest (standard shading) north, northeast and east, since experimentation showed that some features were not evident if the DSM was shaded only from a single direction. Further analysis of the Lidar DSM using carefully constrained colour ramps to differentially shade areas of relatively restricted variation in relief was used to assist in identifying geoarchaeological features.

3.2 Airborne Multispectral Remote Sensing

This element of the project aimed to investigate the potential of airborne multispectral remote sensing to identify cultural, environmental and geoarchaeological remains within the study areas. The study employed existing Daedalus Airborne Thematic Mapper 1268 (ATM) data, from the NERC data archive for the Shelford study area, and AISA EAGLE 1K hyperspectral data for the Sturton study area collected for the project team by Infoterra.

Data were examined to determine effective image processing and enhancement protocols, including which techniques most effectively enhance archaeological and mineral deposit detail, for example crop and soil marks, terrace and palaeochannel location and geometry. Unlike conventional air-photography, in which images comprise an aggregate of reflected solar radiation across the visible spectrum, multispectral imagery allow examination of discrete spectral bands both within and beyond the visible spectrum. This facility allows far greater discrimination of earth surface materials, based on their distinctive spectral reflectance. Combinations of spectral bands are used to produce false colour images by mapping single spectral bands to each of the red, green and blue colour channels of a computer graphics system. Since multispectral data are also stored digitally the spectral reflectance values are also able to be manipulated using mathematical and statistical analyses.

3.2.1 Instruments Used

Daedalus 1268 Airborne Thematic Mapper

The Daedalus 1268 ATM is a multispectral instrument recording spectral reflectance and infrared radiation in 11 discrete bands ranging in wavelength from visible blue to thermal infrared (0.42 – 13.0μm). Reflectance is recorded on an 8-bit digital scale (image pixel values from 0-255) at a typical spatial resolution of 2m.

Channel Bands	Wavelength(nm)	Landsat TM
1	0.42-0.45	

2	0.45-0.52	1
3	0.52-0.60	2
4	0.60-0.62	
5	0.63-0.69	3
6	0.69-0.75	
7	0.76-0.90	4
8	0.91-1.05	
9	1.55-1.75	5
10	2.08-2.35	7
11	8.5-13.0	6

Table 3.1. ATM and equivalent Landsat TM channels

AISA Eagle

The AISA Eagle hyperspectral sensor is a complete pushbroom system with a 1000 pixel swath width, covering the visible and near infra-red spectrum 400 - 1003nm. The spectral resolution of the sensor is 2.9nm. Data for the present study were collected on 18th October 2007 over 34 spectral bands at a spatial resolution of 1m. Spectral details are provided in table N.

Channel	Centre(nm)	Width(nm)	Start(nm)	End(nm)	Comment
1	409.810006	16.360001	401.630005	417.990006	
2	426.180001	16.360001	418.000000	434.360001	
3	442.750013	16.660000	434.420013	451.080013	Blue Veg Response
4	459.930015	17.080000	451.390015	468.470015	
5	477.029990	17.080000	468.489990	485.569990	
6	494.129996	17.080000	485.589996	502.669996	Veg Response
7	511.230002	17.080000	502.690002	519.770002	
8	528.329978	17.080000	519.789978	536.869978	
9	545.775015	17.770000	536.890015	554.660015	Green Veg Max
10	563.209998	17.799999	554.309998	572.109997	
11	580.990027	17.799999	572.090027	589.890026	
12	598.769995	17.799999	589.869995	607.669994	
13	616.550024	17.799999	607.650024	625.450023	Vis Red
14	634.329993	17.799999	625.429993	643.229992	
15	652.119971	17.799999	643.219971	661.019970	
16	669.910010	17.799999	661.010010	678.810009	
17	687.709988	17.820000	678.799988	696.619988	

18	705.519976	17.840000	696.599976	714.439976	Red Edge
19	723.370012	17.840000	714.450012	732.290012	
20	741.329999	18.040001	732.309998	750.349999	
21	759.330022	18.240000	750.210022	768.450022	Oxygen Absorp
22	777.529973	18.240000	768.409973	786.649973	
23	795.779973	18.240000	786.659973	804.899973	Veg Reflect Max
24	814.039983	18.240000	804.919983	823.159983	Waterabsorp
25	832.289983	18.240000	823.169983	841.409983	
26	850.529973	18.240000	841.409973	859.649973	
27	868.760015	18.240000	859.640015	877.880015	NIR plateau
28	886.989995	18.240000	877.869995	896.109995	
29	905.229976	18.260000	896.099976	914.359976	
30	923.489977	18.280001	914.349976	932.629977	
31	941.770006	18.280001	932.630005	950.910006	
32	960.049974	18.280001	950.909973	969.189974	
33	978.340013	18.280001	969.200012	987.480013	
34	995.659981	16.360001	987.479980	1003.839981	

Table 3.2. AISA Eagle Bandset for Sturton-le-Steeple survey

3.2.2 Data Processing

Archive ATM data from the NERC Earth Observation Data Centre (NEODC) were downloaded via FTP using the HP Vista user account with NEODC. Archive data in HDF format were processed and geocorrected before conversion to appropriate formats for analysis; initially to Erdas Imagine image format using Imagine 9 and subsequently to ArcGIS 9.1 grid format for integration into a project GIS. Other GIS, HER and remotely sensed data were extracted from archive and collated to form a coherent project GIS.

Aisa Eagle data were available for an approximately 100km^2 area of the Trent Valley focussed on Sturton-le-Steeple, Nottinghamshire. These data were provided by Infoterra as geotiff files, projected to WGS84 datum and UTM co-ordinate system.

Radiometric and Atmospheric Correction

The digital imagery supplied by NERC comprise ATM data processed to level 1b, that is with radiometric correction but no other post processing, archived in HDF format comprising at sensor digital number (DN) pixel values and flight ephemera.

DN are at-sensor radiance values mapped to a fixed scale (eg 8 bit for ATM; ie 0-255 values. ATM and Eagle data comprise a series of spectral bands, the pixels of which each have a digital number. The pixel DN is a linearly transformed representation of at-sensor radiance for a discrete resolved area of the Earth's surface. As pixel DN is a simple linear transformation of radiance the slope and offset of this linear transformation can be used to calculate radiance.

DN values are affected by both atmospheric and geometric distortion. Atmospheric correction requires conversion of at-sensor radiance to apparent at-sensor spectral reflectance by accounting for temporal changes in solar illumination due to Earth-Sun geometry. However, at-sensor reflectance still has atmospheric scattering effects present. In many cases it is essential to remove or alleviate atmospheric effects by suitable image processing, to produce true at-surface radiance values. This is essential if quantitative comparisons are to be made from different sensors, with different sensor parameters, or from survey flights carried out at different times, where atmospheric conditions may vary between flights. The aim of atmospheric correction is to derive a good estimate of the true at-ground radiance (reflectance).

However, since in the present study only ratio analysis and classification of imagery was to be attempted, and no quantitative analysis was required, it was felt unnecessary to carry out atmospheric correction of the imagery used, particularly as in the absence of contemporary ground control and atmospheric data this would of necessity rely on less than accurate empirical estimation techniques.

Geocorrection

Archive level 1b ATM data were pre-processed using Azimuth Systems Azgcorr 4.8 to combine flight ephemera and radiance data to produce automatically geocorrected level 3 images with real world co-ordinates (OSGB36 co-ordinate system). Where necessary further correction was undertaken using the geocorrection module of ArcGIS 9.2 using an Ordnance Survey 1:2500 base map as a source for GCP.

Eagle data were supplied by Infoterra as level 3 processed flight lines (ie with some radiometric correction and geocorrected to the GPS co-ordinate system (WGS84)). Individual flight-lines were reprojected to the OSGB36 co-ordinate system using the reprojection module of Erdas Imagine. Flight-lines were then combined using the mosaic module of Imagine to produce a single multi-band image file. A rectangular area of interest (AOI) was extracted from the mosaic and imported into ArcGIS for image processing and analysis. Examination of the image showed that reprojection of the original data had produced imperfect results, probably largely due to errors introduced by the GPS and INS systems used at the time of data collection. The image was therefore subject to a second stage of geocorrection within ArcGIS, to fit GCP collected from OS 1:2500 mapping, before further analysis.

3.2.3 Analytical Techniques

Colour Composites

True colour composite (TCC) and false colour composite (FCC) images were created by displaying combinations of geocorrected image bands within ArcGIS. TCC images for ATM data conventionally comprise bands 4-3-2, for Eagle data bands 13-9-3.

FCC images focused on the NIR/R part of the spectrum tend to highlight variations in vegetation vigour reflected in the greenness of vegetation and hence its proportional absorption of red light and reflection of NIR. NIR/R reflectance is a good indicator of cropmark formation and may be expected to enhance cropmarks apparent within the visible spectrum and may expose “latent” variations in crop character apparent only beyond the visible spectrum.

FCC images using the middle and thermal infrared bands of ATM can be expected to be particularly effective at displaying variations in soil character and moisture content and may enhance visible and latent soilmarks. ATM FCC images will be prepared using bands 9-7-3 and 9-8-3. For Eagle bands 31-21-13 proved effective.

Thermal Band Analysis

Band 11 of ATM imagery records energy emitted by the earth surface in the thermal infrared part of the spectrum (8.5-13.0nm; note that there is no equivalent band in Eagle imagery and so this component of the research is limited to ATM imagery only). The energy emitted at these wavelengths is generally related to variations in soil/ground moisture and microtopography, which together affect the temperature of ground. Analysis of the thermal band of ATM data has proven particularly effective at identifying archaeological features. The thermal band for ATM images was examined individually in order to identify archaeological and geomorphological features and assess the efficacy of thermal imagery for archaeological prospection in alluvial environments.

Vegetation Indices

Vegetation indices allow the differentiation of areas of differing vegetation and soil character based on the characteristic reflectance patterns of green vegetation, which typically has low reflectance in the visible (especially red) portion of the spectrum with a sharp increase in reflectance in the near-infrared portion (Yang, 2007; Todd et al, 1998). The majority of indices are thus suitably adjusted ratios of red to NIR reflectance. The most common, the normalised difference vegetation index (NDVI) has been utilised with some success for the archaeological analysis of ATM imagery (Winterbottom and Dawson, 2005). In the present research analysis of ATM, and Eagle data used the NDVI

$$\text{NDVI} = \frac{(NIR - R)}{(NIR + R)}$$

Band selection for generating these indices was based on selection of the maximum vegetation absorption (visible red) and maximum vegetation reflectance bands (NIR)

Principal Component Analysis

Principal component analysis (PCA) is a multivariate statistical technique used to reduce redundancy multispectral image due to the correlation of adjacent spectral bands. PCA will be applied to the ATM and CASI data and experimentally to multi band imagery generated by fusing CASI/ATM and other RS data

These principal components reflect the maximum change in the original data (Mather, 2004). The effect is to compress the changes in reflectance revealed across the 11 or 12 bands of ATM into a lesser number (usually three) principal components. Components may usually be related to particular earth surface properties. PCA has shown some potential in the analysis of Landsat imagery for archaeological purposes (Vining and Wiseman, 2007) while Kvamme (Kvamme 2006) has used PCA to analyse co-registered geophysical survey data from multiple sources. In the present research was used to visually assess multiband ATM. Four components were generated from the 12 band ATM imagery using the multivariate analysis module of ArcGIS. Each of the first three components were examined visually by producing a three band colour composite image and as single component greyscales.

Factors affecting crop and soil mark Formation

The overall aim of this element of the project was to investigate the efficacy of airborne remote sensing, using Daedalus 1268 ATM and AISA Eagle instruments for the prospection of cultural, environmental and geoarchaeological remains. Both anthropogenic and natural features are evidenced buy one or more of the classic means of identification from the air: cropmarks, soilmarks and/or variations in illumination (shadow features). Effective processing of multi and hyperspectral imagery requires some understanding of the physical phenomena giving rise to these features.

In general the amount of sunlight (solar radiation) reflected by different earth surface materials varies greatly in both intensity and wavelength across different materials. Such differences may be a result of their different:

1. bio-physical properties,
2. chemical composition and
3. surface geometry (roughness).

Archaeological cropmarks are produced when buried archaeology affects the growth of overlying crops. This may be as a result of soil moisture stress in summer and/or because of the variations in availability and supply of nutrients, in particular nitrogen and calcium. Generally crops grow taller, more vigorously and mature later over buried negative features, which provide a greater depth of sediment containing moisture and nutrients. Conversely, over buried positive features such as walls that restrict the supply of nutrients and moisture, crops grow with less vigour and mature quicker. In general these phenomena are most evident freely draining soils and substrates, subject to summer moisture stress. Soils that tend to retain water are less prone to cropmark formation.

The essential element of the cropmark is the variation in crop colour and vigour. Spectral response in the visible and NIR parts of spectrum reflects changes in vegetation type, leaf moisture content and the presence of key nutrients. In the visible part of the spectrum (400 – 700nm) the amount of solar radiation reflected is determined by composition and concentration of chlorophylls a and b, caretenoids and xanthophylls which vary due to vegetation type and nutrients status. In the Near Infrared (NIR) part of the spectrum (700-1300nm) the principle variations in spectral reflectance are caused by the number and configuration of internal air spaces within leaf and moisture content of plant. In the Short Wave Infrared (SWIR) part of the spectrum, between 1350 and 2500nm, reflection is most affected by water concentration in plant tissue.

Archaeological soilmarks are largely the results of plough disturbance truncating archaeological features and deposits and by so doing introducing discrete areas of sediment of different character into the ploughsoil. They are most readily seen in areas of shallow soil, with a subsoil of contrasting colour. Differences in sediment character might relate to a number of characteristics, including organic content, mineralogy and particle size. Soilmarks of palaeochannels are perhaps more likely to be betrayed by variations in soil moisture, sediment character (silt/clay channel fills) and organic content of soil if peat or other organic sediments are disturbed. All of these soil characteristics are likely to cause variations in reflectance in the NIR and SWIR parts of the spectrum These are particularly likely to be evident in the thermal infrared (TIR) part of the spectrum (beyond 8500nm) where variations in soil and sediment moisture and microtopography may affect ground temperature.

Shadow features are caused by variations in illumination of the ground surface due to upstanding earthwork features. Such features differentially affect the amount of solar radiation reaching the ground surface. The shadow effect may also lead to local variations in the thermal properties of the ground.

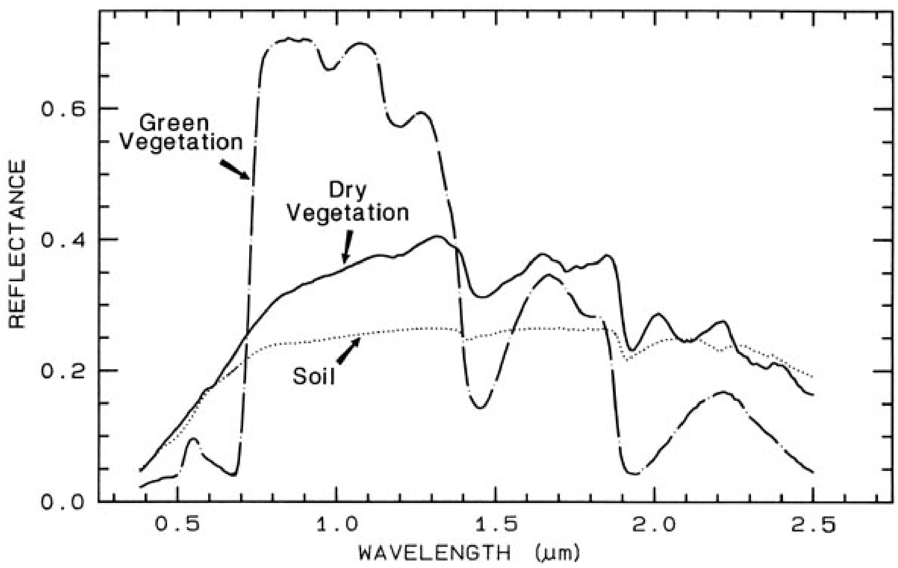


Figure 3.2. Graph showing theoretical reflectance of vegetation and soil in the visible, NIR and SWIR portions of the spectrum.

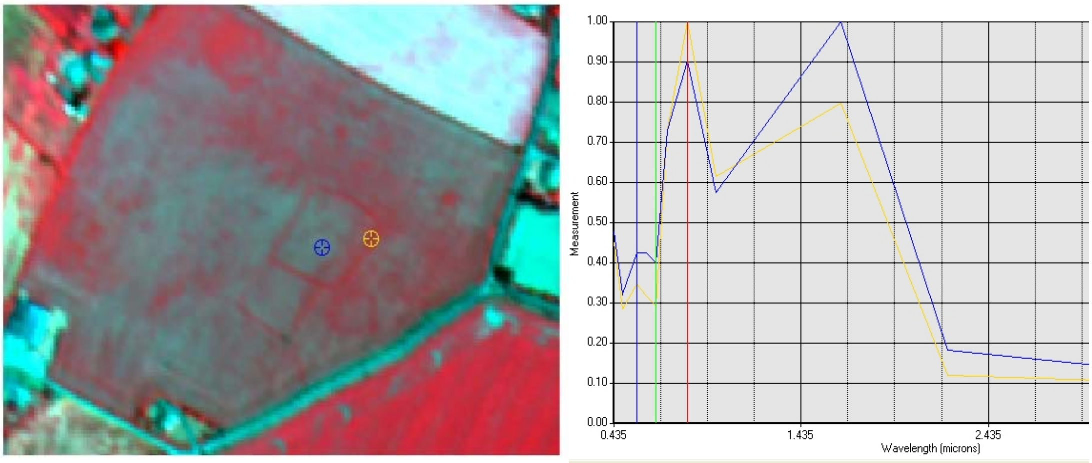


Figure 3.3. Actual spectral reflectance of a cropmark recorded by Daedalus 1268 ATM imagery. In this instance the cropmark (green symbol and graph) appears as a darker green crop in the visible part of the spectrum (ie low green reflectance, high red reflectance) but is most clearly evident in the SWIR (*c*.1500nm) where the cropmark is less reflective than the parched crop that surrounds it.

3.3 GEEP

The Geophysical Exploration Equipment Platform (GEEP) was developed to exploit the recently available innovations of:

- Differential Global Positioning Systems (DGPS) with real-time accuracies of the order of 1m
- Geophysical sensors that can output digital measurements at rates of up to 10Hz,
- Wireless computer networking systems (WLAN).

In combination, these three features make it possible to build a survey system which is:

- self locating,
- can make measurements with multiple sensors while in continuous motion
- can allow real-time data quality assurance (QA) and initial interpretation by transmitting the large, dense datasets to a receiving base station in real-time.

The facility of self-location does away with the need for any prior surveying and pegging of survey lines, and also means that the survey can be modified as it progresses in the light of the data being recorded. With a mechanised system, multiple sensors can be carried simultaneously, with neither the weight of the systems, nor the combined power consumption presenting a problem. For many applications, such as mineral exploration, and environmental surveys, the ability to measure multiple datasets improves the ability to characterise the physical properties of the subsurface. With rapid collection of large volumes of data, there could be problems of both verifying data quality, and storage of the data. Both of these are overcome by using a wireless local area network (WLAN) system to telemeter the data in real-time to a base station. Here a geophysicist can review the data quality, and provide an initial appreciation of the data, and modify the survey plan to concentrate the survey in areas of particular interest.

The system is highly efficient, collecting data at the maximum acquisition rate of the geophysical sensors, and requiring only two operators. Furthermore since the geophysical sensors are carried by a mechanical platform the performance is much more uniform than when carried by a walking person, increasing the inherent quality of the data. The system can carry up to six sensors, the limiting factor being the transmission capability of the telemetry system. In practice, a limit on the number of sensors is imposed by the possibility of mutual interference between sensors. The system was initially developed for exploration surveys for mineral deposits in small fields in Derbyshire, where its agility over irregular terrain was tested. The major limiting terrain property is thick woodland, which inhibits physical motion, and also obstructs both the DGPS location system and the WLAN telemetry.

3.3.1 Physical structure

The GEEP sledge is built of glassfibre and plywood to give a firm mounting position for instrumentation. The fluxgate compass unit and DGPS antenna have fixed permanent positions (Fig 3.4). All these components are essential to system operation and are always present. The base of the hulls sit on Nylon “skis” which provide a durable low-friction running surface for the sledge. Wheels were rejected for a variety of practical reasons, including complexity, geophysical noise, and sledge stability. The sledge is towed by a Kevlar strain member that is encased with electrical cables within the tough outer sheath of the composite towing cable.

The towing vehicle is a small tractor. This was chosen as providing the necessary motive power, with the minimum geophysical signature. When towing the MSP with an 8 m towing cable, it is invisible to EM systems, and produces a magnetic heading error of less than 1 nT. The tractor is necessary to maximise the efficiency of data collection. In routine surveying the system can survey at 7 line-km per hour. Allowing for set-up and pack-away time, as well as relocation between separate fields on a survey site, survey totals of 20-25 line-km per day have regularly been achieved. Using instruments with a sampling cycle of 0.1 Hz, such as the EM38, EM31 or Cs Vapour magnetometers, this gives a sample interval of about 0.15 m along track. The tractor carries an LCD display for the driver showing his survey track plot so that he can check his line positioning and modify it as necessary when he encounters physical obstructions such as trees and field boundaries. The tractor also supplies power to the sledge at 12 and 24 Volts DC. With multiple geophysical instruments operating continuously, changing separate battery packs in each instrument would be highly inefficient.

The data logging base station consists of a WLAN base station linked to a laptop computer. GEEPLog software is used to display the incoming data and to write the serial data strings to text files. Separate data files for each instrument are merged together with the position information in a single database file in CSV format. This can then be directly input to a commercial processing package (e.g. Geosoft Oasis Montage) or subject to further pre-processing in alternative commercial software or user-generated applications. While it is convenient to run the base-station inside a vehicle, on sites with particular access problems, all the base station equipment can be placed in a wheelbarrow and moved as necessary manually. It is possible to run the system with two laptops at the base station linked by an Ethernet hub. In this case the survey observer can be processing data, while monitoring the current survey at the same time.

DGPS system.

The system was initially designed with the basis of the navigation being a differential GPS system. For the mineral surveys that were the original objective, positioning to an accuracy of about 2 m was considered adequate. Since that original design the accuracy of DGPS fixes has been increased by several unrelated changes. The Ordnance Survey have constructed additional DGPS beacons in the UK. The EGNOS European geostationary satellite system giving differential corrections is now in operation. All survey locations for the GEEP used during this project were obtained using EGNOS DGPS. Informal tests show that the accuracy of fixes is sub-metre. For surveys using EM34, a second DGPS was mounted with the second coil on the second sledge. DGPS navigation was chosen since it is simple to operate, readily available, and sufficiently accurate for most applications. In principle any other navigation system could be used if more appropriate. Both RTK GPS, and tracking total station EMD are viable alternatives, as long as they can output a continuous serial data string which can be merged with data from the MSP itself. Neither of these possibilities has yet been explored.

Figure 3.4 The Leicester GEEP system on the Shelford site comprising towing tractor (right), MSP sledge (left, in this case with EM31, and the hired van and trailer(rear) which transports all the equipment and acts as office and workshop on site.

Instrument packages

The physical structure of the GEEP easily accommodates a large range of geophysical sensors. The essential limiting factor to what may be accommodated simultaneously is the issue of mutual interference between sensors. Most obviously, high accuracy magnetic sensors will be degraded if virtually any other system is added to the GEEP sledge. To minimise this, the magnetic sensors are always mounted to the rear of the MSP, away from the electronics modules of other instruments.

Deciding which sensors to use together is a compromise between ultimate data quality and time in the field. If a heading error of a few nannoteslas is acceptable on magnetic data, then the GEEP can be used with multiple magnetometers, EM31, EM38 and Gamma ray spectrometer simultaneously. The situation is analogous to that of borehole logging, where for any specific application it is possible to devise packages of instruments that can run together to optimise file deficiency without unacceptable compromises on data quality. While there can be general guidelines, the detailed solution will be specific to the requirements for any individual survey application.

Planning of survey tracks

It is conventional to collect geophysical data along regular straight lines of a pre-surveyed grid. There is considerable logic behind this in terms of the uniformity of sampling, and subsequent processing of the data. The GEEP concept was however born from the need to cope with surveying in small, complex field shapes in Derbyshire, where any attempt to maintain a regularly spaced rectangular grid would be either very time-consuming or impossible. The positional autonomy of the GEEP system is one of its great advantages. No pre-survey is required. The GEEP can move round obstacles, collecting data where possible, and adapting the survey track plan to the natural barriers present.

A survey plan gradually evolved from field experience. The major influence on this is that the GEEP may have degraded data quality when turning corners. Here, the tractor position is indeterminate relative to the GEEP, and on a tight turn it will often approach the GEEP sledge. This leads to erroneous readings on EM or magnetic sensors. To minimise this, 180-degree turns are avoided where possible. The usual track plan is thus to start by making circuits round the outside of a survey area spiralling in towards the centre at the required track spacing. When such outer tracks have covered sufficient ground all around the periphery of the area for the GEEP system to turn and re-align itself, the remainder of the area is infilled with a grid of parallel lines, ending with perpendicular tie-lines. Such track plans have been used in both the case studies reported here. The advantage of the above system is speed and efficiency. All the accessible area is covered by data tracks efficiently.

3.3.2 Data verification and processing

Post-processing Software

This GEEPLog software outputs a database file which can be used to input directly to Excel, Geosoft Oasis, or any other preferred package. Additional software has been written to speed up the post-processing of the data. The GEEP_PP, takes the ASCII CSV data files produced by the GEEPlog software and can extract particular data types, calculate the corrected position of that geophysical sensor at the time of the measurement, and outputs another standardised ASCII file. This again can be easily read into other software. While these programs do not carry out any fundamental processes that could not be carried out in other packages, their importance is in speeding up the dataflow from initial logging, to meaningful data imaging. With a fairly full instrument load, the MSP records megabytes of data per hour. Efficient handling of this data through the post-processing stage is essential to the usefulness of the system.

In this project, data files from the post-processing software were input to Geosoft Oasis databases, then edited, filtered and analysed in a similar manner to conventional geophysical data. The main difference is that the datasets considered here are large, and densely sampled, with well determined levels of self-consistency proved by track intersections and repeat lines.

Output files from the Geosoft Oasis package map be formatted in a variety of ways, but are typically as .jpg images, shape files, or as XYZ files for incorporation in GIS databases.

3.4 English Heritage CART System

Figure 3.5 The English Heritage cart on the Shelford site. Four Caesium sensors are mounted on a line below the wheel axle. The electronics and batteries are located in the towing handles.

English Heritage has developed a high-sensitivity magnetometer system based on an array of four modified Scintrex SmartMag SM4 total field sensors mounted on a collapsible non-magnetic cart (Figure 3.5 and Linford *et al.* 2007). This system was designed to be easily deployed on a wide range of sites whilst also offering both a high sensitivity (~0.01nT) and data collection at a sample density capable of detecting subtle archaeological anomalies (0.125m x 0.5m). The site at Shelford was chosen to conduct a comparative test between the GEEP and the EH system as the scheduled area of this site contained known archaeological activity identified from the aerial photographic record. A more challenging, heavily alluviated site could have been chosen for the test, but it was considered more important to demonstrate the equivalence of the GEEP system over clearly defined archaeology to complement the other comparative studies conducted with this instrumentation (e.g. Hill and Linford 2004).

3.5 BGS SHELFORD DATA

3.5.1 Shelford Site

As part of the Sustainable Soils Program within the British Geological Survey a number of 3D models of the near surface environment are being constructed at representative field sites around the U.K (Smith *et al*., 2007). One of these field sites, at Shelford, Nottinghamshire, has been developed maintained and instrumented for future research activities in the Earths critical zone (Anderson *et al*., 2004).

The Shelford site is located approximately 9 km east-north-east of Nottingham and is bounded by the River Trent to the north and west, by the A6097 to the east and to the south by the road that links Radcliffe and East Bridgford via Newton. It is generally flat lying between 17 to 20m AOD and gradually rises to 30m towards the south before rising steeply to the road bounding Newton Airfield at ~ 50m AOD. The area is predominantly in agricultural use with grazing areas centred on Shelford and areas of woodland to the east and west of Shelford. There are extensive flood banks along the River Trent and local flood defence measures around Shelford in the form of raised banks.

A 3D model of the Earth's near-surface environment (Ambrose *et al*., 2005; Smith et al., 2007), has been created from a combination of soil, geological, geophysical, hydrogeological surveys of the Shelford site. The 3D model integrates maps of soil and lithological units of a 2km N/S trending catena, representative of landscapes of the Trent valley between Derby and Newark. The dominant bedrock geology is the Permo-Triassic Mercia Mudstone that forms an escarpment that runs down to the river Trent. Overlying this are a series of sand and gravel terraces that form the flood plain of the river Trent. The Mercia Mudstone and sand and gravels represent the parent materials of the majority of soil types mapped on the model. Information collected during the development of this 3D model was made available to the FASTRAC consortia to assist in its pursuance of project objectives.

3.5.2 Geology 1:10K (BGS and Crown Estate Boreholes)

Published 1:10K Solid and Drift geology (BGS, 1996) in the vicinity of Shelford Manor was updated during a 2 day field visit in August 2006. Prior to this the open file report and Memoir (Lamplugh et al. 1908) of the area were examined as well as borehole logs from BGS boreholes and a mineral assessment carried out by the Crown Estates (Brett, 2005). It was ascertained that the area was not subject to a BGS Mineral Assessment Unit Report, but was covered by Rathbone, 1989a and 1989b. During the field walkover geomorphological features and soils were examined by hand auger and logged.

The BGS drilled 8 boreholes in 2006 and a further 6 during 2007 using their in-house Dando Rig to provide hydrogeological data and calibrate the geological mapping. The 100mm diameter cored boreholes were drilled at least 1m into the underlying mudstone bedrock (~

7m) and completed with a 75mm diameter piezometer to permit water level monitoring. Three of the 2006 borehole series were installed with transducers, permitting the measurement of water levels every 15 minutes. Logs of each of these boreholes and associated borehole locations were provided to the FASTRAC consortium.

Further campaigns of borehole drilling and geophysical surveys were commissioned during 2006 and resulted in a line of six 100 mm diameter sonic cored boreholes (~ 3m) being drilled to investigate an apparent cliff like anomaly (See Chapter 7). In 2007 a further thirty six sonic cored boreholes (~ 2m) were drilled to assist in investigating the fate of dissolved nitrate contamination. These boreholes were drilled into differing lithologies that outcrop on a N-S trending transect from the sands and gravels of the valley floor to the top of the mudstone escarpment. Data from these drilling and geophysical activities were provided to the FASTRAC consortium.

Crown Estate

A borehole-based investigation was undertaken on behalf of The Crown Estate over part of their Bingham landholding around the village of Shelford, Nottinghamshire by Robert Brett and Sons Limited between 1st and 3rd November 2004 to ascertain the presence of sand and gravel deposits (Brett 2005). The investigation covered an area of approximately 594 Hectares and comprised drilling 44 boreholes from a Bedford truck mounted drill rig operating a 175mm diameter flight auger. Each borehole was drilled to sufficient depth to prove the underlying solid geology (~ < 7m) and logged noting thickness and horizon depths of overburden, sand and gravel and clay. The depth of water strike was noted and representative bulk samples were taken for Particle Size Analysis. Data contained in this confidential report has been released to the FASTRAC consortium on the basis that (a) point values and positions are not described in detail and are subsumed within the main body of work and (b) that all data holdings containing information abstracted from the report of the investigation are deleted at the end of the project by members of the FASTRAC consortium.

3.5.3 Soil Map 1:10K (Auger Holes)

A detailed 1:10,000 scale soil map (Palmer, 2006) was prepared for the Shelford research site using traditional methods of field soil mapping as described in Palmer (1982) p. 33 based on a detailed survey in Worcestershire, which incorporated a similar suite of soils developed in river alluvium, sand and gravel river terrace deposits and Triassic Mercia Mudstone.

Fieldwork was completed in February and March 2006 and 95 soil observations were described on RUFF cards and input to an Excel spreadsheet. Fifteen soil series were identified; four in alluvium (Wharfe, Trent, Compton and Stixwould); five on the river terraces (Newport, Arrow, Reaseheath, Quorndon and Wigton Moor series); and six on the Mercia mudstone scarp (Worcester, Whimple, Brockhurst, Melbourne, Salwick and Clifton series). The resultant soil maps were supplied to the FASTRAC consortium as ARCGIS 9.2 shape files with an associated database of auger holes logs.

3.5.4 Electrical Resistivity Tomography (ERT)

The purpose of geoelectrical imaging techniques, such as ERT, is to produce spatial models of subsurface electrical property distributions (Loke and Barker, 1996). Through the application of ERT, features with a contrasting resistivity to that of surrounding materials may be located and characterised in terms of resistivity, geometry and depth of burial.

ERT data were collected at the Shelford research site between 2nd and 6th October 2006. Six profiles (A-F) were established following the main geophysical traverse from southeast to northwest. An AGI SuperSting R8 IP resistivity meter was used together with a 64-way switch box attached to stainless steel electrodes via multicore cables. An electrode separation of 3 m was employed on five profiles in order to achieve a compromise between detailed spatial resolution and areal coverage. One profile (F) used a 1 m spacing. A robust measurement command sequence was used comprising variations of the Wenner and

Wenner-Schlumberger arrays and their inverse counterparts (e.g., Kuras et al., 2002). These array types are associated with high signal-to-noise ratios and are therefore resilient against cultural noise, often resulting in datasets that require minimal processing and produce stable inverse model estimates.

Surface topography was accounted for during inverse modelling and high-quality images were obtained on all six profiles, resulting in overall RMS errors of around 1%. Near-surface structure is well resolved, with the maximum depth extent of the models being typically around 11 m below ground level. The lateral discretisation of the ERT models is 1.5 m for profiles A-E, and 0.5 m for profile F.

Data for these traverses were supplied to the FASTRAC consortium as geo-referenced point/line data indicating the spatial location of each traverse in ARCGIS 9.2 format and as jpeg images of ERT 2D cross-sections with associated scales.

3.5.5 GEOCARTA (ARP)

GEOCARTA were commissioned by BGS to use the ARP (*Automatic Resistivity Profiling*) device which is a patented mobile multi-electrodes system: several electrodes are automatically inserted in the soil and roll along the surface (Dabas et al, 2001) at the Shelford research site in October 2006 and February 2007. Using this technique a sequential depth profile focussed on 0.0 to 0.5m (Channel 1); 0.0 to 1.0m (Channel 2) and 0.0 to 1.7m (Channel 3) and simplified soundings were obtained simultaneously. Data acquisition using this technique can be very fast, for example up to 100ha can be surveyed in a day on a transect spacing of 10m.

A pilot study (Geocarta, 2006) covering 39.1 hectares was carried out at Shelford on 5-6th October 2006 with a line spacing of 10m. This was followed up with a Phase 2 study (Geocarta, 2007) between the 19th and 28th February in which measurements were taken over 110.2 hectares again with a line spacing of 10m. Data was provided to FASTRAC consortium members as a series of geo-registered jpeg images depicting apparent resistivity vs landscape position using a normalised scale of 10 ohm.m (blue) to 500 ohm.m (dark red) via green and then yellow.

3.5.6 Ground Penetrating Radar (GPR)

GPR is used to investigate the subsurface by penetration and reflection of high-frequency electromagnetic waves in the ground. Reflections are generated by changes of the complex wavenumber of the soil or rock medium. At frequencies normally used for GPR (> 25 MHz), these changes are dominated by changes in the relative permittivity (dielectric constant) of the ground. The permittivity contrast between two media determines the amplitude of any reflections generated (Davies and Annan, 1989).

A GPR survey was conducted at Shelford between the 2nd & 13th October 2006, using a Pulse Ekko IV™ (low frequency) system manufactured by Sensors & Software Ltd. Measurements were made with centre frequency 100 MHz antennae at 1m separation, orientated broadside to the survey direction and moved in steps of 0.25m. The transmitter voltage was 1000 V, with a sampling interval of 800 ps and signal stacking of 32 times.

The GPR data were processed and plotted using standard procedures (e.g., Annan, 1993) using pulse EKKO™ 1V (version 4) software. A DTM was used to correct for topography and the results are plotted in section form as two way travel time against position. Time-to-depth conversions are shown on the profiles by determining the electromagnetic wave propagation velocity at the sites. This velocity was determined by a Common Mid-Point (CMP) analysis (Annan and Davies, 1976) and was found to around 0.1 m/ns, resulting in an observable signal penetration of approximately 5m. The data are plotted in wiggle trace mode showing the actual waveform where the positive amplitudes are filled in.

Approximately 5 kms of data were collected along the main geophysical transect and on a parallel offset transect, between 500 – 1000m to the west.

Data was provided as point/line data indicating the line of traverse sections and GPR traverse data was available to FASTRAC consortium members on request.

3.5.7 Radiometrics

Ground-based gamma spectrometry was carried out at the Shelford research site during October 2006 using an Exploranium GR-320 with a 76 x 76 mm NaI (Tl) detector mounted in a backpack at an approximate height of 1m.

With the detector at a height of 1 m it would detect gamma rays from an area within about a 10-meter radius (Atomic Energy Commission, USA, 1972). Therefore the field of view or 'footprint' of the ground based gamma spectrometer has a radius of approximately 10 m. Potassium, Uranium, Thorium and total count are recorded. Uranium and thorium are not directly measured, instead the equivalent uranium (eU) value is determined from the ^{214}Bi gamma peak and an equivalent thorium (eTh) value is determined from the ^{208}Tl gamma peak with potassium being measured directly from the ^{40}K gamma peak.

The GR-320 NaI (Tl) detector is internally stabilised with a small ^{133}Ba source. The energy calibration, Full Width Half Maximum (FWHM) and system gain will be tested at the start and end of each day of data collection. The detector is calibrated on the BGS radiometric calibration pads prior to, and after fieldwork. Positional data is collected via a GPS and merged with the gamma spectra through a palm-top computer.

Data was made available to the FASTRAC consortia as point data indicating the line walked during the survey and as a geo-registered jpeg image depicting total counts.

3.5.8 Magnetic Susceptibility

Magnetic susceptibility measurements were made at the Shelford research site under a commission to Cranfield University (J Hanan) using a Bartington Instruments MS2 meter and MS2D Field survey loop (185mm diameter) coupled with a Trimble handheld GPS system (Dearing, 1994) were used to conduct a ground magnetic susceptibility survey on the 7th & 8th of November 2006.

Transect magnetic susceptibility measurements (Mullins, 1977; Maher, 1998) were taken approximately every 30m, where possible, along the transect line previously determined by BGS. An easting and northing reading was recorded by a handheld GPS at each measurement site.

As the majority of spatial variation in soil parent material occurs at the south-easterly half of the site, measurements at a finer resolution were conducted in this region compared with the more extensive sand and gravel units in the areas proximal to the current fluvial margins. The sampling strategy within fields followed a 'W' formation according to BS ISO 10381-1: 2002 (Soil Quality- Sampling. Part 1: Guidance on the design of sampling programmes). In areas that had been recently seeded, or had young emergent crop, sampling followed tramlines to achieve minimal disturbance.

Data was supplied to the FASTRAC consortium as a series of point data depicting measurement sites together with an interpolated geo-registered image.

3.5.9 NERC ATM Imagery

Airborne thematic mapper (ATM) imagery for the Shelford site was collated from data produced during mission 95/9 (file c177101b.hdf) flown on 25/06/1996 by the NERC Airborne Research and Survey Facility (ARSF). Data was licensed for use in the BGS Shelford project via the NERC Earth Observation Data Centre (NEODC; http://www.neodc.rl.ac.uk/). RGB composite images were produced using a combination of bands 11 10 & 5, the former of which correspond to thermal energies (8.5-13; 2.08-2.35 and 0.63-0.69 microns respectively).

3.5.10 Hydrology

The Environment Agency provided River Trent level data from a gauge on the weir at Gunthorpe Bridge. Since May 2007 borehole water level data has been recorded manually on a weekly basis for Boreholes 7, 8, 12, 13 & 14. In contrast over the same period Boreholes 4, 5 & 6 were fitted with down hole transducers that record water levels every 15 minutes.

Daily readings of weather data for the site are supplied from Radcliffe on Trent.

3.5.11 Utility Plans

The following utility plans were obtained for the site :

Severn Trent water and sewerage.	British Gas pipeline
Eon Electricity	BT telephone lines

3.6 SHELFORD AND STURTON AIR PHOTOGRAPHIC DATA

3.6.1 Air Photograph Coversearches

Coversearches were commissioned from the National Monuments Record (Swindon) of both study areas in August 2007. These searches focused at Shelford upon an area centred upon kilometre squares SK6642 SK6742, SK 6643 and SK 6743, extending to all adjoining kilometre squares (SK6541, SK6641. SK6741, SK6841, SK6542, SK6842, SK6542, SK6543, SK6843, SK6544, SK6644, SK6744 and SK6844). At Sturton, the search focused upon an area centred upon kilometre squares SK8183, SK8283, SK8184 and SK8284, again extending to all adjoining kilometre squares (SK8082, SK8182, SK8282, SK8382, SK8083, SK8383, SK8084, SK8384, SK8085, SK8185, SK8285 and SK8385). Details were requested of all oblique air photographs for these areas and of all vertical air photographs of 1:10000 scale or larger. The results of this coversearch are presented in this document as Appendix A-05 and provide a record of all photographs curated by the NMR up to 10th August 2007. Most are monochrome prints, but a small number of oblique photographs of the Shelford study area are in colour.

3.6.2 Examination of Air Photographs

Extensive collections of monochrome oblique and vertical air photographs are held in an archive housed in the offices of Trent & Peak Archaeology in the University of Nottingham. These were examined first and all photographs showing cropmarks, soilmarks and/or earthworks indicative of archaeological remains were set aside for plotting. David Walker and David Knight visited the NMR archives in January 2007, subsequent to plotting by the former of features visible in photographs held by TPA, to check and enhance the plots of potential archaeological features observed in these photographs. Photocopies and digital photographs were taken of all hitherto unseen monochrome and colour NMR photographs showing potential archaeological remains, while prints were ordered of four oblique photographs taken on the 29th June 1976 showing previously unrecorded cropmarks in the Sturton area (NMR photographs SK8282/13/58, SK8282/14/59, SK8282/15/60 and SK8282/16/161). A digital archive of photographs was compiled as part of the project archive, but for copyright reasons only selected air photographs for which appropriate copyright permission has been obtained are included in this report.

3.6.3 Cropmark Plotting

Visible cropmarks were plotted by David Walker to a GIS layer in ESRI's ArcView 3.2 and were subsequently transferred by Dr Lex Comber to ESRI's ArcView 9.2. This process required several stages from photographic print to digital data layer.

Image Preparation

Oblique and vertical aerial photographs were scanned with a Canon Lide-20 flatbed scanner at a resolution of 300dpi and were saved as uncompressed TIFF files. The raw scans were cropped at this stage to remove borders and unnecessary labels and the photographs were organised and reviewed using Google's photograph organiser, Picasa. The majority of the digitised photographs were improved by the application of a histogram stretch, either in Picasa or in the open-source GIMP photo editor, and some were sharpened slightly. These enhancements improved the contrast of the images and consequently the visibility of cropmark features.

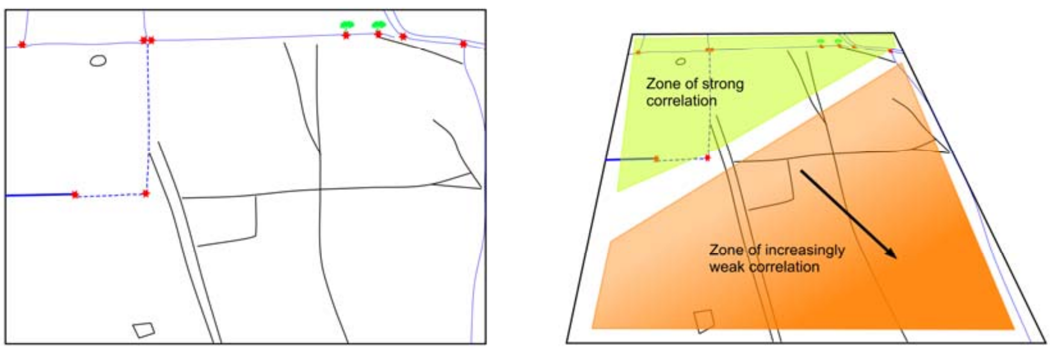
The digitised photographs were reviewed at this stage and their suitability for rectification and cropmark plotting was assessed according to the following three criteria, scored subjectively on a scale of 0 (very poor) to 3 (excellent)

1. quality of the original and digitised photograph, in terms of focus, contrast and clarity of the image.
2. clarity of cropmark features
3. suitability for rectification, taking into account the angle of view and the number of possible control points.

Image rectification

Images were rectified using Leica Geosystems' ERDAS Imagine 9.0 software (hereafter Imagine). The selected images were imported into Imagine and converted to the native .img format, which can be read by ESRI's ArcView and ArcGIS packages. The polynomial rectification method that was applied consists of matching control points on the aerial photograph with control points on another georeferenced image, usually a map. Either first order (stretching, scaling and rotating) or second order (bending and warping) polynomial transformation was applied to the images, depending on the number of available control points and the apparent accuracy of the final result.

Rectification was complicated by the fact that most cropmarks were visible as oblique images, sometimes with severe lateral distortion. This problem was compounded by a paucity in many of the images of good control points such as hedgerows, trees, telegraph poles or field boundaries - as shown in the figure below.



Original oblique photograph, based on SK6642-16-668429.tif. Black lines are cropmarks, blue lines map features. Usable control points are indicated as red stars

Rectified and georeferenced image, showing areas where correlation is strong and cropmark plotting accurate, and areas where correlation is weak due to a lack of control points, and cropmark plotting will be increasingly inaccurate

Fig.3.6: Inaccuracies in cropmark plotting at Shelford arising from the use of oblique photographs with insufficient control point coverage.

The absence of hedgerows, field boundaries and other control points was partially remedied by the use of vertical aerial photographs and historic maps georeferenced to the National Grid and used as reference images for oblique photographs. This allowed otherwise unrectifiable images to be registered, but introduced another layer of potential error to the plotting of the cropmarks.

Cropmark plotting

Following processing in Imagine, the georeferenced images were imported as themes to a GIS database in ArcView 3.2 The identified features were digitised as separate layers (solid cropmarks; soilmarks; rows of pits: ridge-and-furrow; other earthworks) and were later incorporated by Dr Lex Comber into the ArcView 9.2 project database.

The above-mentioned problems ensured that some cropmarks were consistently difficult to plot accurately, with lateral displacements of up to 50m on the ground. Most of the plotting errors were overcome by careful comparison of the cropmark locations on several rectified images and, where possible, by comparison with the results of the magnetometer survey. The least accurate correlations occurred in an area bounded approximately by the following grid coordinates: 466650, 343130; 466850, 342930; 467000, 343050; 466800, 343240. This area lay beyond the magnetometer survey area and lacked secure control points.

The Shelford plots prepared for this project compare interestingly with the cropmark plots compiled at 1:10000 scale in 1995 as part of the National Mapping Programme and with the results of magnetometer and magnetic susceptibility surveys carried out during this and earlier projects. Comparison of the relevant GIS layers reveals some unexpected discrepancies between the most recent plots and the NMP survey, which it is suggested in Chapter 8 reflects in large part the difficulty on many photographs of locating precisely features seen from the air. At Sturton, our survey revealed several faint cropmarks, not recorded during the NMP programme, which may be correlated with an enclosure complex recorded during a magnetometer survey conducted by Oxford Archaeotechnics in November 2003 (see Sturton GIS on project DVD). From the methodological perspective, comparisons of the results of geophysical and air photographic surveys at both sites emphasise the significant benefits of combining these complementary techniques during archaeological evaluation.

3.7 BOREHOLE DATA

Crown Estates data scanned and converted to digital form using OCR software.

BGS borehole data supplied in digital form.

Data comprised borehole locations and graphical logs, but also for the crown estates data, grading analyses at systematic intervals down each log.

Due to the of the wide separation of the boreholes necessarily resulting in low spatial sampling of the aggregate deposit, separate statistical analyses for individual units within the aggregate deposit are not possible. Thus the grading data has been bulk averaged for each borehole.

3.8 RESOURCE ESTIMATION

3.8.1 "Quality" of an aggregate deposit

Calculations devised for the previous AGSIM report were used to indicate how 'ideal' a sample is with respect to a specification envelope for a proposed product. This allows minimum waste planning to be undertaken in terms of the future proposed working scheme. These calculations were originally set up in the AGSIM project using the old BS 882 and BS 1200 standards, and so have had to be modified slightly to be based on the new EU aggregate specifications: EN 12620 (CP), EN 12620 (MP), EN 12620 (FP). The four techniques are described below, full calculations and results can be found on the accompanying DVD. An excel worksheet was used for conversion/interpolation of data from British Standard to the EU Standards sieve sizes.

Although not all saleable material is sold with respect to the EU standard specifications, these do account for the vast majority of saleable products. To be within specification, the percentage passing a particular sieve size needs to fit within a specification envelope defined by the maximum and minimum permissible values on each sieve. Generally the closer the percentage passing value on a particular sieve size is to the centre line of the specification envelope, the more scope there is for natural variation within the product, or during processing, while still being an in-specification product. It is important to note that this does not imply that the centre line is actually the best performing material. Table 3.3 and Fig 3.7 show the centre line, upper and lower limits for various sieve sizes for EN 12620 (CP) specification.

EU Standards – EN 12620 (CP)					
	8mm	**6.3mm**	**4mm**	**500µm**	**63µm**
Upper Limit	100	100	99	45	3
Lower Limit	100	95	85	5	0
Centre Point	100	97.5	92	25	1.5

Table 3.3: Upper and lower % passing limits and the centre line values for sieve sizes of EN 12620 (CP). For complete set of the upper and lower % passing EU specification limits see Appendix A at the back of the report.

Full sets of sieve grading data were obtained (from 28mm to 63µm) and so to simulate washing and screening, the data was cut to less than 4mm fractions. This was done by firstly converting the data to the percentage retained by each sieve, recalculating the percentage retained back to 100% once the greater than 4mm sieve values had been removed, and then finally the data was converted back into percentage passing values. These percentage passing values were then used directly in data preparation for quality mapping.

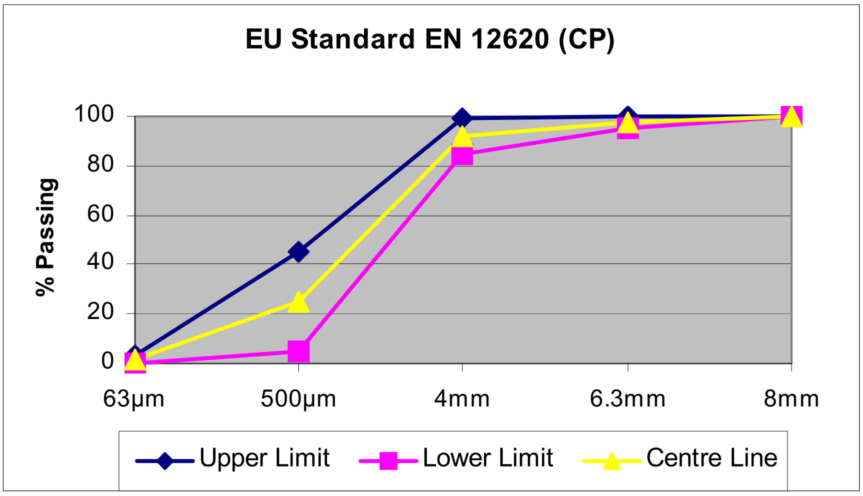


Figure 3.7: Upper and lower % passing limits and the centre line values for sieve sizes of EN 12620 (CP).

Figure 3.8 is a composite envelope diagram for the four quality mapping factors detailed in the AGSIM report. It is an experimental example for an arbitrary sieve size which shows the returned C.L.P.V., Absolute C.L.P.V., Absolute Step and Exponential Absolute PEW values for all possible % passing values. Note that due to the large range of values returned C.L.P.V. and Absolute C.L.P.V. values have been multiplied by 100.

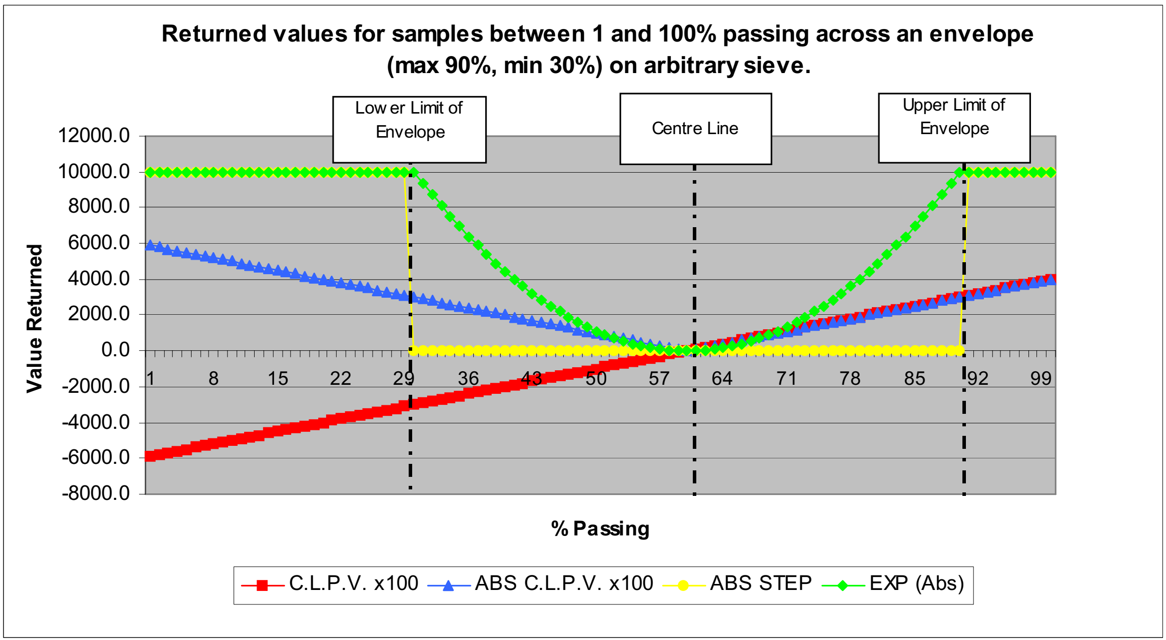


Figure 3.8: Graph showing the four Quality Mapping functions used to analyse the data sets.

The four quality mapping functions are detailed individually in the following sections, using graphs of the data from Broom to illustrate the values returned.

3.8.2 C.L.P.V. (Centre Line Proximity Value)

The C.L.P.V. function represents the actual difference in percentage passing on any given sieve between the sample and the centre line of the envelope. Using EN 12620 (CP) as an example (Table 3.1), the 4mm sieve has a centre line value of 92% which is assigned a C.L.P.V. value of 0. If the percentage passing value is 95%, a C.L.P.V. value of 3% is assigned. If the percentage passing is 70% then a C.L.P.V. value of –25% is returned.

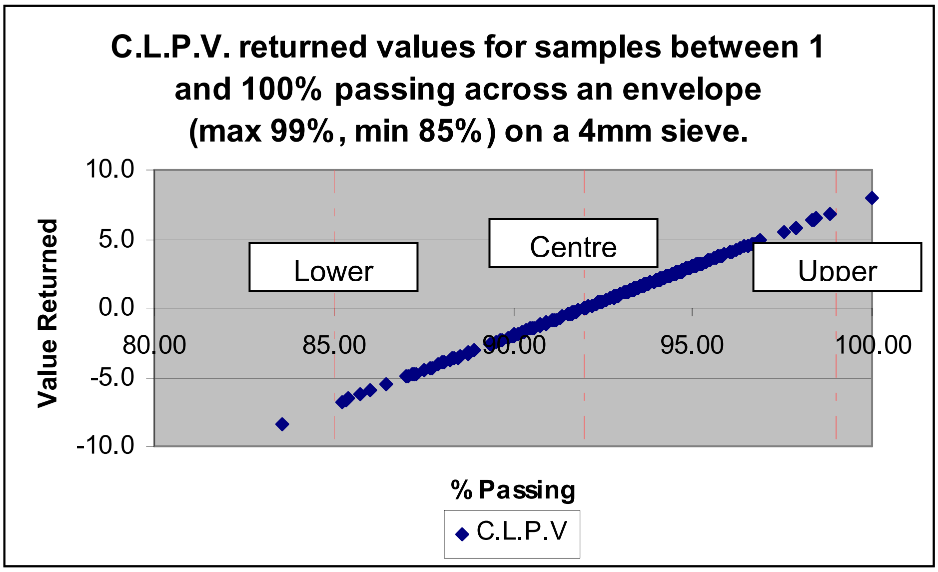


Figure 3.9: Graph showing C.L.P.V. values returned for EN 12620 (CP) on a 4mm sieve for a complete data set.

Values returned for all sieve sizes are summed to give a C.L.P.V. value for the entire sample. The C.L.P.V. function is important as it determines the 'closeness of fit' between samples and an ideal material. Positive and negative values reflect finer and coarser material respectively. The summing of all individual sieve sizes for one sample, positive and negative values for separate sieve sizes will cancel out and so could provide a value similar to the centre line. Despite this, a general view of the sample gradings with respect to the centre line can be achieved.

3.8.3 Absolute C.L.P.V.

The Absolute C.L.P.V. is calculated in the same way as the C.L.P.V. value, but the returned value is positive whether the sample is finer or coarser than the centre line. Absolute C.L.P.V. values change in a linear fashion away from the centre line value. Figure 3.7.4 graphically represents the Absolute C.L.P.V. function for a complete dataset.

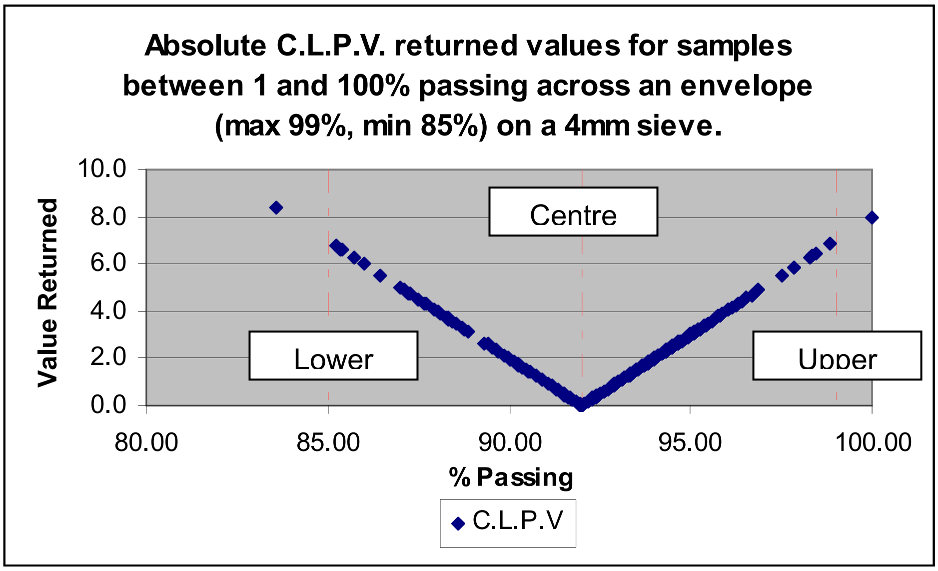


Figure 3.10: Graph showing Absolute C.L.P.V. values returned for EN 12620 (CP) on a 4mm sieve for the complete data set.

3.8.4 Absolute Step

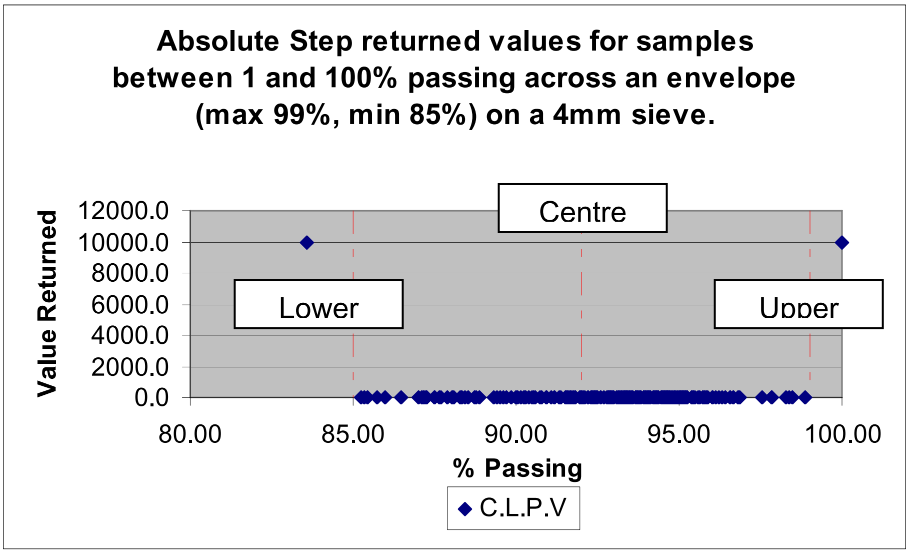


Figure 3.11: Graph showing Absolute Step values returned for EN 12620 (CP) on a 4mm sieve for the complete data set.

An Absolute Step function is used for clarity of presentation to emphasize "out of specification" samples. It uses the Absolute C.L.P.V. calculation but returns an arbitrary high value of 10,000 if the individual sieve size falls outside of the specification envelope.

Using the EN 12620 (CP) 4mm sieve example again, a percentage passing of 85% is –7% away from the centre value but within the specification range, and so gives the value –7. A reading of 81% is outside the range and so a value of 10,000 is returned. When plotted spatially and contoured, these values do distort the contouring of samples which are within specification. Therefore care must be taken in defining actual areas of the deposit demonstrating out of specification values.

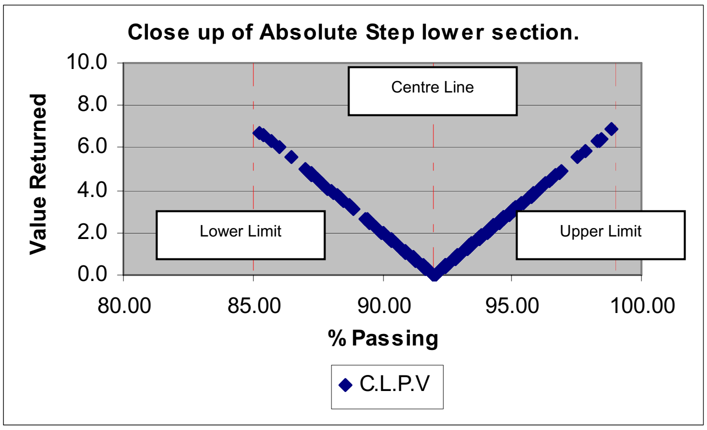


Figure 3.12. Close up of lower section of Fig 3.11, showing Absolute Step values returned for EN 12620 (CP) on a 4mm sieve for the complete data set.

3.8.5 Exponential PEW

The Exponential Absolute PEW (Percentage Envelope Width) function uses the same principles as Absolute Step for out of specification material while also clearly indicating whether gradings are just within or comfortably within the specification envelope (Fig 3.6). The main point here is that a 1% difference in percentage passing near the centre line is of less significance than a 1% difference that takes the value near or outside of the specification envelope.

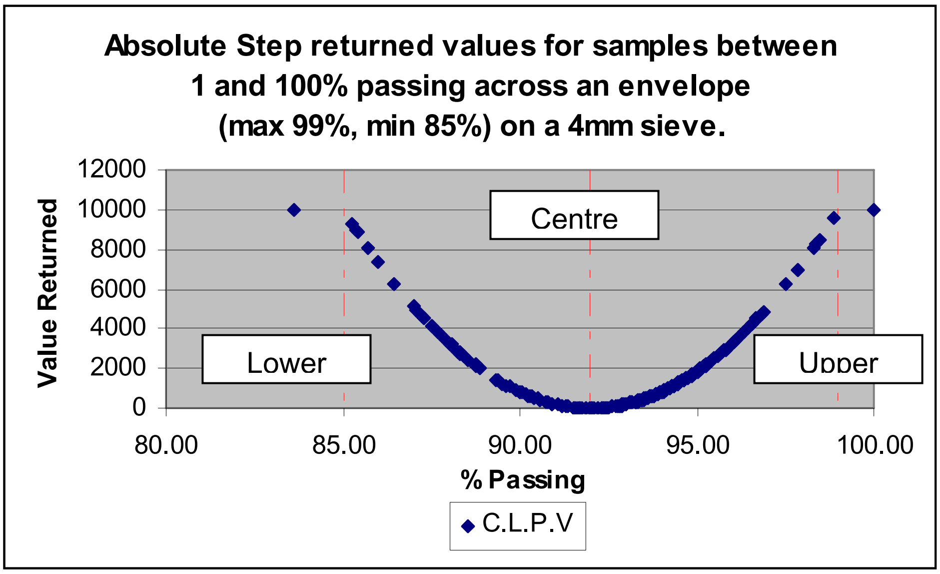


Figure 3.13: Graph showing Exponential Absolute PEW values returned for EN 12620 (CP).

An exponential function is therefore used, based on the proportion of the envelope width. This is a risk based presentation highlighting proximity of the sample to being out of specification. Again the exponential function gives values of 10,000 if the percentage passing falls outside of the specification envelope, and a value of 0 to the centre line (mean). The difference from the centre line is calculated as a percentage of the distance from the centre line to the envelope boundary. This value is then raised to the power 2 which gives values that increase exponentially as the envelope boundary is approached.

3.9 Software preparation

Quality mapping data has been reformatted for use in the Surfer and MicroMODEL software packages.

For Surfer the data simply needed to be cut and pasted into a more suitable and basic format which was put directly into a Surfer spreadsheet and saved as a data file (.dat). Only one line could be used for header information. Information used to produce the Surfer spreadsheet are borehole name, northings, eastings and elevation, percentage gravel, sand and silt. The C.L.P.V., Absolute C.L.P.V., Absolute Step and Exponential PEW values were summed for each EU specification. The data file was then processed as described in chapter 5 (Graphical Representation).

MicroMODEL required three separate tab delimited files, collar, survey and assay, to be produced. The collar file contains borehole name, northings, eastings, and elevation so that each borehole can be easily located. Azimuth and dip values are also required, although these boreholes are all near vertical, values still need to be entered for the program to run effectively. For this purpose a zero value was entered for both azimuth and dip readings. The survey file consists of the borehole name, unit depth, azimuth and dip. The actual data (percentage gravel, sand and silt, and quality modelling values) is put into the assay file along with the borehole name and depths from and to, for each sample. These files can be saved as tab delimited data files, which can be easily imported into MicroMODEL during initial set up.

A variety of “Quality” factors have been calculated from this data to show the spatial variation within the deposit.

3.10 HISTORIC AND MODERN MAPPING DATA FOR STURTON

It was decided at the outset of the project that all available historic maps including all or part of the study area (Chapter 5) should be incorporated into the project database, together with the following modern Ordnance Survey maps:

1:10000 and 1:25000 raster backdrops

Meridian line data

MasterMap object data (including administrative boundaries; heritage and antiques; rail; structures; water; buildings; land; roads, tracks and paths; terrain and height)

Earlier editions of Ordnance Survey maps, commencing with the first edition 1” map, 1849, were added to the project GIS with the aim of elucidating recent landscape changes and facilitating the identification of correlations between geophysical anomalies or features observed from the air and comparatively modern field boundaries, drains or other artificial features. These comprise the following:

County Series 1:10560, 1st Edition (1849-1899)
County Series 1:10560, 1st Revision (1888-1914)
County Series 1:10560, 2nd Revision (1900-1949)

County Series 1:10560, 3rd Revision (1922-1969)
County Series 1:2500, 1st Edition (1854-1901)
County Series 1:2500, 1st Revision (1893-1915)
County Series 1:2500, 2nd Revision (1906-1939)
National Grid 1:10000, 1st Imperial Edition (1948-1977)
National Grid 1:10000, 1st Metric Edition (1969-1996)
National Grid 1:10000/1:10560 (all latest editions)

All map data were downloaded from Edina Digimap.

In addition to early Ordnance Survey maps, a digital copy was provided by Nottinghamshire Archives of a map of the area around Sturton that was published in 1769 by Grundy and Kells (Notts archives: LA 2S). This cannot be correlated precisely with modern Ordnance Survey maps, but this detailed map nonetheless provides a unique insight into the mid-eighteenth century landscape of a stretch of the Trent Valley in and around Sturton parish and, in particular, recent changes in the course of the River Trent. The map is reproduced in this report by kind permission of the Nottinghamshire Archives office.

For copyright reasons, it has not been possible to include the OS historic and modern maps of Sturton in the project DVD.

4 Case Study – High Resolution Geophysics

4.1 Rationale for High-resolution surveys

Geophysical measurements are always beset by the problem of establishing their precision and accuracy. Ultimately the precision and accuracy divide into two components, the 3 dimensional position of the sensor when the measurement was taken, and the magnitude of the value recorded by the sensor. Usually the two effects are tested simultaneously by taking repeat readings, but in this case it may not be possible to divide the total uncertainty into the proportions attributable to each of the basic components. The whole issue is compounded by the problem of spatial sampling, the interval between reading stations on the ground. If sampling stations are well separated, short-wavelength components of the anomaly field cannot be determined (Nyquist sampling limits), and the field gradients at a particular station, which are important in determining the coupling between positional errors and anomaly magnitude errors, cannot be determined. If spatial sampling intervals are halved to reduce the problem, the data volume is quadrupled.

Modern geophysical instruments are designed to cycle rapidly (~10 Hz) so that even if used on a moving platform at walking speed, the spatial sampling interval is no greater than about 200 mm. Combined with automated data logging systems to handle the volume of data, surveys can thus be conducted with effectively continuous sampling. This takes little more time than more widely sampled data, and hence is no real cost in the field. The ability to view the short-wavelength sensor value variation as an aid to assessing instrument noise levels as well as revealing real short-wave anomalies is an enormous advantage in data processing. Using such instruments the few disadvantages (mainly data processing time) associated with dense data sampling, and more than outweighed by the resulting quality, and confidence in the quality, of the data. The dense spatial sampling allows more precise analysis of precision and accuracy, and a high-resolution dataset results. Provided the instrumentation is adequate for the task, the advantages of densely-sampled high resolution surveys are overwhelming.

4.2 Technological developments

As technology advances, particularly digital and communications technology, data collection and processing applications must continuously evolve. Considerable impact on geophysical surveying has come from developments in navigational systems (Differential Global Positioning System, DGPS), geophysical sensor development, rapid wireless data transmission, and the rise in power of field-portable computers. The combination of these factors leads to the opportunity to collect more accurate data, better located, and transmit it to field computers for Q/A and processing. All of this can be done more quickly. The overall result is to be able to collect more data and process it more quickly, leading to an increase in quality and a decrease in cost of the survey. Additionally, the prospect lies ahead that the data can be processed and displayed in a geologically meaningful way in near real-time. This not only reduces costs further, but also leads to the possibility of modifying surveys in real-time, to design and conduct follow-up detailed surveys to investigate interesting features. The advantages of seeing an interpretable image in near real-time, over a written report some weeks later are immense.

An approach to harnessing these advances in technology has led to the design of a Multi-Sensor Platform (MSP). The key concepts derive directly from the points above. Firstly, no single geophysical parameter can be uniquely diagnostic of a particular subsurface structure. Measuring multiple physical parameters simultaneously, vastly increases the value of the data for geological interpretation. For instance, iron and saturated clay are both electrically conducting, but only one is both conducting and strongly magnetic. Combining multiple data sets requires very accurate navigation. This constraint becomes less difficult if the measurements are made simultaneously by sensors in fixed relative positions. Making multiple measurements on one pass over the ground also inevitably speeds up the survey process. This is the first driving logic of building a system that has multiple sensors to record different parameters simultaneously.

This does however lead to two other problems: mutual interference between sensor systems, and the need to monitor data quality as the survey proceeds. The first can be solved by minimising the electronic equipment close to the sensors, by having an extended vehicle. Both problems can be solved, at the price of additional technological complication, by telemetering the data from the sensors to a fixed ground station where it can be logged and displayed for instant QA. Different surveys will demand different combinations of sensors, so a multisensor system that is "open" to accommodate any selection from a wide range of possible geophysical sensors is advantageous.

4.3 The English Heritage CART System

As part of the research it was decided to survey a trial site to assess the level of archaeological information that may be obtained from data collected with the GEEP towed system compared with more conventional methodology. Whilst the majority of archaeological evaluation in the UK is conducted using hand-held fluxgate gradiometers, arrays of multiple high sensitivity caesium magnetometers have been favoured for some time on the continent. These instruments are also particularly well suited to low lying, river valley sites where very weak magnetic anomalies might be expected.

English Heritage has developed a high-sensitivity magnetometer system based on an array of four modified Scintrex SmartMag SM4 total field sensors mounted on a collapsible non-magnetic cart (Figure 4.1 and Linford *et al.* 2007). This system was designed to be easily deployed on a wide range of sites whilst also offering both a high sensitivity (~0.01nT) and data collection at a sample density capable of detecting subtle archaeological anomalies (0.125m x 0.5m). The site at Shelford was chosen to conduct a comparative test between the GEEP and the EH system as the scheduled area of this site contained known archaeological activity identified from the aerial photographic record. A more challenging, heavily alluviated site could have been chosen for the test, but it was considered more important to demonstrate the equivalence of the GEEP system over clearly defined archaeology to complement the other comparative studies conducted with this instrumentation (e.g. Hill and Linford 2004).

A total area of 7 ha was surveyed with the EH magnetometer system at the Shelford site, at a sample density of 0.125m x 0.5m, over a survey grid established in the field using a differential global positioning system (GPS). Unlike the GEEP system, there is no onboard GPS to provide direct navigational or positional control during data acquisition. Instead a 100m guide line is established on the ground for each traverse of the array and fiducial markers are manually entered in to the data stream at 10m intervals by the cart operator. Whilst this system is, no doubt, prone to some positional error (estimated to be less than 0.1m) even and consistent density of coverage over the survey area is maintained.

Full details of the survey are provide in (Linford and Martin forthcoming) and a grey tone image of the data is shown in Figure 4.2 superimposed on the base Ordnance Survey map. The only corrections made to the measured values displayed in the enclosed plots were to zero-mean each instrument traverse to remove the directional sensitivity and short period drift of the instruments. A 2m x 2m thresholding median filter (Scollar *et al.* 1990, pp492) was also applied to curtail the response of near surface ferrous detritus, that can be distracting in the final plot of the data.

Figure 4.1 The English Heritage cart on the Shelford site. Four Caesium sensors are mounted on a line below the wheel axle. The electronics and batteries are located in the towing handles.

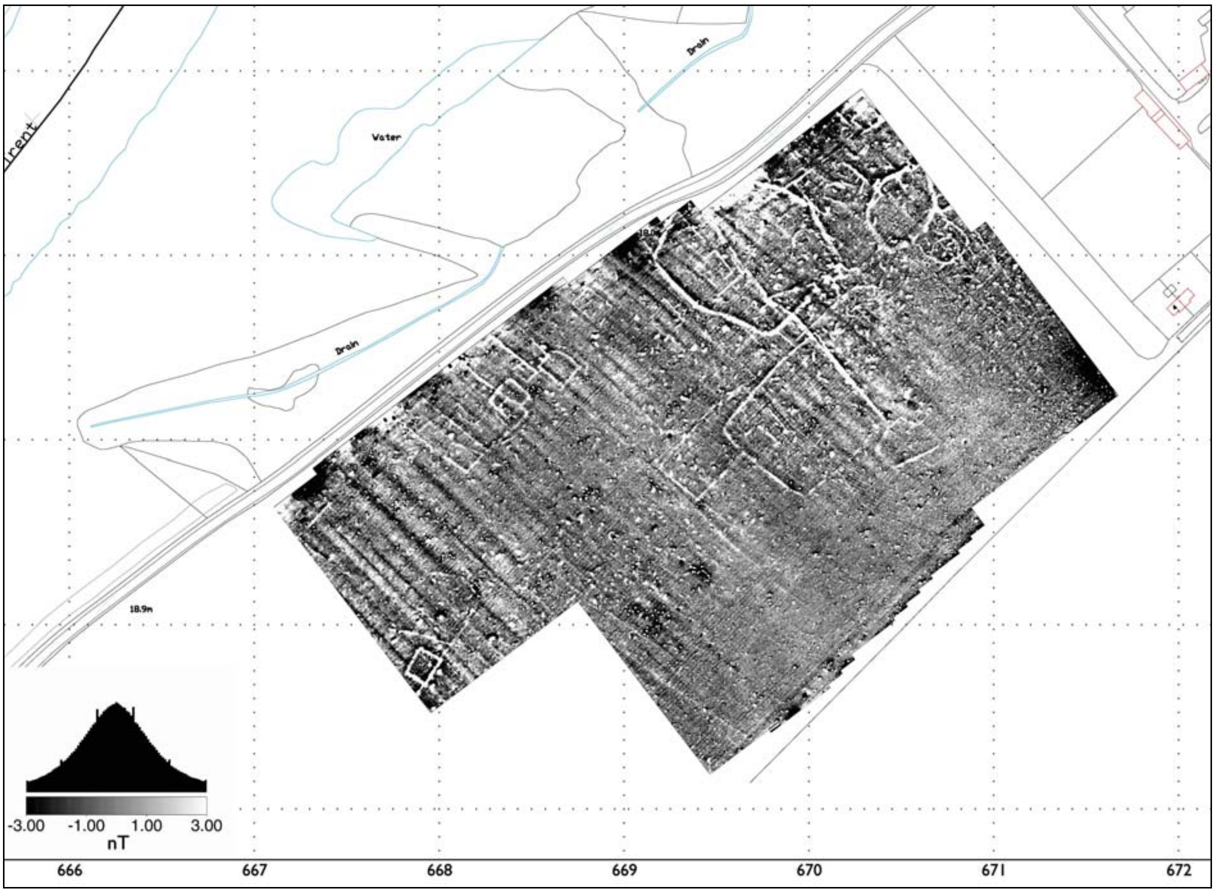


Figure 4.2 The magnetic data produced by the English Heritage cart on the Shelford site.

One disadvantage of operating as an array of total field sensors opposed to a vertical gradiometer configuration is a greater sensitivity to vehicles passing along the road within approximately 30m of the eastern field boundary. This detrimental effect is observed to be of limited spatial extent and generally demonstrates a low frequency negative response superimposed over the data in these areas. An estimate of the local response due to a passing vehicle was made by applying a low-pass Gaussian filter (radius 1m) and subtracting this from the original data.

4.4 The GEEP system

The Geophysical Exploration Equipment Platform (GEEP) was developed to exploit the recently available innovations of:

- Differential Global Positioning Systems (DGPS) with real-time accuracies of 1m
- Geophysical sensors that can output digital measurements at rates of up to 10Hz,
- Wireless computer networking systems (WLAN).

In combination, these three features make it possible to build a survey system which is:

- self locating,
- can make measurements with multiple sensors while in continuous motion
- can allow real-time data quality assurance (QA) and initial interpretation by transmitting the large, dense datasets to a receiving base station in real-time.

The facility of self-location does away with the need for any prior surveying and pegging of survey lines, and also means that the survey can be modified as it progresses in the light of the data being recorded. With a mechanised system, multiple sensors can be carried simultaneously, with neither the weight of the systems, nor the combined power consumption presenting a problem. For many applications, such as mineral exploration, and environmental surveys, the ability to measure multiple datasets improves the ability to characterise the physical properties of the subsurface. With rapid collection of large volumes of data, there could be problems of both verifying data quality, and storage of the data. Both of these are overcome by using a wireless local area network (WLAN) system to telemeter the data in real-time to a base station. Here a geophysicist can review the data quality, and provide an initial appreciation of the data, and modify the survey plan to concentrate the survey in areas of particular interest.

The system is highly efficient, collecting data at the maximum acquisition rate of the geophysical sensors, and requiring only two operators. Furthermore since the geophysical sensors are carried by a mechanical platform the performance is much more uniform than when carried by a walking person, increasing the inherent quality of the data. The system can carry up to six sensors, the limiting factor being the transmission capability of the telemetry system. In practice, a limit on the number of sensors is imposed by the possibility of mutual interference between sensors. The system was initially developed for exploration surveys for mineral deposits in small fields in Derbyshire, where its agility over irregular terrain was tested. The major limiting terrain property is thick woodland, which inhibits physical motion, and also obstructs both the DGPS location system and the WLAN telemetry.

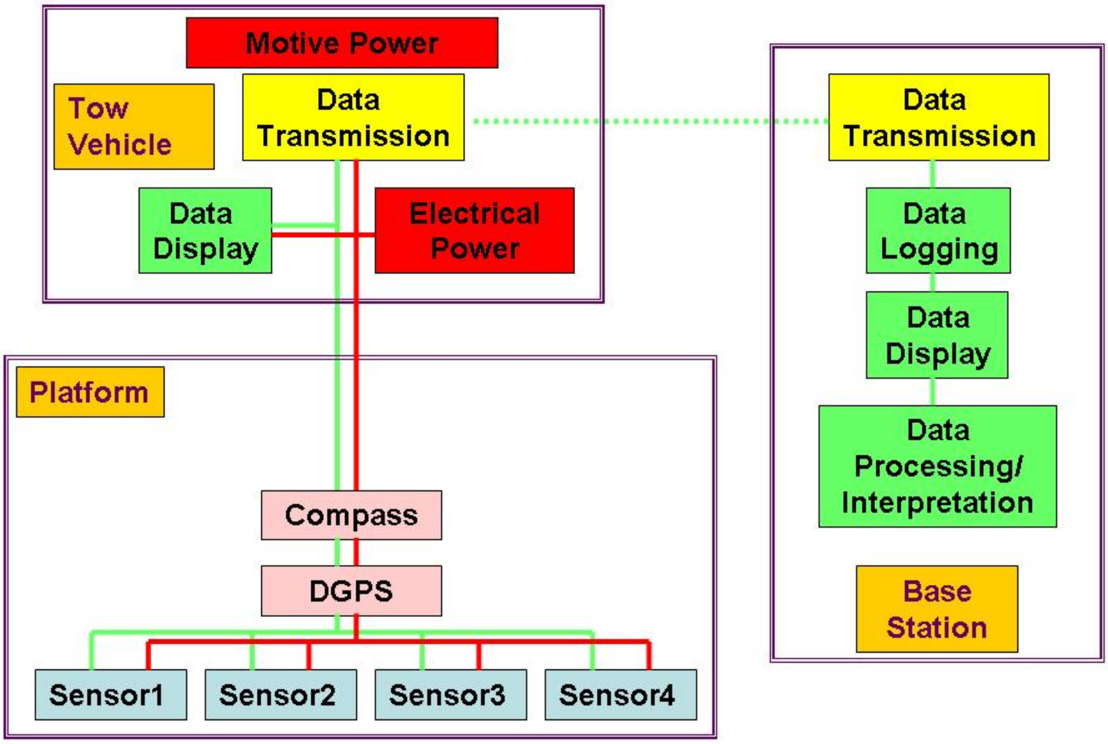


Figure 4.3 Schematic diagram of the GEEP system.

4.4.1 Physical structure

The GEEP sledge is built of glassfibre and plywood to give a firm mounting position for instrumentation. The fluxgate compass unit and DGPS antenna have fixed permanent positions (Fig 4.1). All these components are essential to system operation and are always present. The base of the hulls sit on Nylon "skis" which provide a durable low-friction running surface for the sledge. Wheels were rejected for a variety of practical reasons, including complexity, geophysical noise, and sledge stability. The sledge is towed by a Kevlar strain member that is encased with electrical cables within the tough outer sheath of the composite towing cable.

The towing vehicle is a small tractor. This was chosen as providing the necessary motive power, with the minimum geophysical signature. When towing the MSP with an 8 m towing cable, it is invisible to EM systems, and produces a magnetic heading error of less than 1nT. The tractor is necessary to maximise the efficiency of data collection. In routine surveying the system can survey at 7 line km per hour. Allowing for set-up and pack-away time, as well as relocation between separate fields on a survey site, survey totals of 20-25 line-km per day have regularly been achieved. Using instruments with a sampling cycle of 0.1 Hz, such as the EM38, EM31 or Cs Vapour magnetometers, this gives a sample interval of about 0.15 m along track. The tractor carries an LCD display for the driver showing his survey track plot so that he can check his line positioning and modify it as necessary when he encounters physical obstructions such as trees and field boundaries. The tractor also supplies power to the sledge at 12 and 24 Volts DC. With multiple geophysical instruments operating continuously, changing separate battery packs in each instrument would be highly inefficient.

Figure 4.4 The Leicester GEEP system on the Shelford site comprising towing tractor (right), MSP sledge (left, in this case with EM31, and the hired van and trailer (rear) which transports all the equipment and acts as office and workshop on site.

The data logging base station consists of a WLAN base station linked to a laptop computer. GEEPLog software is used to display the incoming data and to write the serial data strings to text files. Separate data files for each instrument are merged together with the position information in a single database file in CSV format. This can then be directly input to a commercial processing package (e.g. Geosoft Oasis Montage) or subject to further pre-processing in alternative commercial software or user-generated applications. While it is convenient to run the base station inside a vehicle, on sites with particular access problems, all the base station equipment can be placed in a wheelbarrow and moved as necessary manually. It is possible to run the system with two laptops at the base station linked by an Ethernet hub. In this case the survey observer can be processing data, while monitoring the current survey at the same time.

DGPS system.

The system was initially designed with the basis of the navigation being a differential GPS system. For the mineral surveys that were the original objective, positioning to an accuracy of about 2 m was considered adequate. Since that original design the accuracy of DGPS fixes has been increased by several unrelated changes. The Ordnance Survey have constructed additional DGPS beacons in the UK. The EGNOS European geostationary satellite system giving differential corrections is now in operation. All survey locations for the GEEP used during this project were obtained using EGNOS DGPS. Informal tests show that the accuracy of fixes is sub-metre. For surveys using EM34, a second DGPS was mounted with the second coil on the second sledge. DGPS navigation was chosen since it is simple to operate, readily available, and sufficiently accurate for most applications. In principle any other navigation system could be used if more appropriate. Both RTK GPS, and tracking total station EMD are viable alternatives, as long as they can output a continuous serial data string which can be merged with data from the MSP itself. Neither of these possibilities has yet been explored.

Instrument packages

The physical structure of the GEEP easily accommodates a large range of geophysical sensors. The essential limiting factor to what may be accommodated simultaneously is the issue of mutual interference between sensors. Most obviously, high accuracy magnetic sensors will be degraded if virtually any other system is added to the GEEP sledge. To minimise this, the magnetic sensors are always mounted to the rear of the MSP, away from the electronics modules of other instruments.

Deciding which sensors to use together is a compromise between ultimate data quality and time in the field. If a heading error of a few nannoteslas is acceptable on magnetic data, then the GEEP can be used with multiple magnetometers, EM31, EM38 and Gamma ray spectrometer simultaneously. The situation is analogous to that of borehole logging, where for any specific application it is possible to devise packages of instruments that can run together to optimise file deficiency without unacceptable compromises on data quality. While there can be general guidelines, the detailed solution will be specific to the requirements for any individual survey application.

Planning of survey tracks

It is conventional to collect geophysical data along regular straight lines of a pre-surveyed grid. There is considerable logic behind this in terms of the uniformity of sampling, and subsequent processing of the data. The GEEP concept was however born from the need to cope with surveying in small, complex field shapes in Derbyshire, where any attempt to maintain a regularly spaced rectangular grid would be either very time-consuming or impossible. The positional autonomy of the GEEP system is one of its great advantages. No pre-survey is required. The GEEP can move round obstacles, collecting data where possible, and adapting the survey track plan to the natural barriers present.

A survey plan gradually evolved from field experience. The major influence on this is that the GEEP may have degraded data quality when turning corners. Here, the tractor position is indeterminate relative to the GEEP, and on a tight turn it will often approach the GEEP sledge. This leads to erroneous readings on EM or magnetic sensors. To minimise this, 180-degree turns are avoided where possible. The usual track plan is thus to start by making circuits round the outside of a survey area spiralling in towards the centre at the required track spacing. When such outer tracks have covered sufficient ground all around the periphery of the area for the GEEP system to turn and re-align itself, the remainder of the area is infilled with a grid of parallel lines, ending with perpendicular tie-lines. Such track plans have been used in both the case studies reported here. The advantage of the above system is speed and efficiency. All the accessible area is covered by data tracks efficiently.

4.4.2 Data verification and processing

Post-processing Software

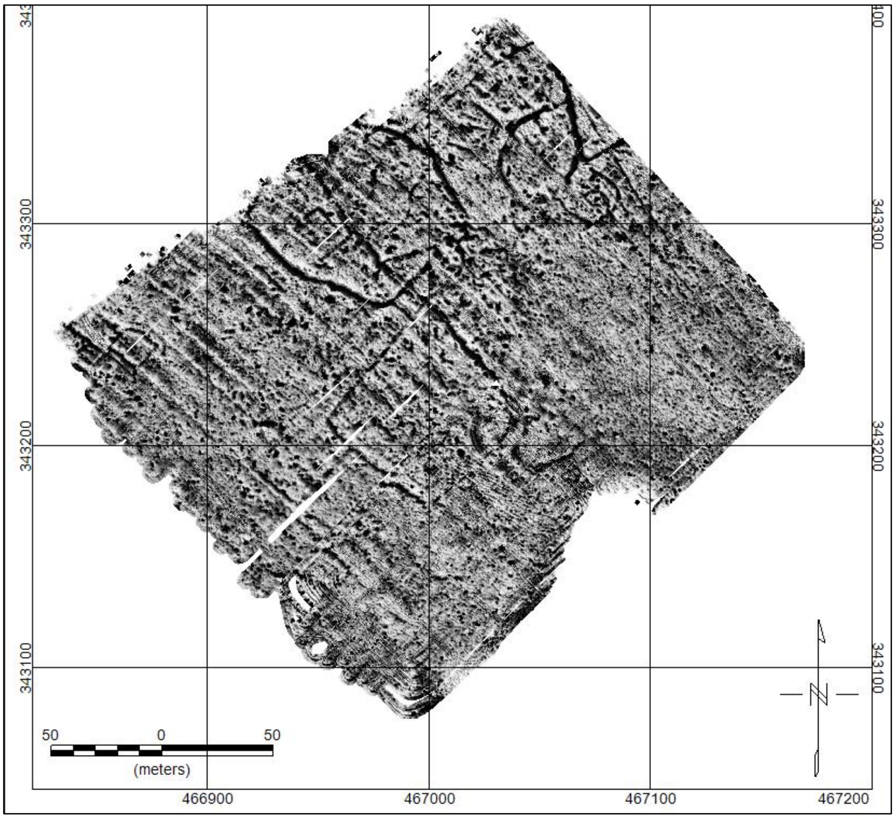
This GEEPLog software outputs a database file which can be used to input directly to Excel, Geosoft Oasis, or any other preferred package. Additional software has been written to speed up the post-processing of the data. The GEEP_PP, takes the ASCII CSV data files produced by the GEEPlog software and can extract particular data types, calculate the corrected position of that geophysical sensor at the time of the measurement, and outputs another standardised ASCII file. This again can be easily read into other software. While these programs do not carry out any fundamental processes that could not be carried out in other packages, their importance is in speeding up the dataflow from initial logging, to meaningful data imaging. With a fairly full instrument load, the MSP records megabytes of data per hour. Efficient handling of this data through the post-processing stage is essential to the usefulness of the system.

In this project, data files from the post-processing software were input to Geosoft Oasis databases, then edited, filtered and analysed in a similar manner to conventional geophysical data. The main difference is that the datasets considered here are large, and densely sampled, with well determined levels of self-consistency proved by track intersections and repeat lines.

Output files from the Geosoft Oasis package map be formatted in a variety of ways, but are typically as .jpg images, shape files, or as XYZ files for incorporation in GIS databases.

4.4.3 GEEP Data – Archaeomagnetics

(a)



(b)

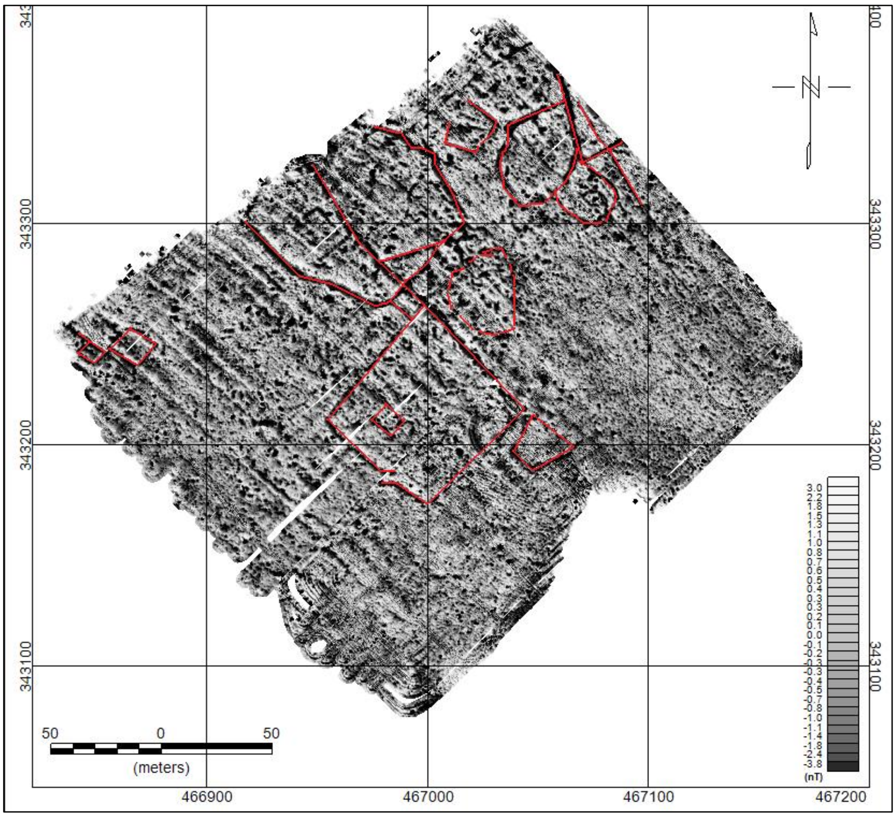
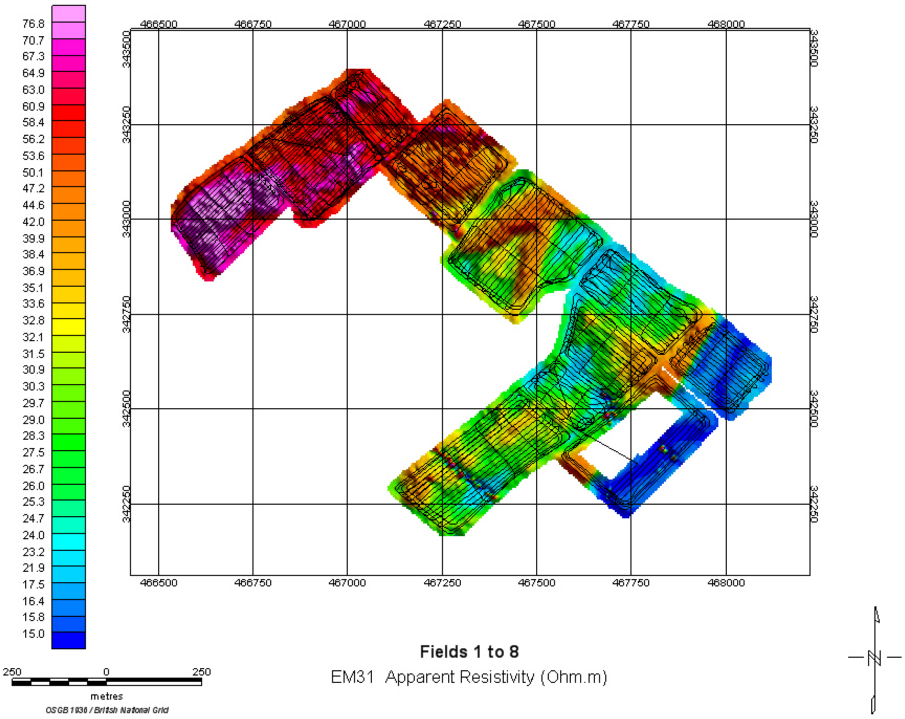
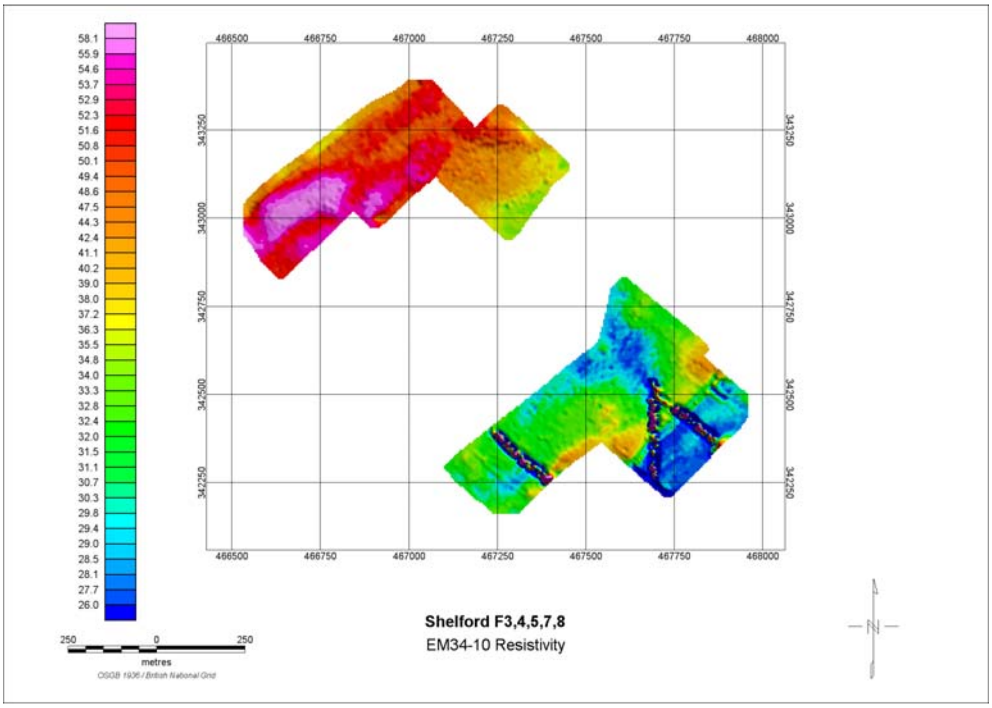


Figure 4.5. (a) Archaeomagnetic survey using total magnetic field values, with overlaid interpretation shown in (b).

4.4.4 Mineral assessment data from the GEEP system



(a)



(b)

Figure 4.6 Resistivity surveys over the Shelford area using (a) EM31 system and (b) EM34-10 system. Both show a similar range of resistivity values. The EM34-10 system has a deeper penetration and is detecting both the aggregate deposit and an effect of the conductive mudstones below.

5 Sturton: mapping the terrace-floodplain interface

5.1 Introduction

The western half of the Sturton-le-Steeple study area comprises a low terrace of sands and gravels, demarcated by a clearly discernible break in slope from the alluvial silts and clays that extend eastwards across the modern floodplain towards the River Trent. Borehole data retrieved from transects running across the terrace and floodplain demonstrated a substantial depth of alluvial silts and clays to the east of the terrace, incorporating peat of variable thickness across most of the floodplain. These alluvial deposits were shown to mask several small sand and gravel 'islands' in the modern floodplain which might have served as foci for prehistoric or Romano-British activity (Challis 1999; Elliott 2004) and adjacent to the eastern edge of the terrace a major palaeochannel of the Trent running from south to north (Fig.5.1). This channel incorporated thick peaty deposits and a rich assemblage of pollen, plant macrofossils and insect remains. Radiocarbon dating of associated organic material showed the channel deposits to have accumulated from the late Neolithic into the Iron Age, emphasising thereby the significant potential of the channel for study of the later prehistoric environment of this stretch of the lower Trent Valley (*ibid.*59).

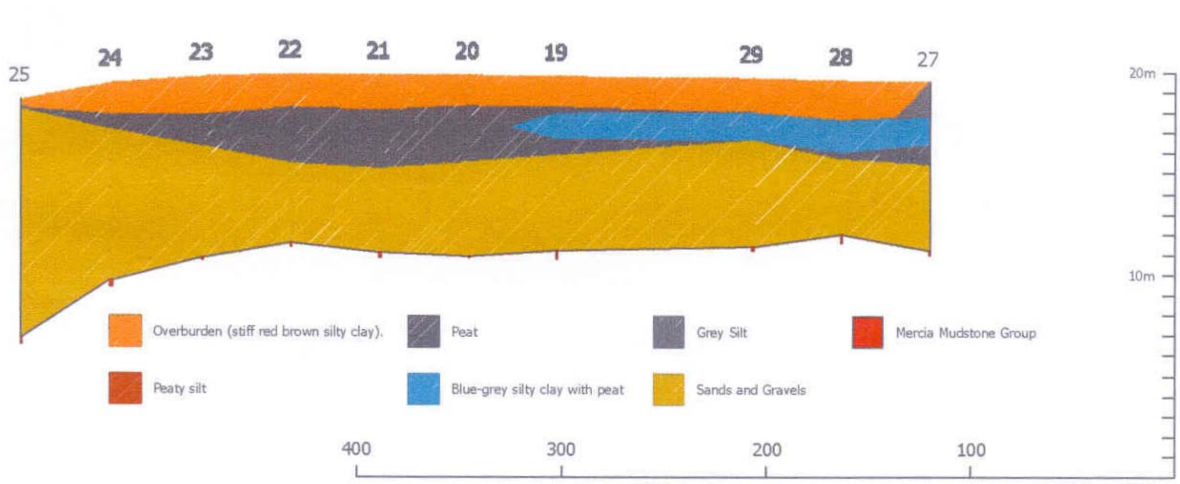


Figure 5.1 Section across the eastern edge of the terrace of the Trent reconstructing the palaeochannel now filled with peat.

The location of this area, spanning the interface between river-terrace and alluvial floodplain, provided an excellent opportunity to test the potential of GEEP, LIDAR and hyperspectral data for early determination of the archaeological and palaeoenvironmental potential of a typical block of Lower Trent landscape. Key issues, of crucial significance for assessing the cultural and palaeoenvironmental resource of this area, include the following:

- Location and configuration of the terrace-floodplain interface
- Location and characterization of relict Holocene river channels, both in the floodplain and on the terrace.
- Mapping and characterization of alluvial deposits with potential for the preservation of palaeoenvironmental and cultural remains.

- Identification of sub-alluvial sand and gravel islands which could have served as foci for prehistoric or Romano-British activity (potential for the preservation beneath alluvium of significant cultural and palaeoenvironmental remains, including perhaps the vestiges of prehistoric or later trackways: Elliott 2004, 59).
- Tracking into the modern alluvial floodplain of features and deposits associated with the terrace-edge Romano-British settlements recorded during fieldwalking, gradiometer survey and trial excavations.

The results of each survey are discussed in turn (Chapter 5.2 - 5.4). The results are reviewed in a final section (Chapter 5.5) and the effectiveness of the field and data collection techniques employed in this project is assessed. Information obtained from the earlier desk-based assessment (Challis 1999) and evaluation (Elliott 2004) work is discussed where appropriate.

Supporting information is contained in the project GIS, compiled by Dr Lex Comber and Dr Katy Mee with assistance from Lee Elliot and Dr Gary Priestnall (Appendix 3). The area immediately north of the study area remains the subject of a planning application, and it was agreed with Lafarge Aggregates Ltd prior to commencement of the project that only data obtained for the area lying outside the current planning application area would be made available for this study. Data in the project GIS therefore relate wholly to a *c*.60ha block of terrace and floodplain demarcated on its northern side by the boundary of the planning application area and elsewhere by a boundary marking the edge of the application area considered during the initial desktop assessment (Challis 1999) and subsequent evaluation work (Elliott 2004).

5.2 GEEP Surveys

It was intended to conduct a series of surveys at Sturton using the GEEP system, primarily using EM systems to measure ground conductivity. This site was the first visited during the fieldwork, and the data collection was hampered by a series of factors. There were electronic failures of the GEEP telemetry systems, which lost several working days. Two complete days were lost to rain, and after these delays, while the system was then operational, the farmers had disc-harrowed the fields and although it was possible to traverse across the freshly cultivated surface, the survey progress was very slow, especially since there was continuing wet weather. There are thus no significant data from this project to report.

Additional resistivity imaging profiles were planned to run along a line of boreholes to be drilled by Lafarge, but logistic difficulties affecting Lafarge have prevented this from going ahead during the time-span of this project.

5.3 Airborne Lidar

1m spatial resolution Lidar last pulse digital surface model data were examined for evidence of terrace and floodplain geomorphology. The height-shaded Lidar data (Figure 5.2) clearly portrays the major geomorphological features of the terrace and floodplain as variations in topography, often on the order of only a few tens of centimetres.

The terrace edge is clearly evident as a marked break in slope, trending roughly north-west to south-east across Figure 5.3 (points B, A. C. E. F). Considerable variation is evident in the character of the terrace edge. Minor channels draining the terrace are evident at points B, C and perhaps E, raising the possibility of waterlogged deposits with increased palaeoecological potential within these channels as they cross the terrace and alluvial fan deposits masking the terrace edge.

Isolated island of terrace material are evident emerging from the floodplain deposits at point d. These islands rise little more than 0,75m above the surrounding floodplain and probably mark the tops of larger terrace remnants largely concealed by latter alluviation. The general character of the terrace edge and the location, height and topography of these island features is apparent in the lidar derived profiles shown in Figures 5.4 and 5.5 (profiles 1 and 2).

To the south the terrace edge shows an odd stepped profile (E on Figure 5.2; profiles 4 and 5 on Figures 5.4 and 5.5). This step, creating an area of lower terrace approximately 1m in elevation below the main body of the terrace, defies immediate explanation, but might indicate an episode of river incision into the terrace edge and might perhaps be equated with the clear river eroded breach in the terrace further to the south in the vicinity of the Roman town of Littleborough at F on Figure 5.2, and evident in profile 7 (Figures 5.4 and 5.5). There is also a slight indication of an area of raised elevation close to the eastern edge of the floodplain adjacent to the present channel of the Trent at G on Figure 5.2 and apparent in profiles 4 and 5 (Figures 5.4 an 5.5). This might indicate a further isolated fragment of terrace material.

Lidar last-pulse intensity imagery was also examined for evidence of terrace and floodplain geomorphology (Figure 5.3). In general the intensity data provides little additional information as intensity variation within the study area appear to be dominated by land use and crop rather than geomorphology. However, the minor channel draining the terrace at A is clearly evident as a high intensity return. This would tend to suggest that the channel is filled with dry sediments and thus probably of low palaeoecological potential. Conversely, an area of high intensity "dendritic" channels within the floodplain at B on Figure 5.2 appear to be roddens (they are also faintly apparent as raised features in the Lidar elevation data) and suggest that the floodplain in this area may be dominated by peat deposits that have shrunk, (probably due to drying out) and exposed underlying sand and silt filled drainage features in positive relief.

Figure 5.2. Lidar last-pulse digital surface model. The boundary between the lower lying floodplain (darker shading) and the elevated terrace is clearly apparent. Close examination reveals a wealth of geomorphological detail in both the terrace and floodplain deposits.

Figure 5.3. Lidar last-pulse intensity image. In general in this image crop cover and land use appear to be the dominant factors affecting variations in intensity, with little obvious distinction between floodplain and terrace.

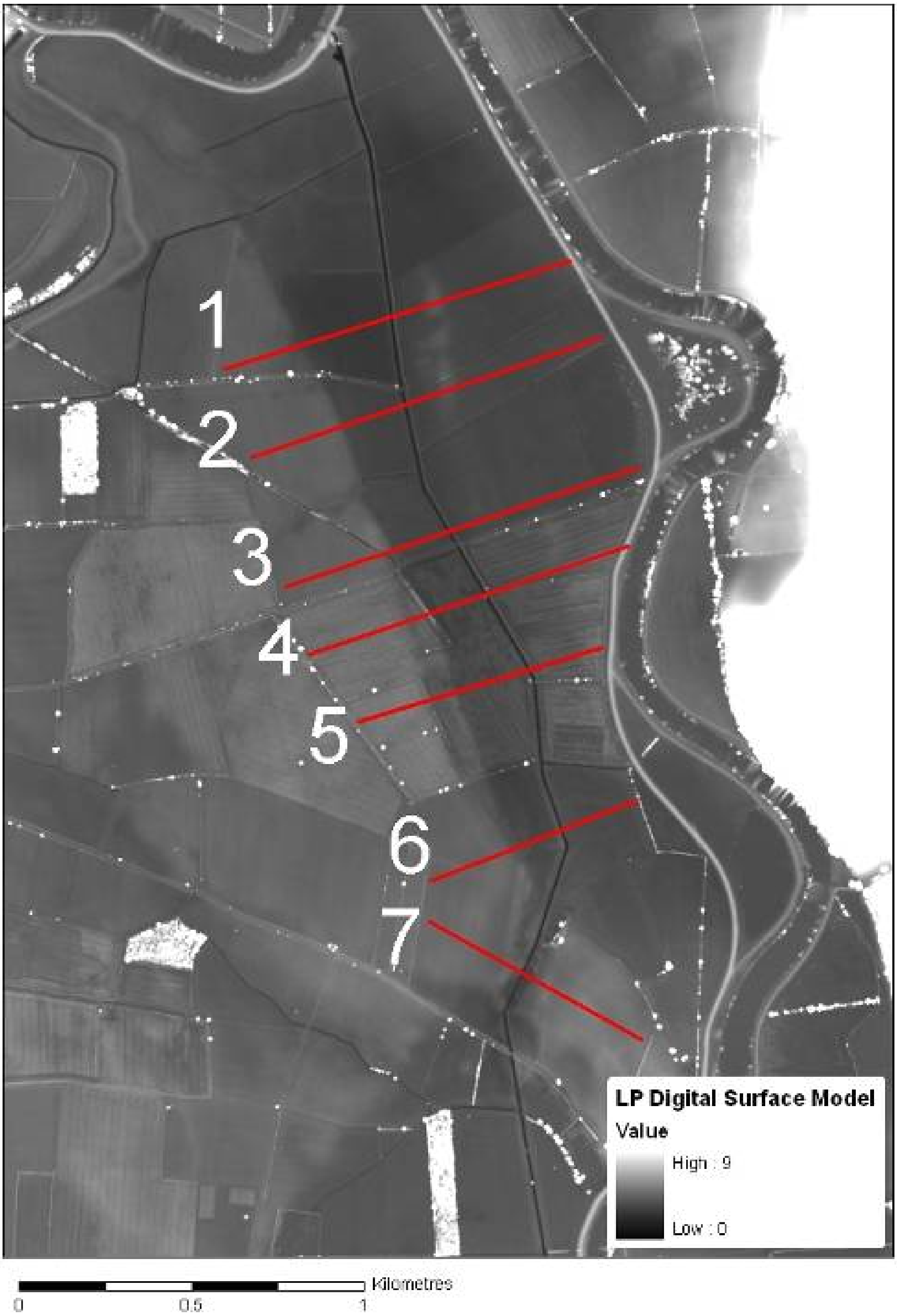


Figure 5.4. Lidar last pulse digital surface model, red lines indicate profiles across terrace edge in Fig 5.5.

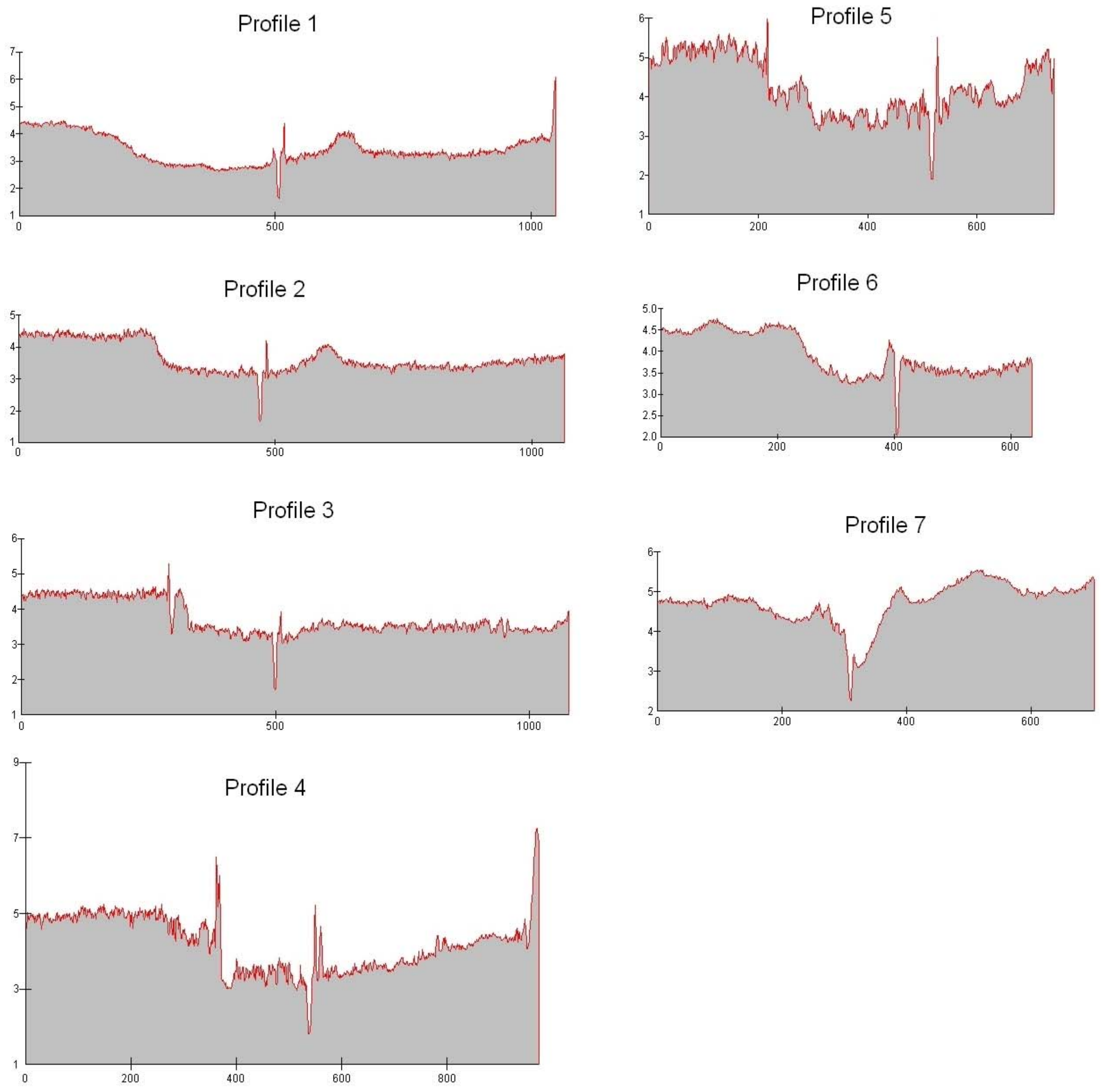


Figure 5.5. Lidar derived profiles across the river terrace edge at Sturton.

5.4 Hyperspectral Data

AISA Eagle 34 band hyperspectral data for the study are were collected for the project team by Infoterra on 18th October 2007, some two months after the Lidar survey. At the point of hyperspectral survey much of the study area was bare earth, having been harvested and ploughed. To some extent this has limited the effectiveness of the hyperspectral survey as in general vegetation is far more likely to betray underlying geomorphological features through resulting variations in crop growth and character evidenced across the visible spectrum and particularly in the NIR (*cf* Shelford chapter).

Nevertheless a suit of standard analytical processes were applied to the Eagle data in an attempt to identify aspects of terrace and floodplain geomorphology (Figures 5.6 – 5.12).

A true-colour composite image (Figure 5.6) shows approximately the equivalent of a colour aerial photograph of the study; general land use, in particular the brown tones of the bare earth fields is readily apparent. Features evident from the lidar flight can be identified on this image, largely as variations in soil colour and include a channel feature crossing the terrace at A, rodden-like features on the floodplain at B and the summits of the gravel islands in the floodplain, evident as distinctly lighter soil colour at C. Similar areas of lighter soil are evident on the terrace edge at D, perhaps suggesting that both C and D represent areas of active erosion of terrace deposits by ploughing introducing sand and gravel from the underlying terrace into the ploughsoil. Beyond the southern edge of the study area the terrace edge in the vicinity of Littleborough is very clearly marked by variations in soil colour.

In general these same features are evident in the false colour composite image (Figure 5.7) which makes use of NIR bands to emphasis soil variation. Variations in soil character evident in this image, particularly to the south of the study area, might indicate varying aggregate character.

In general vegetation based analysis and indices are not particularly revealing using the available imagery. Eagle band 23, (Figure 5.8) which approximates to the point of maximum vegetation reflectance in the NIR, centred at 795nm, should indicate maximum difference between vigorous and senescent vegetation. Little is apparent in the bare earth areas, although variations in vegetation character reflecting the rodden-like features at B. Similarly the Normalised Difference Vegetation Index (NDVI; Figure 5.9) which highlights the difference in red and NIR reflectance of vegetation, shows little of great significance beyond highlighting fields with growing crop (pale tones). The rodden-like features at A are again apparent. Eagle band 27 (Figure 5.10) equates to the NIR plateau at c 870nm, soil variations are slightly emphasised in this spectral region; the paler tones of features at B,C and D may indicate areas where terrace material of different spectral reflectance to the surrounding ploughsoil has been brought to the surface by deep ploughing.

Finally, Principal Component Analysis (PCA) was applied to the Eagle data. PCA removes redundancy in adjacent bands of a hyperspectral image brought about by correlation between bands by statistically generating a lesser number of bands that are uncorrelated and contain the majority of the variation in the original image. In this instance 5 principal components were generated to account for most of the variation in the original data. Component 2 (Figure 5.11) accounts for much of the variation in the original data and provides a good visual summary of the soil and vegetation changes discussed, in particular rodden-like features at A, possible areas of deep ploughing erosion at B and C and the clearly marked terrace adjacent to Littleborough at D. A pseudo three-dimensional view of PC2 draped over Lidar terrain data in Figure 5.12 clearly highlights the relationship between topography and soil and sediment character.

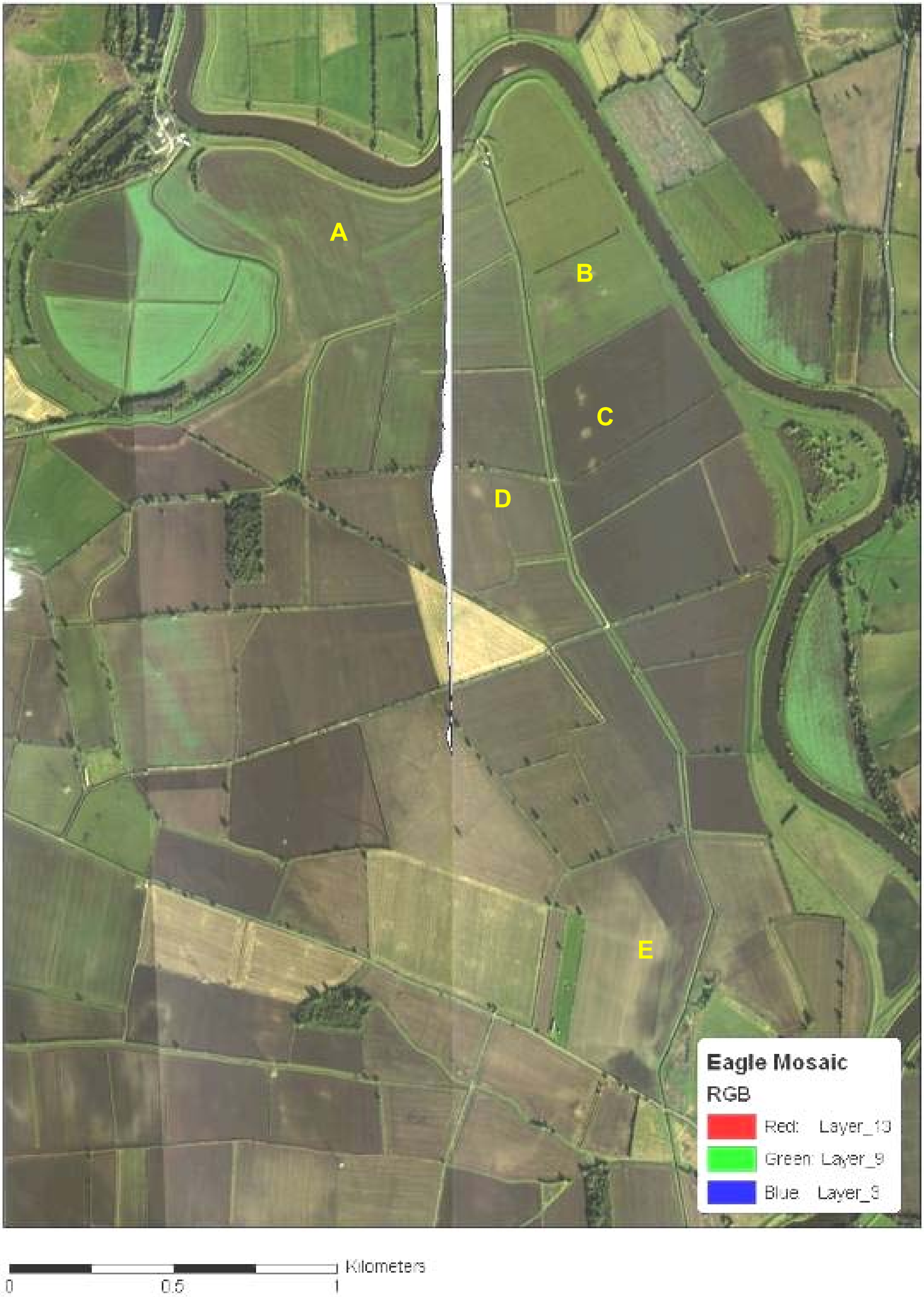


Figure 5.6. Eagle true colour composite (Band 13-9-3)

Figure 5.7. Eagle false colour composite (Band 34-21-13) highlighting soil and vegetation variations apparent in the NIR.

Figure 5.8. Eagle band 23 (maximum NIR reflectance of green vegetation). There is little variation across the study area which is largely bare earth.

Figure 5.9. Eagle NDVI. The lack of vegetation across most of the study area renders this index of limited use in identifying anthropogenic and geoarchaeological features of the landscape.

Figure 5.10. Eagle band 27, the NIR Plateau. Soil variations are most apparent at this part of the spectrum

Figure 5.11. Eagle principal component 2. This band most effectively highlights the soil and vegetation variations across the study area.

Figure 5.12. Eagle Principal Component 2 draped over the lidar DSM. In combination these data effectively highlight the terrace edge.

5.5 Conclusions: effectiveness of geophysical and remote sensing surveys

The Lidar digital surface model data has proven highly effective for revealing aspects of terrace and floodplain geomorphology, including terrace surface drainage features, the terrace edge and isolated terrace fragments. The true three-dimensional nature of these data is of particular use, allowing generation of cross-feature profiles.

On unvegetated fields Lidar intensity and hyperspectral data are of limited use.

Eagle hyperspectral imagery does serve to identify several areas of possible plough erosion of underlying sediments.

6 Case Study – Shelford Mineral Assessment

6.1 Borehole data

The Mineral Assessment study was undertaken on the Shelford site. Sturton was also initially considered for detailed statistical analysis on a line of proposed boreholes and geophysical coverage. Due to logistical problems Lafarge were unable to return the contract drillers to the site in time for the data to be collected for the project. Fortunately the main site for Mineral Assessment was the Shelford site based upon a series of investigations undertaken by the BGS for research purposes and a confidential sand & gravel drilling report.

Evaluation of the BGS borehole data showed that drilling had been undertaken for a variety of reasons and using a range of drilling techniques. Most of the boreholes were shallow for detailed assessment of the soil profiles, holes drilled through the soil and gravel but not sampled for grading analysis, or holes drilled utilising non-industry standard techniques. This absence of grading data effectively excluded the majority of the holes from the resource estimation process. A set of grading analyses for a set of recent boreholes drilled by a sonic drilling technique did become available a few days before the project report was completed.

The various drilling techniques achieve very different sample recovery and hence grading results from the same deposit. It is therefore good practice not to combine data from the different techniques. As a result of this the accumulated BGS borehole data was useful for an overall geological model and calibration of the geophysical data but of less use in the assessment of the sand & gravel resources.

A borehole investigation specifically for sand & gravel had been undertaken on behalf of The Crown Estate on landholding around the village of Shelford, Nottinghamshire by Robert Brett and Sons Limited between 1st and 3rd November 2004 (Brett 2005). The investigation covered an area of approximately 594 Hectares and comprised drilling 44 boreholes from a Bedford truck mounted drill-rig operating a 175mm diameter flight auger (Fig 6.1). Most boreholes were drilled to sufficient depth to prove the underlying solid geology (~ < 7m) and logged, noting thickness and horizon depths of overburden, sand and gravel and clay. The depth to water strike was noted, but in only two holes, and 'representative' bulk samples were taken from some parts of the deposit for Particle Size Analysis.

Since data contained in this confidential report has been released to the FASTRAC consortium on the basis that point-values and positions are not described in detail and are subsumed within the main body of work, only general points can be made regarding the data and specific examples about correlation of the geology or geophysics with individual boreholes were not permitted by the terms of the information release. The data was also only cleared for use in the project well after most of the field geophysical work was completed.

Notwithstanding these issues of confidentiality the Brett investigation has provided the best data on which to undertake an assessment of the area for sand & gravel based on both industry standard methods and techniques developed in previous ALSF MIST funded projects (AGSIM, ADICT & WARM-IT). It covers the broader Shelford area and encompassed the fields covered in detail for the geophysical and allied surveys.

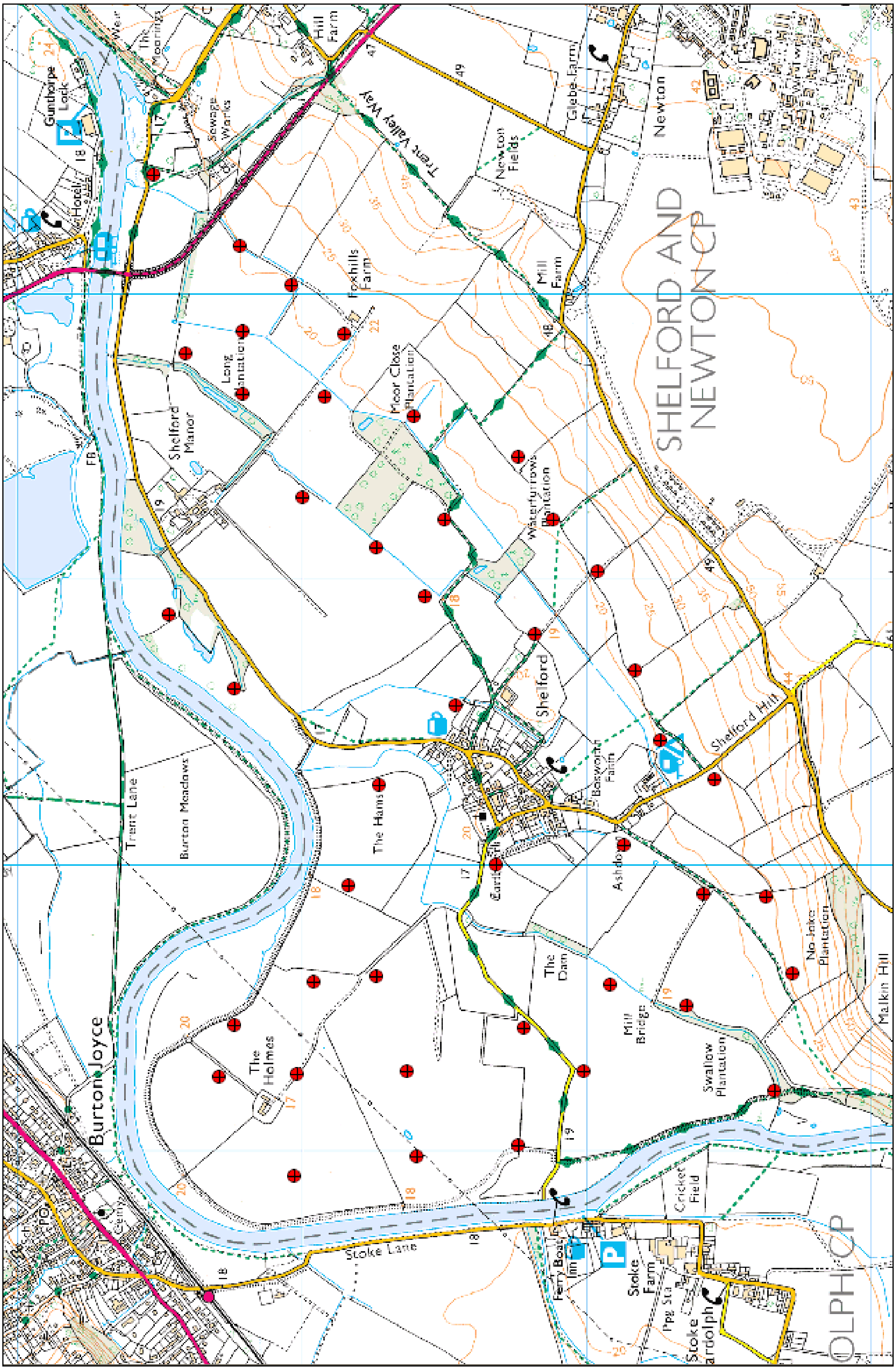


Fig 6.1 Borehole Location Plan for the 2004 Sand & Gravel Exploration Programme undertaken by Robert Brett and Sons Limited.

6.2 The Brett Sand & Gravel investigation

The Sand & Gravel deposits at Shelford are Lower Terrace Trent gravels overlying Gunthorpe Formation red marls of the Mercia Mudstone Group, and would be expected to be similar to those worked by Tarmac nearby at Holme Pierrepoint. Such fluvial deposits are, in industry terms, regarded as of high quality being generally clean i.e. a low silt & clay content, and relatively consistent. Variations in proportions of gravels are common and the distribution of sand sizes varies, with sporadic thin silty or clay lenses; but this is very minor compared to the high variability in glacial or some fluvioglacial deposits

The boreholes were drilled on an approximately 300m grid. This is widely spaced for a full site survey (typically around 100m grid) but Shelford is a very large site and, in similar situations elsewhere, around 200m grids are still commonly used for mineral assessment where continuity of the deposit is assumed to be present. The boreholes at Shelford were drilled by continuous flight auger with logging and sample collection at the rig. From the borehole logs it appears that water strike has only been recorded in two holes.

The report was in paper form so the grading data were scanned, checked and compared to the printed grading curves. It has been assumed that each sample is representative of the logged unit from which it was derived, as the full unit depth was frequently not sampled.

Hole 19 samples were attributed to each of the major units described on the borehole log as sample intervals were not provided. Sampling from boreholes 22, 28 and 29 indicates five missing results. Three duplicate gradings given in the dataset probably relate to the missing data for boreholes 31 & 33 but it is unclear which grading relates to which sample. The first recorded grading for the interval was used in both cases and the remaining data deleted. Overall three holes worth of data were unusable presumably due to miss-labelling during the drilling or laboratory work.

Some sample intervals incorporate several logged units, most only cover part of a unit, some incorporate interburden clays or the base of deposit, and a few cover only the shallowest part of the deposit. The gradings should therefore only be seen as indicative of overall deposit quality and for an accurate assessment more robust sampling to logable unit boundaries is needed.

Although complicated locally, the logs generally suggest a downward coarsening sequence with periodic silty & clayey interburden. In practice it is very likely that the deposit would be worked as a single full depth face or wet excavation. The gradings for each unit were therefore used to compile a composite borehole grading based on a weighted average of the sampled unit thicknesses. This approach is also supported by the preliminary conclusions in the Brett report that the gravelly sands alone would fail to match the required grading for medium concreting sand but that the combined sands and gravel would produce a more saleable product. In order to achieve this, the site would need to be worked in a way that evens out production of the coarser and finer areas and this is the approach taken by the quality mapping discussed in Section 6.3 below.

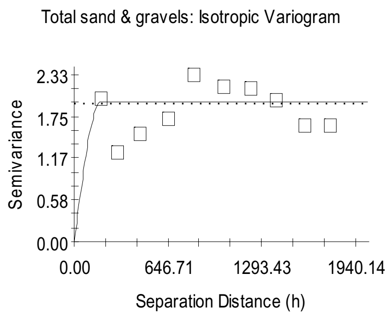
For an initial resource assessment the Brett report has separated the area into five blocks and the deposit into an upper gravelly sand unit and lower coarser sand & gravel. The block volume and tonnages were calculated from average gradings and deposit thickness encountered by holes within the block. This indicated a substantial resource to be present. This distribution of holes and the resource estimate would undoubtedly be improved by some additional infill drilling if the site were ever to be considered for mineral extraction and a planning permission application prepared.

6.3 Variogram Analysis of particle size data

Variability of the deposit, and the degree to which a sufficient level of drilling has been undertaken can be measured using variography. These are important for ensuring that a statistically valid and reliable deposit assessment has been made and may also be used in the justification of a reserve declaration.

The geometric parameters such as deposit or overburden thickness are generally easier to characterise and typical surveys have borehole spacings that fall well within the variogram ranges. Quality parameters are more difficult to assess. The sand, silt and gravel splits provide a crude measure, while more specific information can be derived from individual sand and gravel size fractions. Since use in construction material applications requires that the particle size of the sand falls within certain specification envelopes each size fraction is important in the assessment of quality.

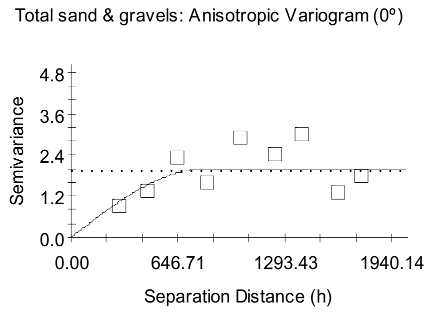
The variogram for total sand & gravel thickness is shown in Fig 6.2



Spherical model (Co = 0.00100; Co + C = 1.96144; Ao = 186.00; r2 = 0.000; RSS = 1.21)

Fig 6.2 Hole-effect - deposit structure

The total mineral thickness has been modelled to a spherical model but demonstrates a classic ‘hole-effect’ indicative of structure within the deposit. In such fluvial deposits this frequently relates to channelling. Fig 6.2 is the omni-directional or isotropic variogram but variability can also be analysed in a directional sense. Fig 6.3 indicates a variogram with better structure and longer range in a north-south direction while Fig 6.4 shows a similar hole effect along the E-W direction. The Trent meanders are mainly aligned parallel to this N-S direction on the western side of the site. The deposit area inside these, and on which the greatest proportion of holes are drilled, probably host old channels aligned in this orientation accounting for the anisotropy within the variograms. The remote sensing data, ATM and LIDAR, however suggests that abandoned channels in the NW corner of the site align predominantly E-W (Fig ((Ch 8 1-4 &6) before swinging predominantly N-S in the western and southwestern areas. Further analysis of the data set isolating areas of the deposit to evaluate would help resolve this.



Spherical model (Co = 0.00000; Co + C = 2.00000; AMajor = 800.00; AMinor = 600.00; r2 = 0.179; RSS = 18.2)

Fig 6.3 Better spherical model N-S direction

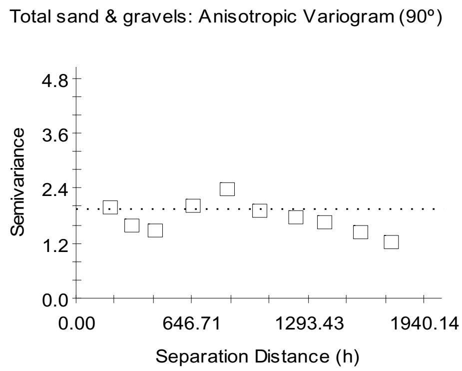
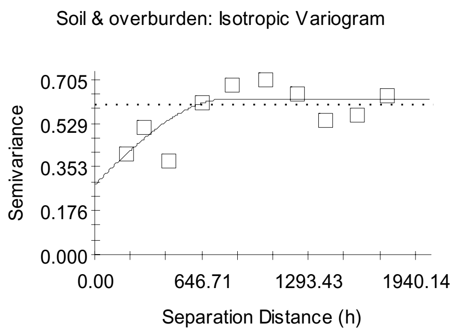


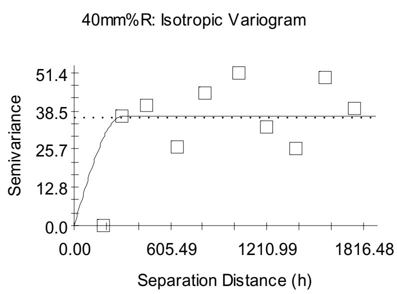
Fig 6.4 Hole effect model E-W direction



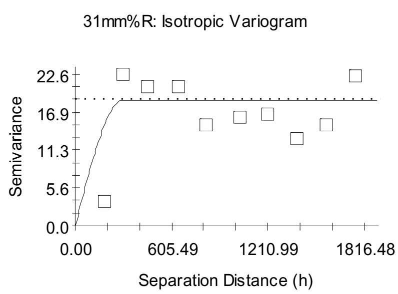
Spherical model (Co = 0.28281; Co + C = 0.62700; Ao = 793.96; r2 = 0.552; RSS = 0.0506)

Fig 6.5 Complex variogram with multiple 'holes'

The overburden variogram (Fig 6.5) also shows ample evidence of cyclicity in the deposit structure. The individual grading size fractions were analysed as shown in Fig 6.6

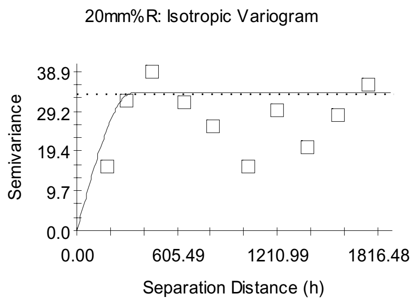


Spherical model (Co = 0.10000; Co + C = 36.78907; Ao = 302.15; r2 = 0.668; RSS = 1587.)

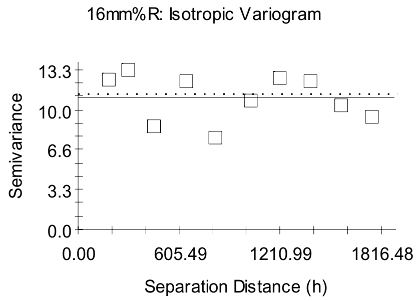


Spherical model (Co = 0.01000; Co + C = 18.66687; Ao = 299.82; r2 = 0.645; RSS = 239.)

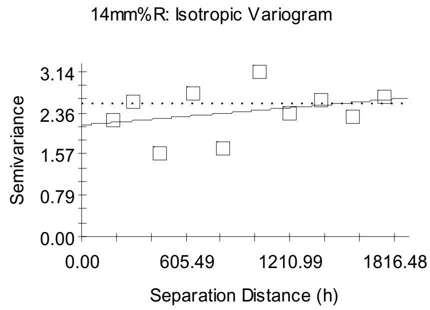
Figure 6.6 (part a) Variograms for individual sand & gravel size fractions



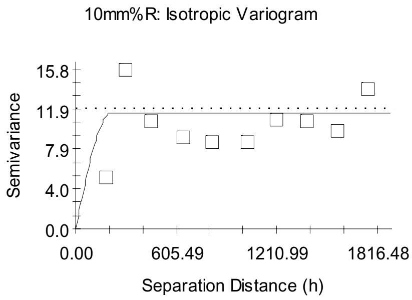
Spherical model (Co = 0.01000; Co + C = 33.58116; Ao = 332.36; r2 = 0.254; RSS = 738.)



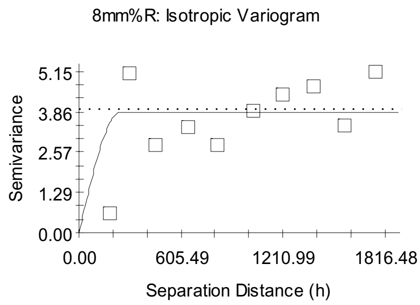
Linear model (Co = 10.96428; Co + C = 10.96428; Ao = 1760.50; r2 = 0.054; RSS = 33.5)



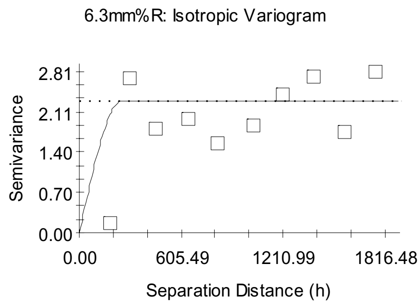
Linear model (Co = 2.12462; Co + C = 2.60500; Ao = 1760.50; r2 = 0.099; RSS = 1.83)



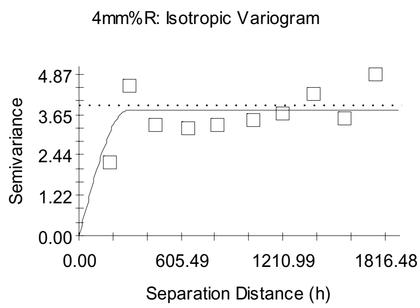
Spherical model (Co = 0.01000; Co + C = 11.52926; Ao = 212.39; r2 = 0.382; RSS = 90.2)



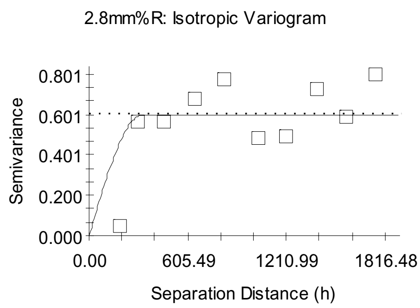
Spherical model (Co = 0.01000; Co + C = 3.86900; Ao = 247.79; r2 = 0.602; RSS = 15.4)



Spherical model (Co = 0.00100; Co + C = 2.30478; Ao = 254.42; r2 = 0.667; RSS = 5.56)

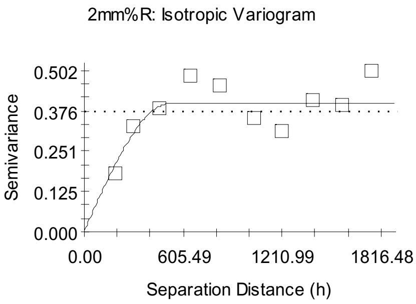


Spherical model (Co = 0.01000; Co + C = 3.77838; Ao = 290.13; r2 = 0.453; RSS = 3.70)

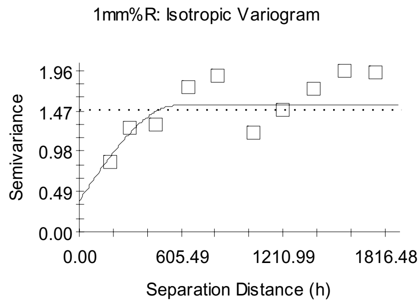


Spherical model (Co = 0.00100; Co + C = 0.59853; Ao = 325.09; r2 = 0.742; RSS = 0.292)

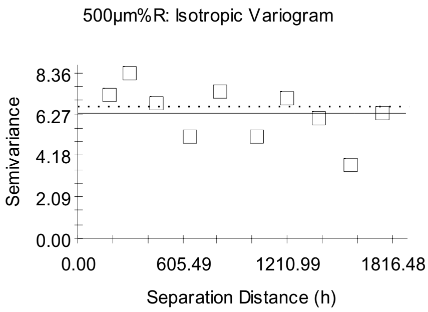
Figure 6.6 (part b) Variograms for individual sand & gravel size fractions



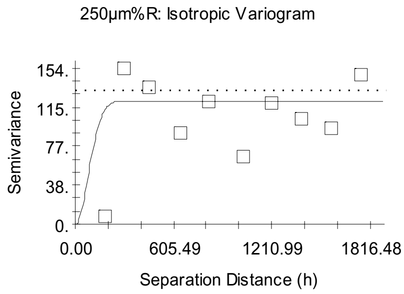
Spherical model (Co = 0.00500; Co + C = 0.39961; Ao = 523.51; r2 = 0.637; RSS = 0.0314)



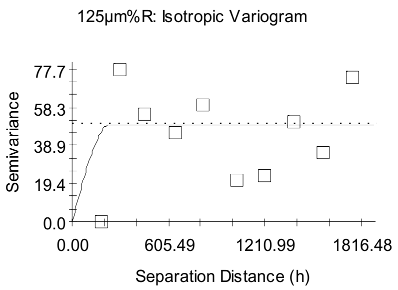
Spherical model (Co = 0.38200; Co + C = 1.53429; Ao = 579.51; r2 = 0.576; RSS = 0.704)



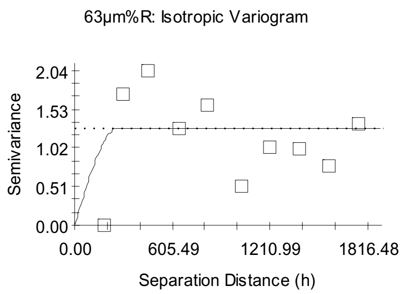
Linear model (Co = 6.33529; Co + C = 6.33529; Ao = 1760.50; r2 = 0.303; RSS = 16.7)



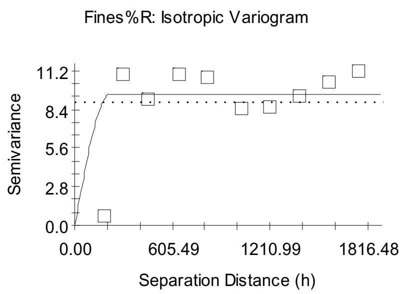
Gaussian model (Co = 0.10000; Co + C = 121.39410; Ao = 112.88; r2 = 0.610; RSS = 18047.)



Spherical model (Co = 0.10000; Co + C = 49.66883; Ao = 239.86; r2 = 0.404; RSS = 5354.)



Spherical model (Co = 0.00100; Co + C = 1.28331; Ao = 269.65; r2 = 0.431; RSS = 3.11)



Spherical model (Co = 0.01000; Co + C = 9.54993; Ao = 219.97; r2 = 0.896; RSS = 83.8)

Fig 6.6 (Part c) Variograms for individual sand & gravel size fractions

The variogram analysis is undertaken on the % retained, not % passing grading data. The actual % passing value for any sieve size is controlled by the amount of finer and coarser material in the grading distribution not by the abundance on that sieve alone. In a variogram therefore the individual size fraction variability would not necessarily reflect the real-life abundance changes or its geological controls.

The size fractions form rather spiky variograms (Fig 6.6) which have been either spherically modelled with ranges around 200-300m or fitted with linear models frequently demonstrating a pure-nugget effect. As a result of the boreholes being spaced around 300m apart the justification for a spherical model is largely based on a comparison of only two boreholes which are close enough to fall within the shortest lag. These two holes are relatively similar in grading, perhaps largely coincidently, and so the first point demonstrates a low variance. On almost all variograms the support for each of the longer lags is based on 30-40 pairs of boreholes and so provides a more robust measure of variance. Even on the spherically modelled variograms these are all distributed around the overall sample variance.

The variograms are therefore probably best modelled as linear pure nugget effect models indicating an absence of demonstrable short range correlation. This is caused by the lack of closely spaced boreholes that could be used to construct the shorter lags on the variogram. A true measure of the intrinsic variability for the deposit cannot therefore be ascertained with any confidence.

In common with the deposit geometry variograms, most of the particle size variograms also show a hole-effect. The depositional processes associated with river channel formation also lead to grading changes.

A typical industry survey would have boreholes around 100m apart so have a better prospect of creating a reasonable variogram. Fluvial sand & gravel deposits typically demonstrate ranges of several hundred meters allowing borehole surveys with spacings of 100-200m. A further benefit of a whole site geophysical survey prior to drilling is that the boreholes can be redistributed from a comprehensive grid to incorporate some closely spaced holes providing short lag data on a variogram that may be used for justification of reserve declarations.

6.4 Quality Mapping

In most site assessments for sand & gravel resources the gradings from the borehole samples are plotted to visualize the variation in silt (fines), sand gravel & oversize size fractions (Figs 6.7 to 6.10). The deposit thickness and overburden variations are also of importance for extraction planning and reserve quantification (Figs 6.11 to 6.12).

To assess the suitability of the deposit for producing particular sand types the borehole gradings are also manipulated to create a simulated processed grading to compare against product specifications. As described in this report, Section 3.8 a more detailed approach to the quantification of the samples' match to the specifications has been developed (AGSIM, ADICT, & WARM-IT projects, Jeffrey et al 2004a, 2004b, 2005)

A series of quality maps for the Shelford site have been compiled and are detailed in Figs 6.13 to 6.15 below. The data in each plan is presented in three ways: as illuminated surfaces, vector maps and contours. The contour plots and grid files have been incorporated into the site GIS database while the surface plots are more useful as a clearer visual presentation of the data. The vector plots provide a useful method to compare with gradient based geophysical data plots.

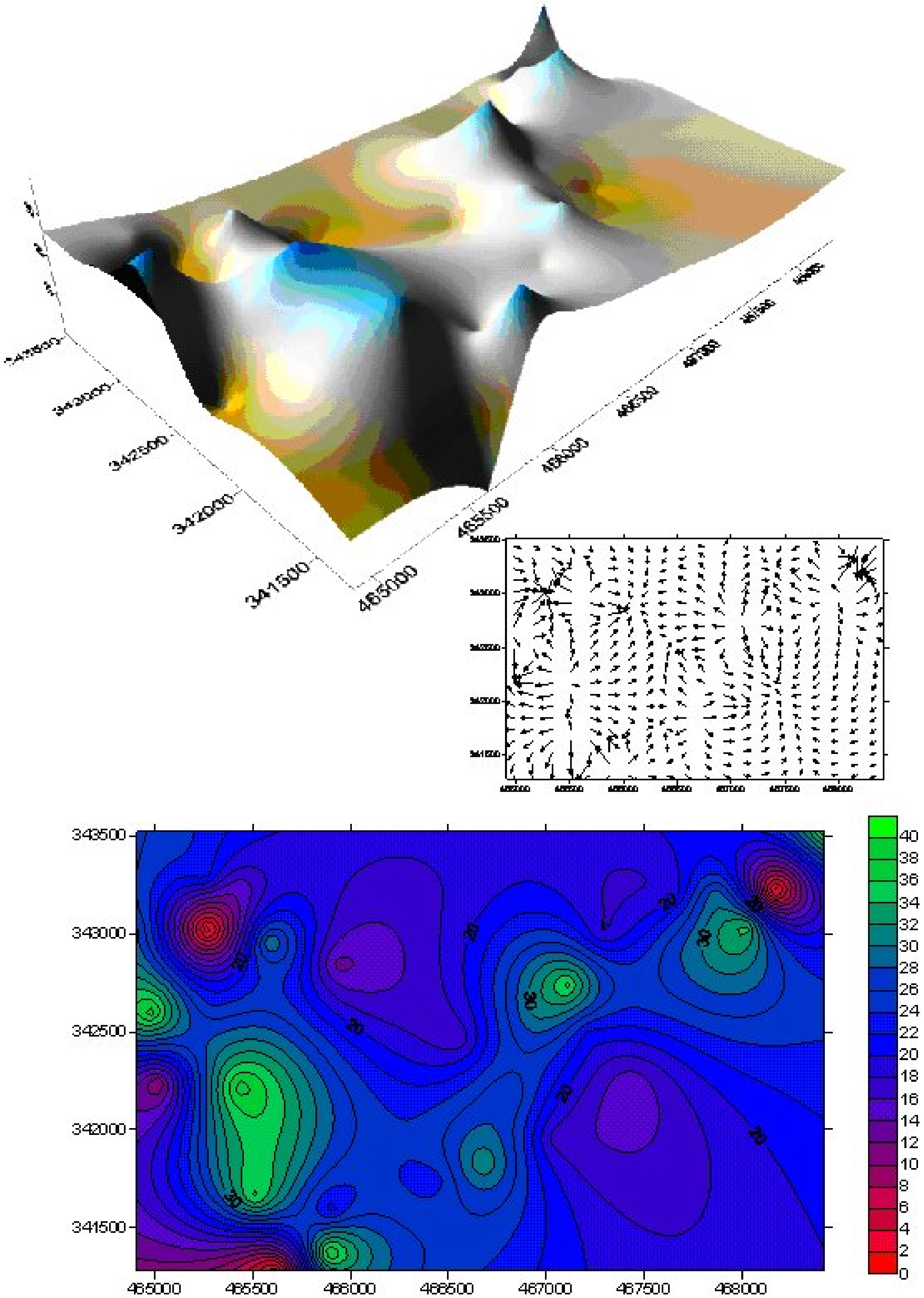


Fig 6.7 Oversize content at Shelford

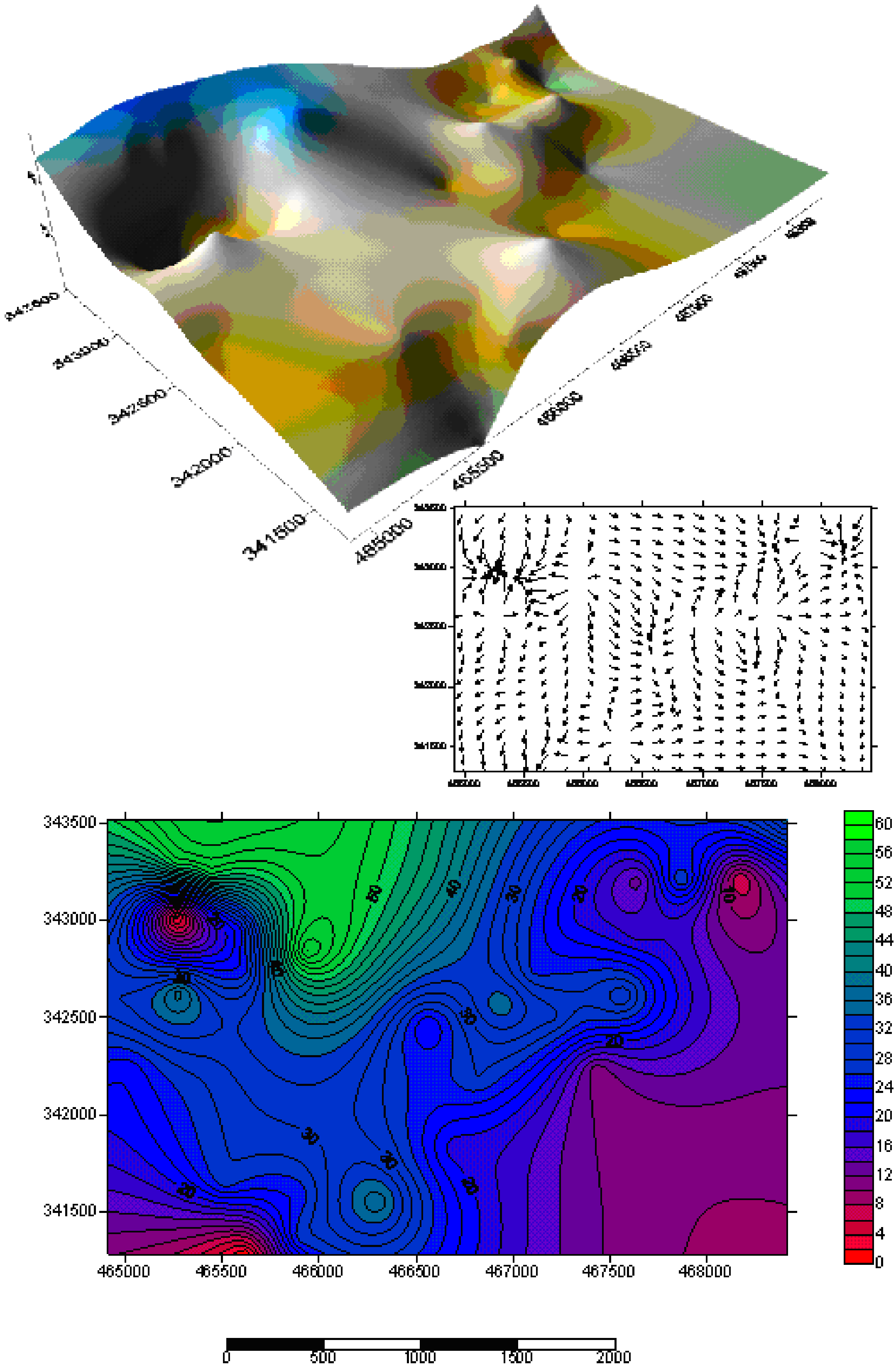


Fig 6.8 Gravel content at Shelford

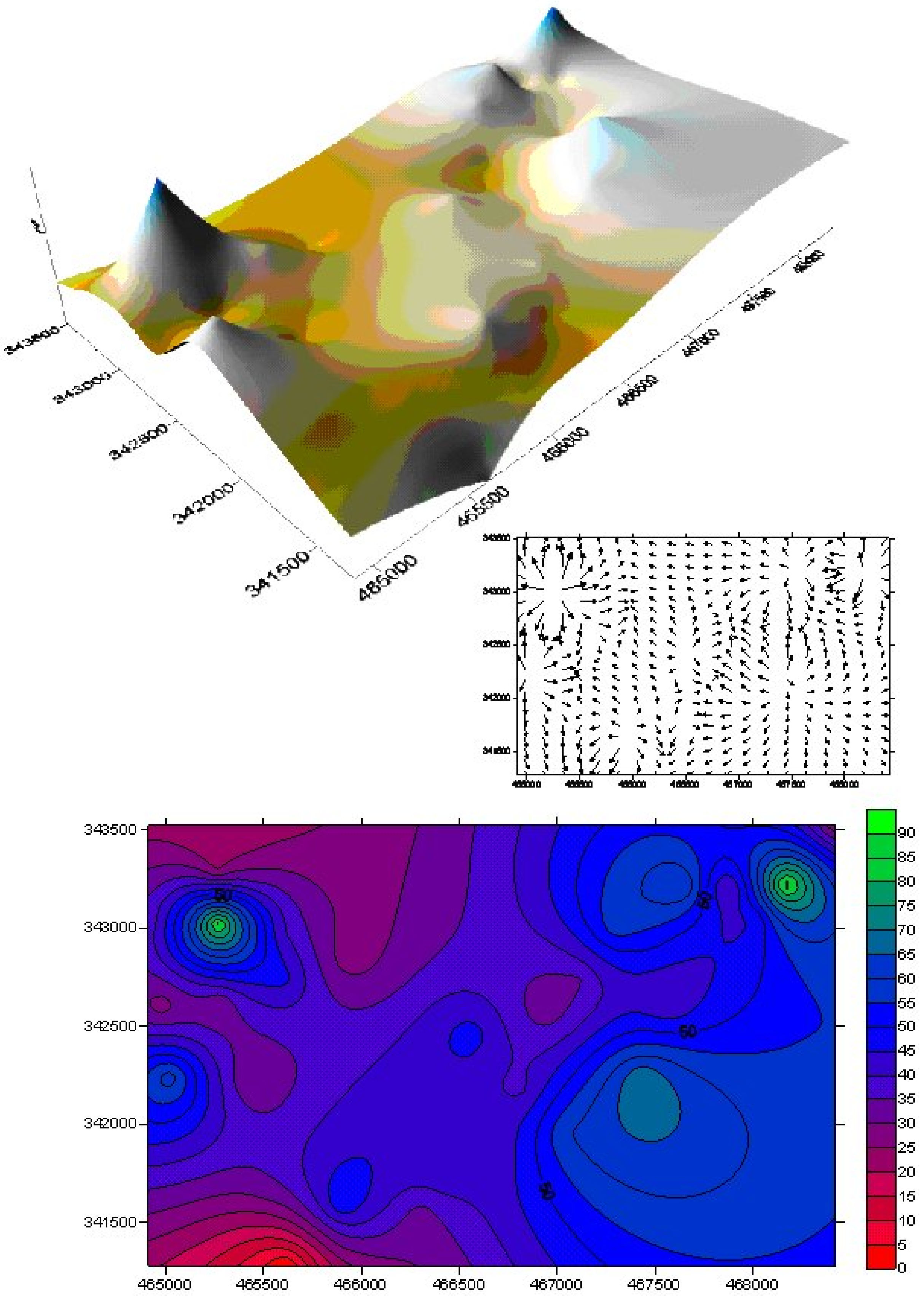


Fig 6.9 Sand content at Shelford

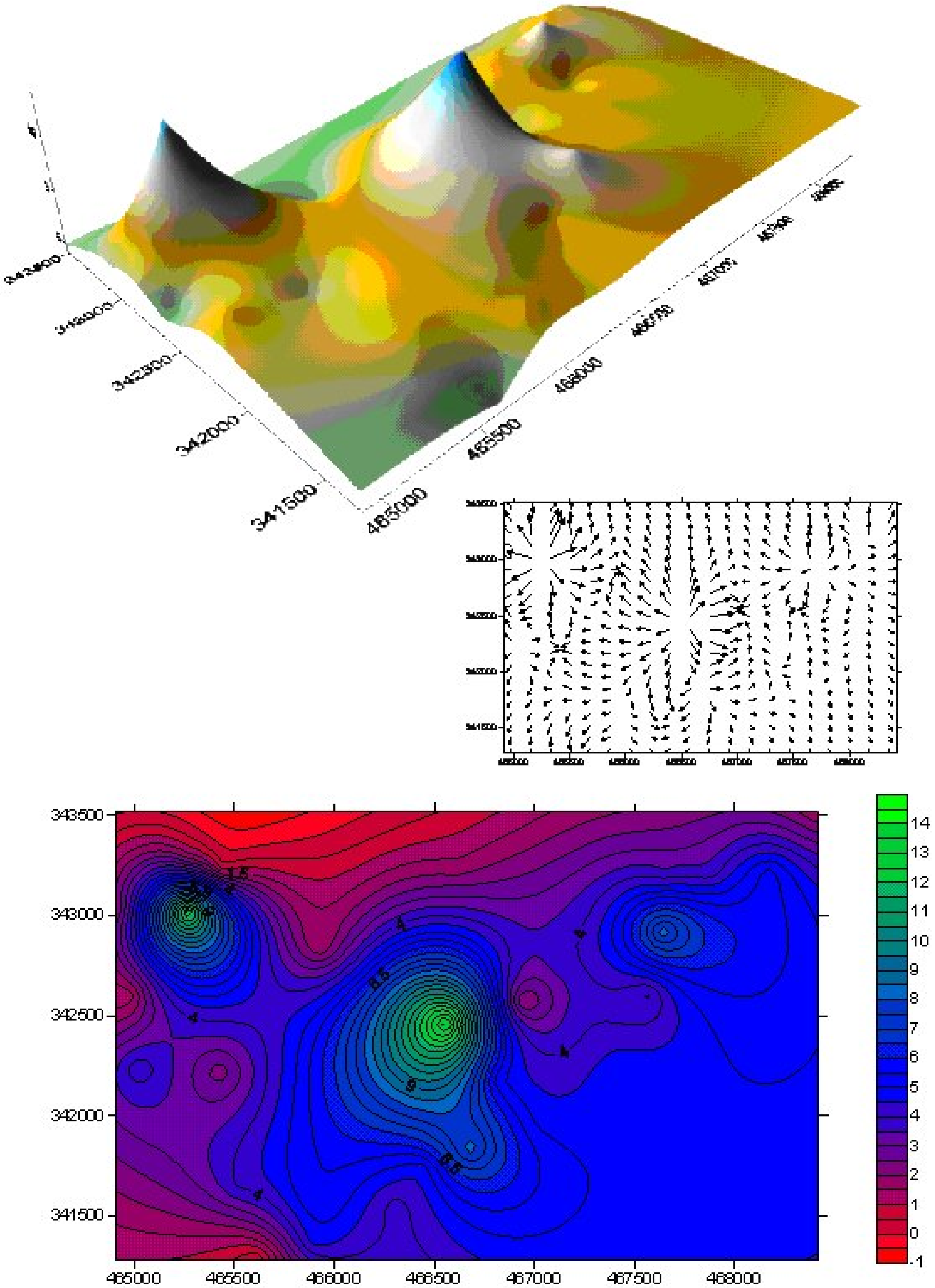


Fig 6.10 Fines content at Shelford

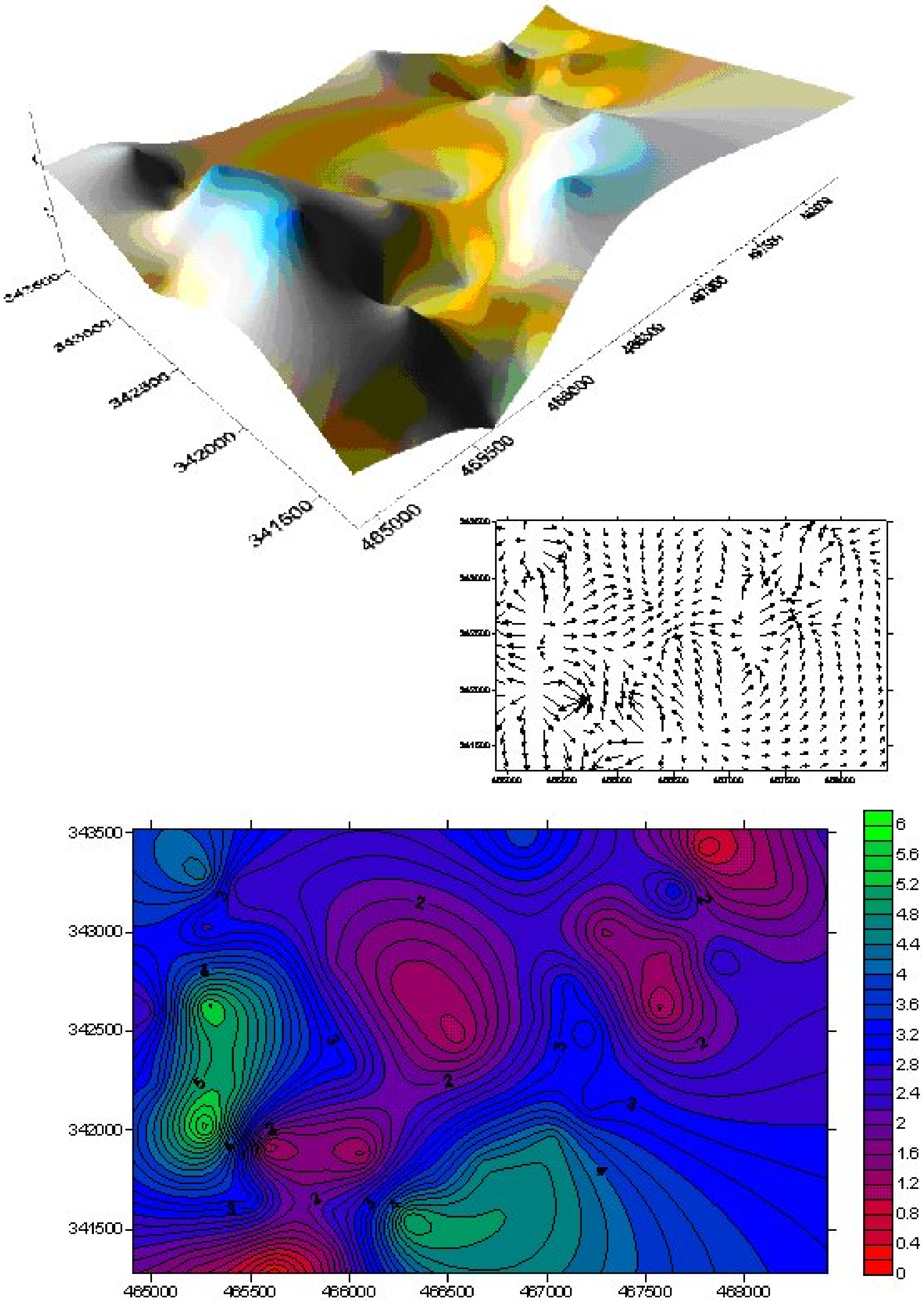


Fig 6.11 Mineral thickness (m) at Shelford

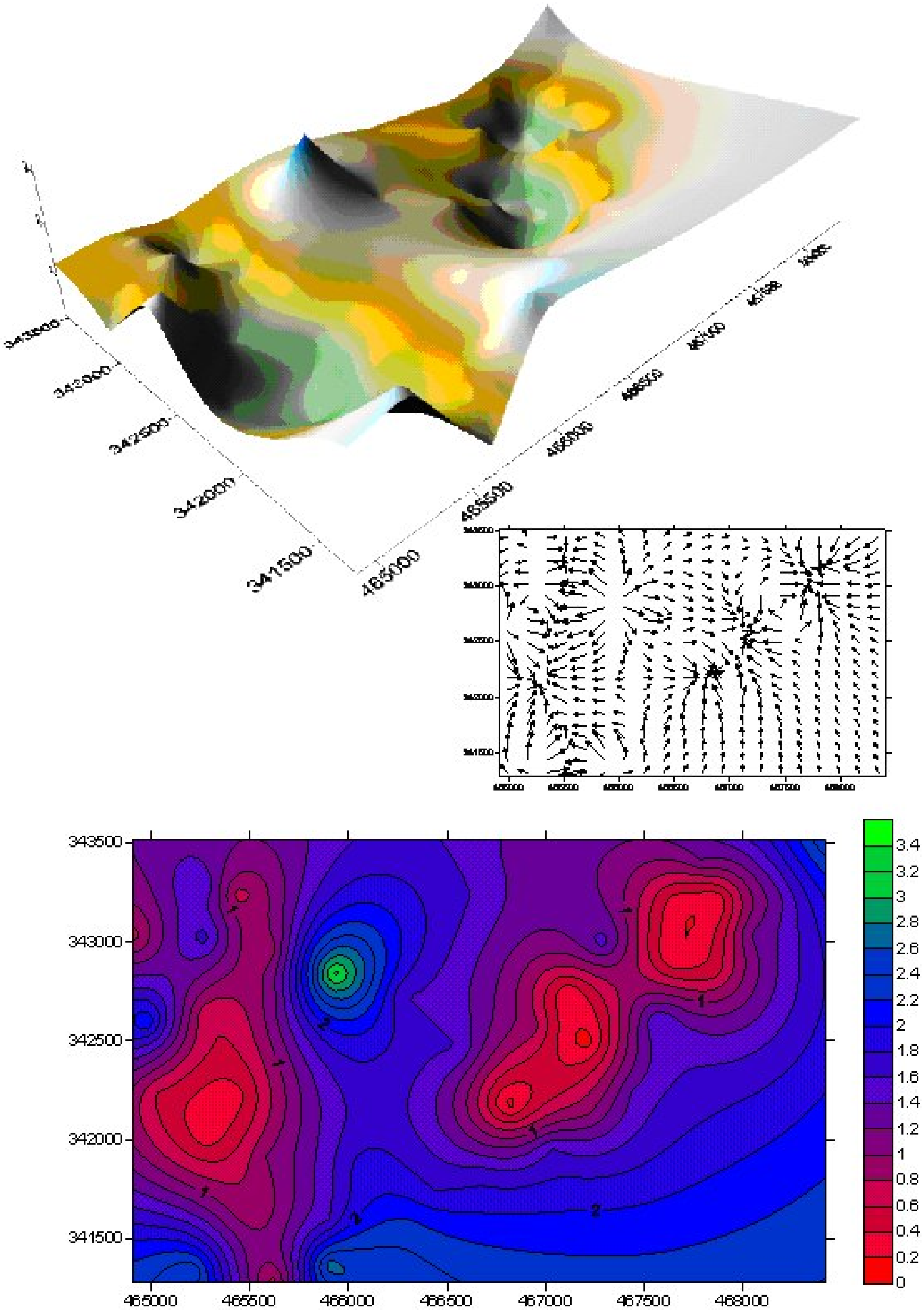


Fig 6.12 Overburden thickness(m) at Shelford

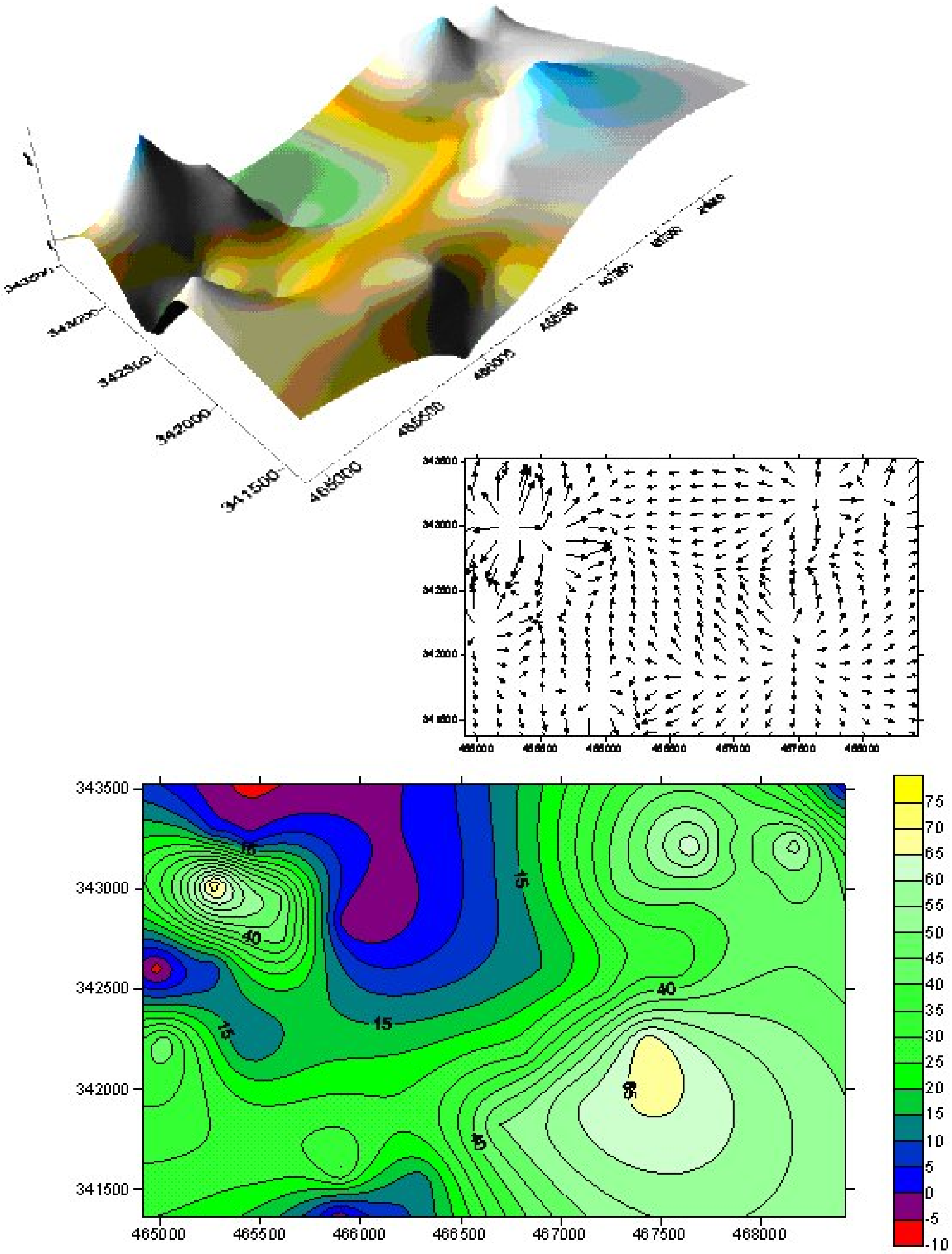


Fig 6.13 CLPV plots for EU product specification CP at Shelford

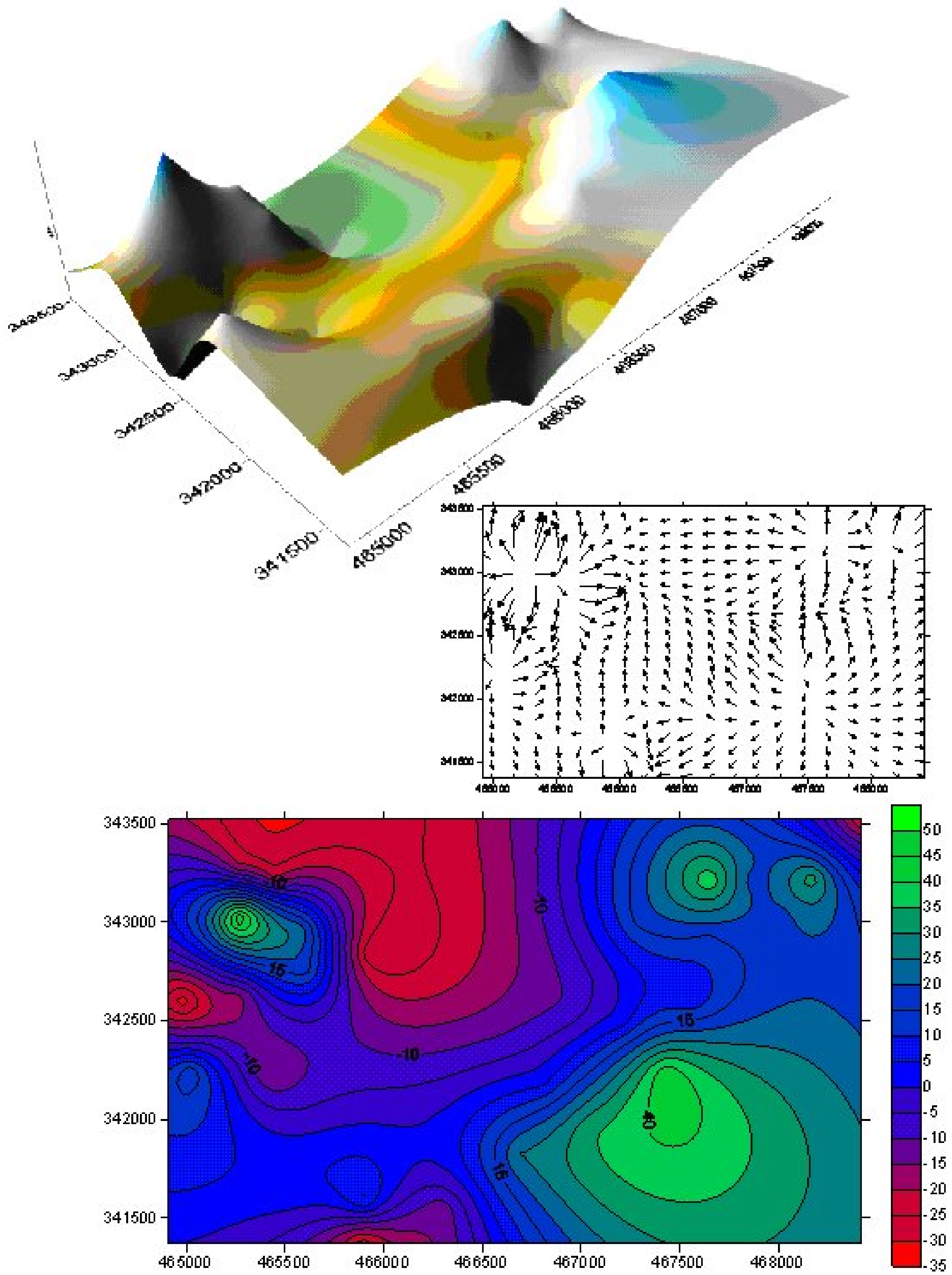


Fig 6.14 CLPV plots for EU product specification MP at Shelford

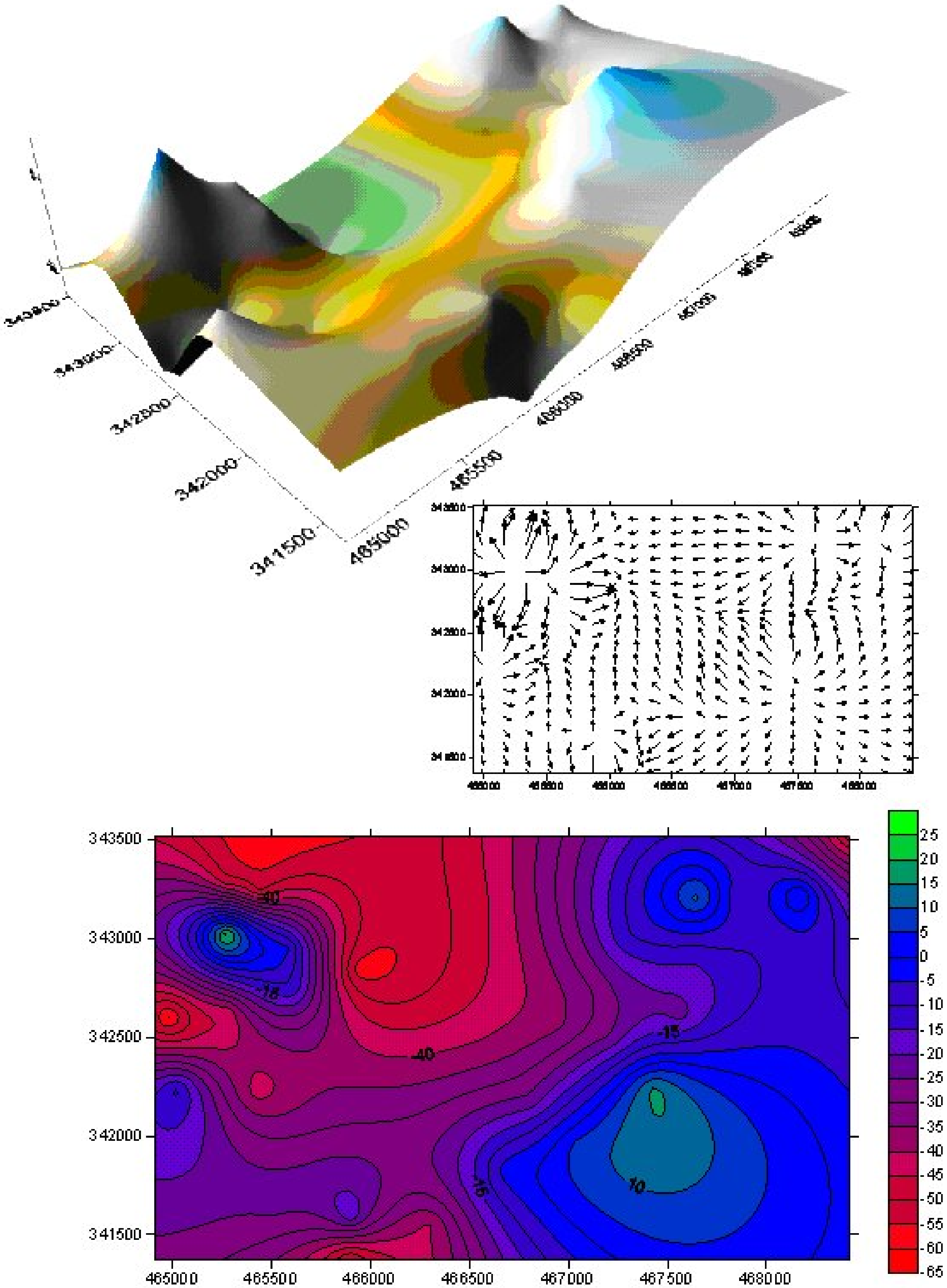


Fig 6.15 CLPV plots for EU product specification FP at Shelford

The different scale of the areas covered by the boreholes and geophysics makes direct comparison between the two surveys difficult in this case study. In a more localised borehole survey these data could be correlated to assess the use of the geophysical data as a support to deposit modelling and its additional impacts on the evaluation process.

The oversize, gravel, sand and fines plans show the required antipathetic relationship of percentage components. The centre-line proximity values for the coarse, medium and fine sand products clearly shows that the bulk of the site can most easily produce the EU MP medium grained product as suggested in the Brett report however this is spatially varied and the south-eastern part of the deposit is a better match to produce finer sand, probably representing the finer marginal or overbank deposits. (NB. Care must be taken on plots of this type to ensure interpretations are not influenced by edge effects in the contouring).

6.5 Benefit of whole site geophysical and remotely sensed data to mineral assessments

The available borehole data did not permit a rigorous evaluation of the benefits of the whole site geophysical and integrated multi dataset approach, however the Mineral Assessment survey did suggest particular advantages and areas for future development. Specific benefits that could be envisaged, or have been demonstrated include:

1. Use geophysics to provide better correlation between boreholes.
2. Better assessment of overburden and bedrock variability allowing improved modelling of deposit geometry. Similarly it is possible in some circumstances to derive improved assessment of deposit quality (particularly clay & fines) between borehole sites.
3. Use of geophysical data as an independent assessor of deposit variability.
4. Potential to redeploy drilling from systematic grids to target boreholes for ground truthing of geophysical surveys and closely spaced holes for geostatistical assessments.
5. Reduction in drilling costs & ground damage. Aids pre-drilling services search
6. Evaluate archaeological assets across the whole site thus reducing excavation costs by focussing on identified areas only.
7. Use deposit modelling techniques and quality maps to illustrate spatial variation in ability to produce specific products allowing better extraction planning. Allows better site planning, minimizing waste production and maximising resource recovery. One negative side of the recommended approach is that if the geophysical data permitted fewer holes to be drilled, the grading data on which accurate quality maps could be constructed would also decrease.
8. Use geostatistical methods to indicate sufficiency of drilling, support for reserve declaration and integration of remote sensing, geophysical and drilling interpretations.
9. Better data visualisation and presentation in support of planning applications.

Specific aspects of the deposit modelling process to develop:

1. Feather edges of deposit

Point data in the form of boreholes is poor at defining the edges of deposits. In many fluvial deposits these are 'feather-edges ' of thin mineral and the position is determined by either topographic contours or interpreted as midway between barren and mineral bearing holes around the periphery of the deposit. At the Shelford site the deposit edge is defined by a steep paleoslope or cliff line to the southeast. Mineral thicknesses and therefore deposit volumes are significantly affected by the accurate definition of this buried bedrock feature. The geophysical data provides a much improved method of locating this continuously across the site and therefore can contribute to more accurate resource estimation. The use of 3D deposit modelling as compiled for this site by the BGS in its Sustainable Soils Programme would also allow this to be incorporated volumetrically at an early stage of the site investigation and allow some limited ground truthing drilling around the periphery of the deposit as opposed to stepping out in a grid pattern and then interpreting the boundaries. The data requirements for such a model are however significant and a means to compile this from limited drilling and surface geophysical coverage currently seems the most cost-effective approach.

2. Overburden and bedrock variation

Where response contrasts are present the continuous data coverage of the geophysical survey provides much higher resolution on bedrock or overburden variability. Unfortunately these still usually need 'calibration drilling' to assess the causes of the different responses and attempt to quantify them in terms of deposit geometry. The use of Lidar and hyperspectral data has the potential to develop a much better view of floodplain deposits based on variation in water contents, minor topographic features vegetation and soil types. The project generated excellent ATM & LIDAR imagery over the detailed study area, but additional imagery covering the broader Shelford site was unfortunately not available for this study. A brief review of this however demonstrates the potential to visualise a range of geological and geomorphological features that would greatly assist the interpretation of broader borehole and geophysical datasets.

3. Discriminating gravel from sand rich areas

The ability of geophysics to delimit deposit grainsize is limited and mainly operates through variation in porosity, density or pore fluid composition. This is a major area for further work to assess its potential to become a predictor of grainsize in materials of similar bulk mineralogical composition. As discussed above the remotely sensed hyperspectral and Lidar data provides the potential to improve discrimination in this area as well.

4. Silt and clay content

Conductivity & resistivity methods should present a means to allow the quality of the deposit in terms of its fines proportion to be assessed. The difficulty rests in isolating these responses from those of water content, and bulk rock composition. Although grain sizes may be similar the response of clays as opposed to silts is very different. The development of work to discriminate the response from these two materials will be of great help if EM systems are to give as good results as can sometimes be achieved by resistivity methods. These are commercially significant elements of a deposit and can cause important technical as well as financial challenges when working a deposit.

5. Overall quality variability

The assessment of deposit variability is an important part of the site appraisal. Current industry practice is usually restricted to compiling sections where discrete and correlatable horizons of different quality can be identified. The quantification of variability is however rarely attempted. For this study the use of geostatistics gave a measure of deposit variability and could be used as the financial justification for additional or more targeted drilling.

6. Improved correlation between boreholes
Given the different scales over which the surveys were undertaken only 5 holes (BH 7,8,9,11,13) are either within, or in reasonable proximity to, the area covered in detail by the geophysical survey. The EM data is also a bulk average of the sampled depth so immediate correlation between holes is difficult to ascertain. Three of the holes are in areas of contrasting EM responses but the correlations with specific mineral thickness, overburden thickness and bedrock depth is unclear. Clearly a larger number of borehole sites are needed to establish the controlling factors on the EM31 response. High quality resistivity sections can improve correlation as demonstrated in the WARM-IT deposit studies at Bulls Lodge Quarry.

The actions and decision making processes involved in a typical site assessment have been developed into a flowsheet. A parallel flowsheet illustrating the proposed process, involving wholesite geophysics and multi dataset integration, evaluated in this project has also been compiled with indications of the potential benefits (Fig 10.1 &10.2). What is needed to fully evaluate this approach is a rigorous cost-benefit analysis based on a real site assessment.

7 Case Study – Mineral and Archaeology relationships

7.1 Introduction

In addition to archaeological inferences, remote sensing (both satellite and airborne) and aerial photography (crop marks and landscape features) have also been extensively used to assist in the identification and delineation of geological features, which relate to the geological structure and thence mineral resource potential of a particular site (i.e. Gupta, 2003).

The Trent Valley is one of the major sources of sand and gravel in the UK and since the publication in 1960 of the seminal survey of the English river gravels, *A Matter of Time,* has been recognised as an area with significant archaeological remains preserved in rich aggregates resources (RCHME 1960, 12-15, 37-42, fig. 5; *e.g.* Plate 4c; see also Whimster 1989). This is especially evident in the middle reaches of the valley on the low sand and gravel islands that protrude, as at Shelford, above the broad alluvial floodplain of the Trent. Many of these terraces display from the air dense palimpsests of cropmarks indicative of a long history of human exploitation of this riverine environment. The elongated sand and gravel island occupying the northern part of the Shelford study area displays a particularly impressive range of cropmarks, which it is suggested below probably relate principally to later prehistoric and Romano-British activity (Chapter 8). Scatters of prehistoric lithic artefacts (Notts HER: L8244) would support the case for prehistoric activity on this gravel island, although in the absence of excavation none of the recorded features may be precisely dated. Post-Roman activity is attested by the discovery of Saxon fired clay loomweights and pottery at Granby house, Shelford (Notts HER: L1804). Away from the village of Shelford, extensive ridge and furrow surviving as low earthworks on the eastern outskirts of the village and elsewhere recorded as cropmarks, soilmarks or linear magnetic anomalies, implies that much of the study area coincides with an area of open fields that were subsequently enclosed. A clearly defined annular cropmark with a cross in the centre (Chapter 8, Fig.8.9) may best be interpreted as the ground plan of a post-medieval or modern post-mill, with the central cross marking the foundations of the cross-trees, thus providing persuasive evidence that some cropmarks may relate to comparatively recent activity.

Within the spatial limits of the Shelford site, the following observations and correlations have been noted in respect of geological and geomorphological features that control the spatial extents, distribution and quality of the sand and gravel resource.

7.2 Investigation of Deposit Boundaries, Palaeolandscape and Associated Archaeological Features.

The northern and western limits of sand and gravel resource estimation as described by Brett, 2005 (on behalf of the Crown Estates) are bounded by clear geographical and operational features (the River Trent and the main A6097).

The southern limits for sand and gravel resource estimation at Shelford appear to be defined on the basis of pre-existing 1:50K geological maps (British Geological Survey, 1996 and Brett, 2005). The bounding line delineating this southern extent coincides with the generalised (at 1:50K) boundary of Quaternary Head deposits (poorly stratified clay or silt with abundant pebbles and rock fragments of late Anglian to Flandrian age) and local bedrock (Middle Triassic Mudstone of the Gunthorpe Formation [mudstone, red-brown] with indurated beds of green dolomitic siltstone). Additional data collected as a result of the BGS Shelford Project and FASTRAC (Chapter 3 of this report) have enabled this boundary to be better defined and characterised within the context of the palaeolandscape.

Automatic resistivity profiling (ARP) undertaken for BGS by Geocarta shows that a distinct feature consistent with a “cliff” occurs approximately 10 to 15M north of the Head-Bedrock boundary (Fig 7.1). This feature has been further resolved in ERT surveys (Fig 7.2 and Fig 7.3) undertaken by BGS and by the FASTRAC team to be a covered linear cliff approximately 3 to 5m high marking a distinct but previously unidentified boundary between the bedrock and sand and gravel deposits which extend north of this feature. The feature is also shown in GPR traverses undertaken by the BGS. However, the cliff line is less prominent as the GPR traverse appears to transect a ravine/collapse feature in the cliff line evident in electrically based EM and ARP surveys.

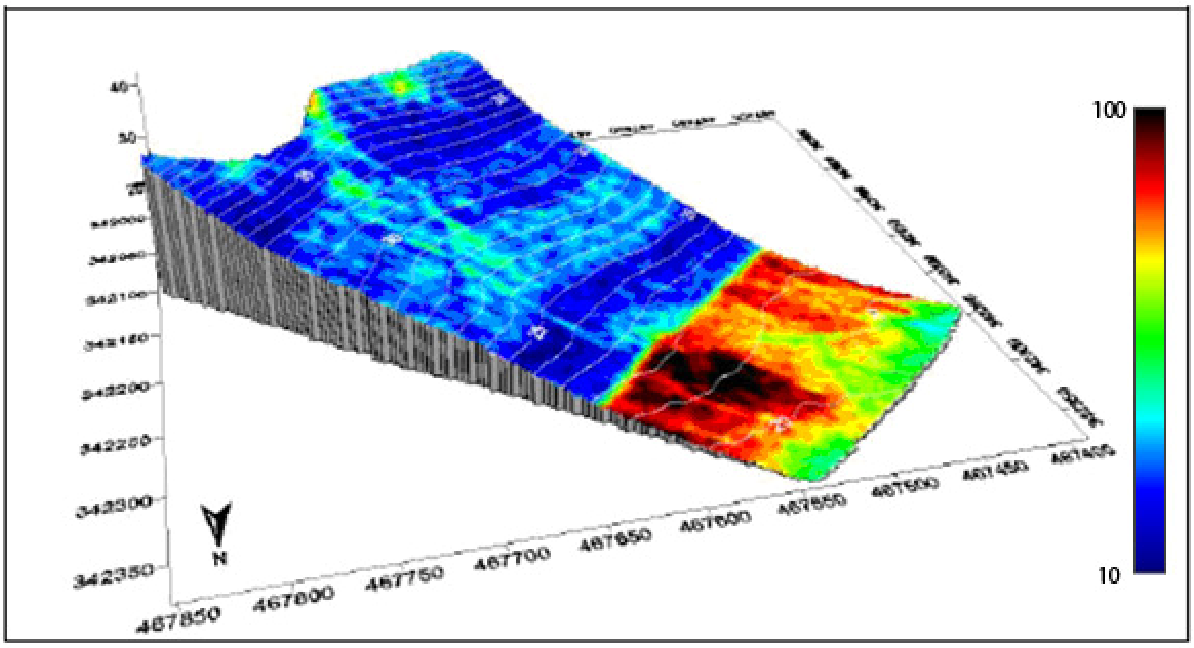


Figure 7.1: ARP image of linear feature associated with a buried cliff line, draped over DTM and referenced to British National Grid. Data represents resistivity model for 0 to 1.7m, Blue = 12 ohm.m to Black 100 ohm.m.

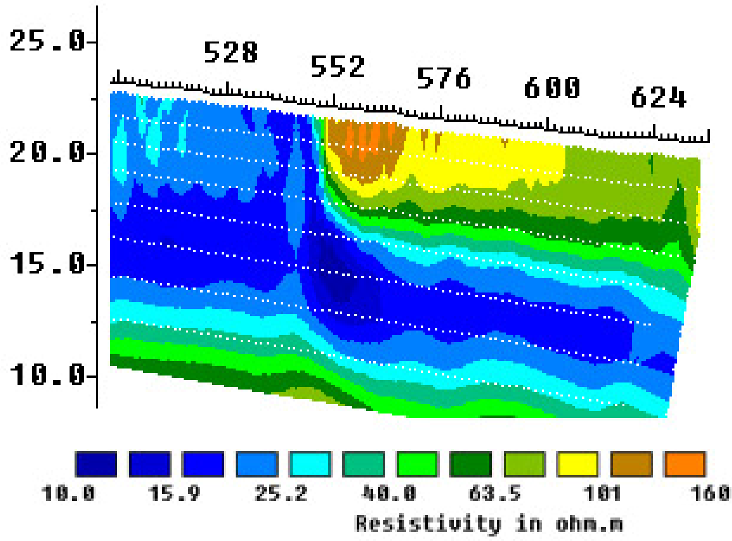


Figure 7.2: S-N trending ERT section across linear feature associated with a buried cliff line referenced to height above ordinance datum extracted from BGS ERT cross section 1-6.

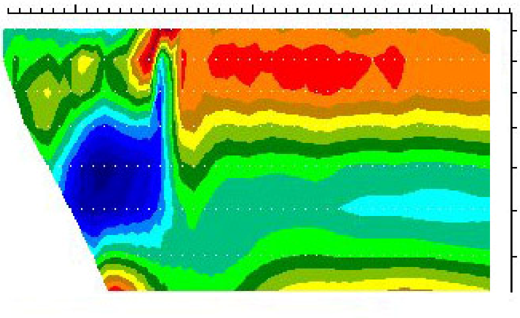


Figure 7.3: S-N trending ERT section across linear feature associated with a buried cliff line referenced to height above ordnance datum extracted from FASTRAC ERT cross section R2. Colour scale Blue = 20 ohm.m to Red 200 ohm.m.

Analysis of airborne thematic mapper (ATM) imagery for the Shelford site (Fig 7.4) clearly shows a linear feature coincident with this buried cliff line. The feature can be identified in all spectral bands of the ATM imagery but is most clear in a combination of bands 11 10 & 5, the former of which correspond to thermal energies (8.5-13; 2.08-2.35 and 0.63-0.69 microns respectively). The feature can be mapped for over 2km by using a combination of ATM images. It can also just be identified in high-resolution aerial photography of the site (Fig 7.5) taken at the same time of the ATM scene. A schematic diagram (Figure 7.6) summarizes this information and compares geophysical and remotely sensed data to ground truth data derived from a set of 5 boreholes commissioned by BGS to validate the presence of the cliff feature. The diagram demonstrates a clear spatial relationship between boundary features observed by geological investigation, ARP and ATM. Whilst it would have been impossible to have identified this cliff feature directly from ATM and airborne photography/cropmarks, the strength of integrating data from a variety of techniques is clearly demonstrated and would have provided a more accurate estimation of the southern boundary of sand and gravel resources at Shelford for the purposes of resource evaluation.

Figure 7.4: False colour composite of NERC ATM image (Bands 11(Red) 10(Green) & (Blue)) showing distinctive signature line of buried "cliff" feature emphasised by white spots over a distance of approximately 600m SW to NE.

Figure 7.5: Airborne photography from the same flight as Fig 7.4 showing signature line of buried "cliff" feature emphasised by white spots over a distance of approximately 1.5km corresponding to features identified in Figs 7.1 through 7.4.

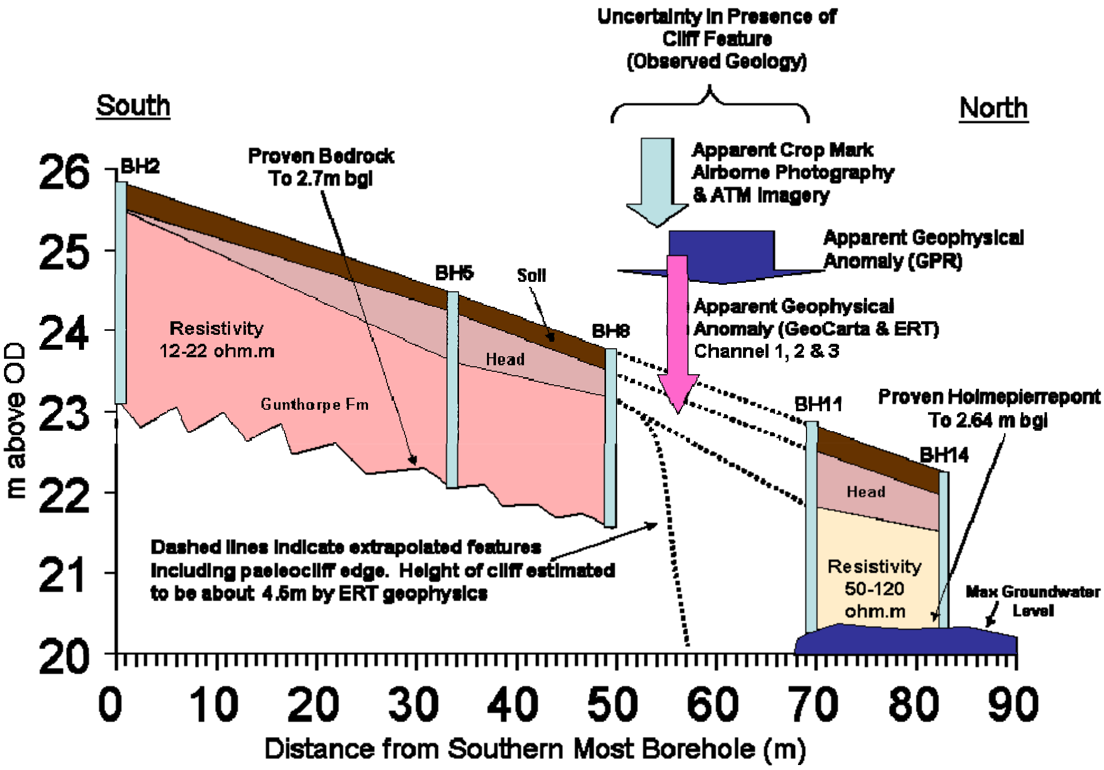


Figure 7.6: Schematic diagram comparing geophysical and remotely sensed data with borehole information collected from a north – south trending traverse across the apparent cliff feature. The width of each of the solid filled arrows indicates the uncertainty associated with the identified feature. Further work is scheduled to improve geological control of this feature.

The cliff feature would also have been a significant part of the area's palaeolandscape from the Late Devensian glacial maximum (27,000 to 20,000 ^{14}C BP). We may envisage mudstone cliffs that would have been smaller than those at Radcliff-on-Trent (upstream) and Gunthorpe (downstream) but of similar character. As well as providing a bounding feature, the cliff line offers potential opportunities for archaeological preservation and investigation in which material or animal remains washed off palaeosurfaces might have accumulated and been preserved. Such features would be consistent with electrically resistive anomalies observed to lie perpendicular to the main cliff feature in Fig 7.1. These anomalies, when viewed within the context of other datasets available to FASTRAC, might consequently be considered as indicating areas of moderately high prospectivity in respect of Palaeolithic remains.

A group of cropmarks to the South of this cliff feature (468000, 342600) are unusual in that they are directly occurring over the mudstone. However, these cropmarks are occurring directly over a series of mapped skerry bands (indurated beds of green dolomitic siltstone), which tend to weather to form sandier soils than the mudstone. These soils are mapped at Shelford as being stagnogleyic argillic brown earths (Wf) which are both sandier and more permeable than the more abundant argillic palaeosols of the Worcester soil series (wM) that have formed over the mudstone slopes at Shelford. In addition, these relatively hard skerry bands tend to form bench-like features in the landscape, which might prove attractive for habitation due to the existence of a readily formed platform and locally available stone.

[ATM data based on mission 95/9 (file c177101b.hdf) flown on 25/06/1996 by NERC Airborne Research and Survey Facility (ARSF). Data are provided courtesy of the Natural Environment Research Council, through the NERC Earth Observation Data Centre (NEODC)]

[High resolution Airborne Photography based on mission 95/9 flown on 25/06/1996. Image identifier = 1997_05b_9177_1997-05-26. Data are provided courtesy of the Natural Environment Research Council, through the NERC Earth Observation Data Centre (NEODC)]

7.3 Investigation of Deposit Heterogeneity, Quality, Palaeo-landscape and Associated Archaeological Features.

ATM, LIDAR and airborne photography collated during FASTRAC allow the delineation of areas within the main alluvial environment (comprising of predominantly “first terrace” of “floodplain terrace” deposits of the Holme Pierrepont sand and gravel formation) that appear to be high, well-drained, agriculturally poor environments (for example Fig. 7.7). These features are consistent with well-drained lobe shaped sand and gravel bars attributable to an ‘anastomosing’ or ‘braided’ river channel system (Fig. 7.8). In such systems, longitudinally orientated raised gravel bars are commonly separated by more finely graded but compositionally similar material overlain by finer silty deposits (Collinson, 1978) as observed across the Shelford site. The depositional environment of the Holme Pierrepont formation differs considerably from that of the more modern alluvial sediments lying immediately west and to the north of the Shelford field site. These sediments being deposited by a relatively sluggish meandering river system characterised by point bar structures and associated backwater environments (Allen, 1970 and Carney and Napier, 2005).

There is some evidence from borehole data that the presence of highly resistant skerry beds (a very fine-grained, dolomitic sandstone) within the mudstone may have played a role in defining the course of the present River Trent. For example, the weir at Gunthorpe less than 1km downstream from Shelford was built upon a pre-existing skerry outcrop (Steve Mathers, BGS Pers Comm) and it is possible that similar structures within the river bed may have led to the development of a depositional environment with multiple river channels/braids.

The inter-bar structures commonly contain higher concentrations of clays and other fines in superficial layers may account for their apparently distinctive geophysical signature (decreased electrical resistivity) when compared to the main bar structures (Fig 7.7c). However, in some cases ERT surveys indicate that the geophysical anomaly extends right to the base of the deposit, potentially indicating a buried channel feature.

The higher ground as characterised by the sand and gravel bars closely correlates with cropmark complexes suggesting extensive activity predominantly in the later prehistoric and Romano-British periods (Fig 7.10 and 7.11 & refer to crop mark maps in other chapters) and with near-surface and subsurface geophysical surveys (Fig 7.7) which appear to extend to the full depth of the alluvial environment (supported by ERT, EM and ARP data). Neighbouring alluvial zones preserve comparatively little evidence of prehistoric or Roman

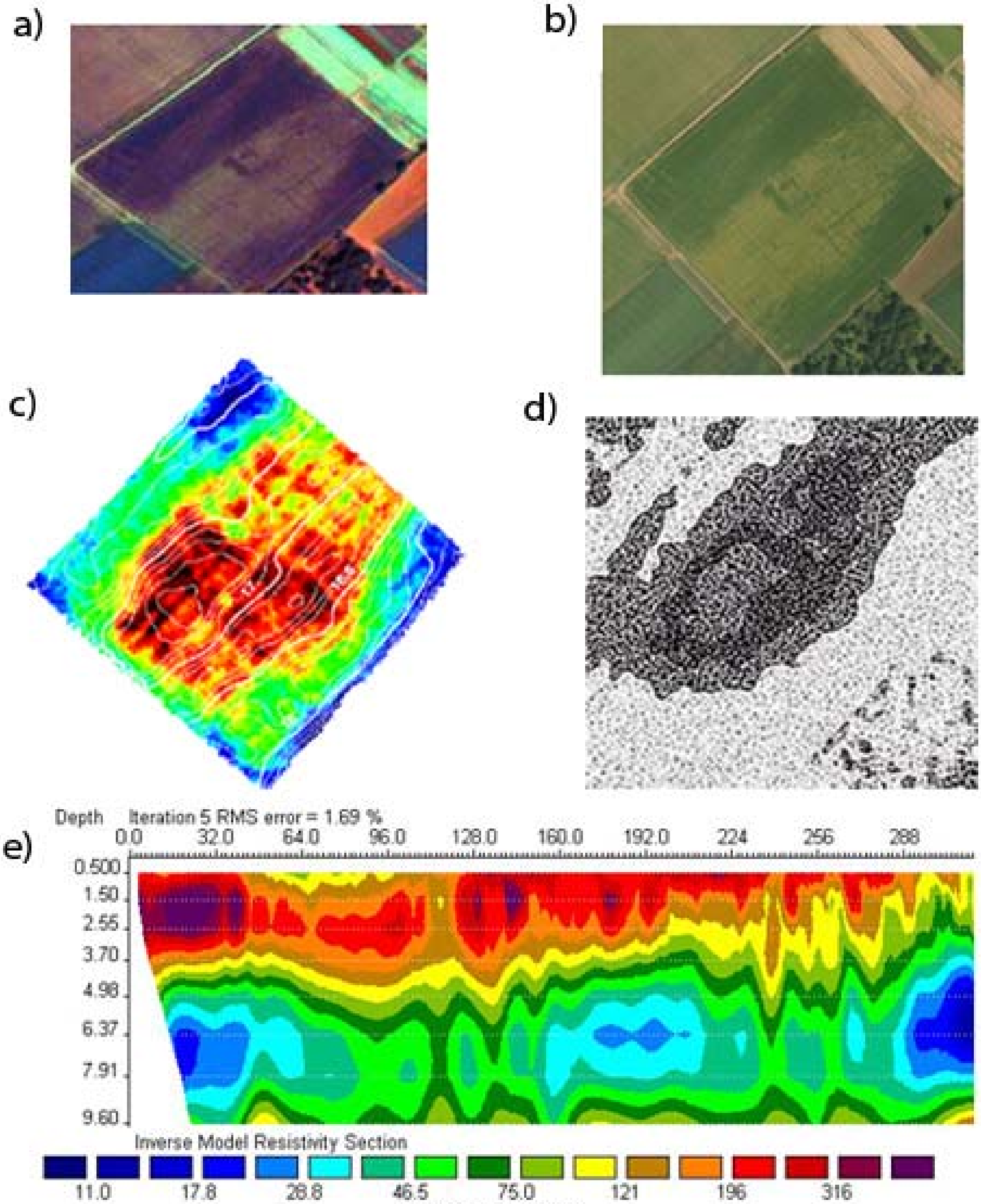


Figure 7.7: Collection of images showing example of sand and gravel point bar structure (approx 270m in length) just to the north of the Moor Close Plantation at Shelford. (a) ATM image bands as per Fig 7.4 clearly showing extent of structure; (b) High resolution aerial photography (as per image 7.5) showing poor crop yield of sandy well drained soil (undifferentiated Quarndon Soil Series); (c) ARP image showing continuity between observed photographic data and subsoil/alluvium resistivity (0 to 1m), blue correspond to 50 ohm.m whilst black corresponds to 300 ohm.m; (d) Digital terrain model (combination of Nextmap™ and EA LIDAR imagery, darker parts of the image represent higher topography) image showing raised nature of feature (approx 0.5m above surrounding field) and (e) ERT cross section through point bar feature show increased resistivity to a depth of approximately 3.5m BGL and then decreased resistivity consistent with Gunthorpe Formation bedrock. Groundwater level at the time this survey was undertaken was approximately 1m below surface.

Figure 7.8: Pictures of modern day active braided river systems (Dinali River, Alaska and Ngaruroro River, New Zealand) showing classic braded river and associated gravel bars. Such a system might be representative of that at Shelford 20,000 years BP. Pictures from drshellie.blogsome.com and www.alluviale.com.

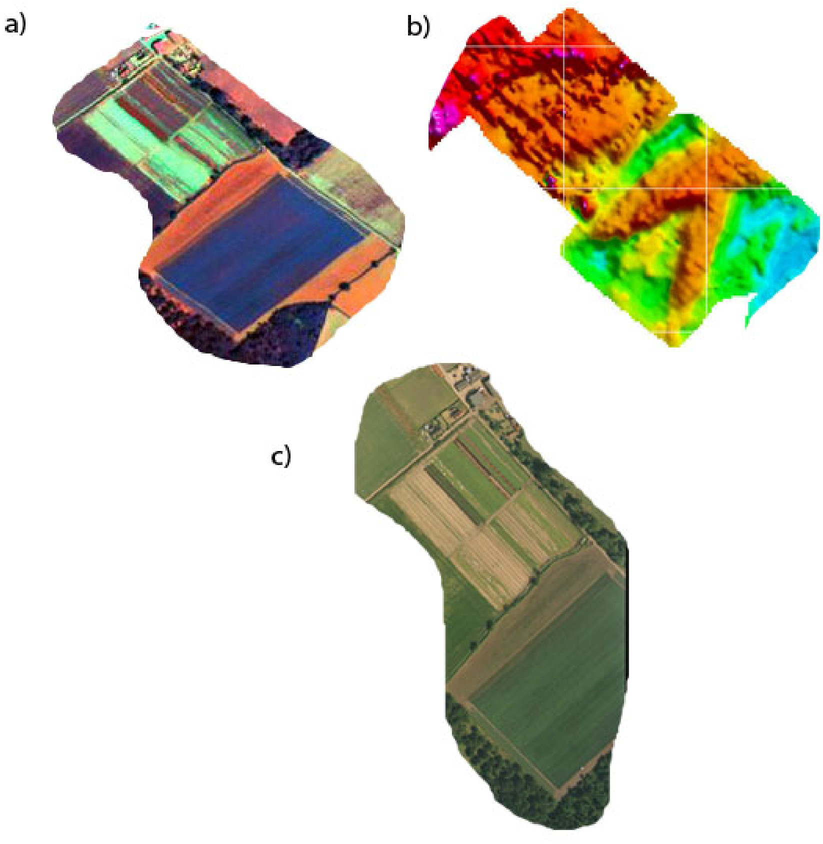


Figure 7.9: Schematic diagram comparing geophysical and remotely sensed data for two fields to the east of the Moor Close Plantation at Shelford demonstrating that the point bar structures evident from the EM31 geophysics (image b) are obscured by crop related signatures in both the ATM (image a) and optical photography (image c).

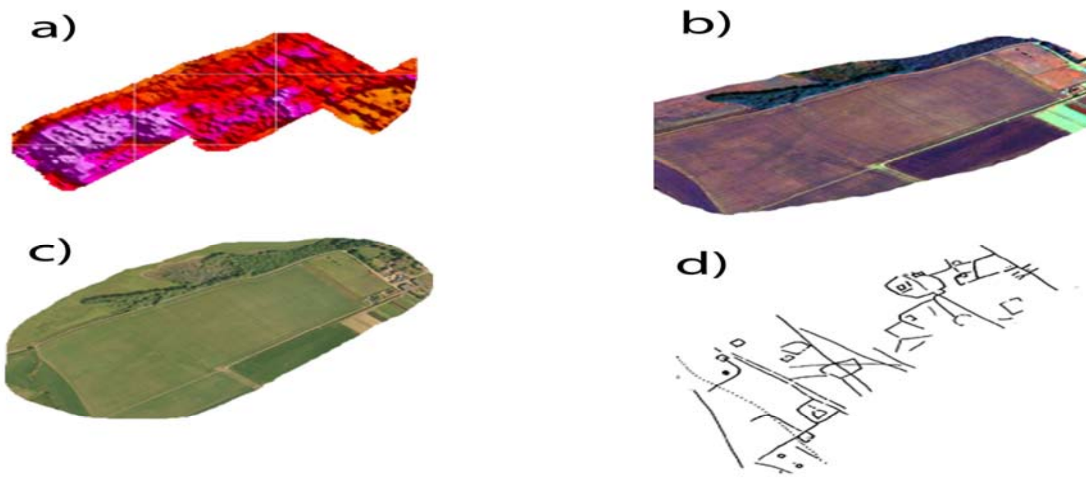


Figure 7.10: Schematic diagram comparing geophysical and remotely sensed data for the scheduled monument site at Shelford demonstrating poorly defined point-bar structures in the optical images (b) and (c) but clear structures in EM31 geophysics images. Image (d) represents cropmarks identified on this site for comparative purposes.

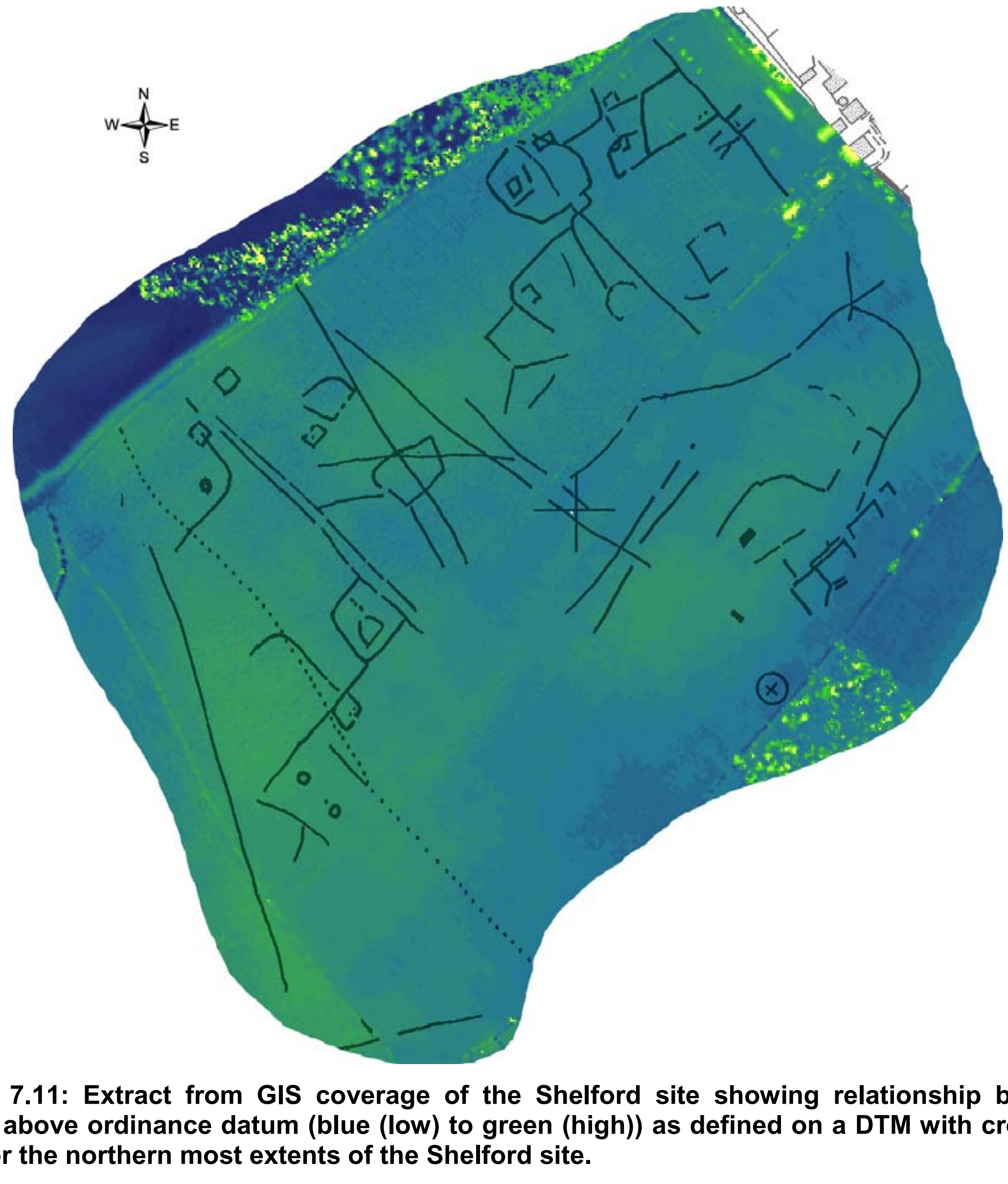


Figure 7.11: Extract from GIS coverage of the Shelford site showing relationship between height above ordinance datum (blue (low) to green (high)) as defined on a DTM with cropmark data for the northern most extents of the Shelford site.

activity, but this could signify only the sealing of archaeological features and deposits beneath later alluvium or such evidence being obscured by modern land use patterns. Equally, more recent, relatively thin head deposits (typically <1m in thickness Fig 7.12) recognised as covering the alluvium towards the southern extent of the floodplain terrace study area may also seal important and comparatively well preserved archaeological and palaeoenvironmental remains [note head deposits mapped at Shelford using the BGS 1995 mapping specification do not differentiate between slope foot deposits formed by runoff and creep, (McMillan and Powell, 1999)].

Figure 7.12: Picture of BGS borehole 26 just to the east of the Shelford site showing 4m of core trending from brown soil through approximately 1m of head into brown and then grey sands and gravels of the first terrace Holme Pierrepont deposits. Such head deposits represent a combination of down slope hill washing and creep postdating the deposition of the Holme Pierrepont alluvial material (probably for more than 10,000 years). More recent material could consequently be considered as covering evidence of crop marks whilst earlier material could preserve older artefacts and archaeological signatures.

The ability of spectroscopic methodologies (ATM and airborne photography) to define these gravel bar systems across the whole of the Shelford Research site appears however to be variable, in some cases apparently due to masking by vegetation cover. For example, fields shown in Fig 7.9 show no evidence of sand and gravel bar structures on the surface (images 7.9a and 7.9c) despite the presence of strong geophysical anomalies (7.9b). The partial masking of optical signatures is also apparent in the field protected by Ancient Monument status (Fig 7.10), which is associated with numerous crop mark features.

Whilst there is a strong circumstantial link between the observations made using geophysical and remote sensing and the heterogeneity and quality of the sand and gravel deposit at Shelford, there is currently insufficient evidence to correlate directly a numerical change in sand and gravel content and/or quality with a specific geophysical response. This situation emphasises the need for an iterative stage in field investigations where hypotheses developed on the basis of completed geophysical surveys and sedimentology can be further tested and validated by using an orientated sampling approach.

From the archaeological perspective, the identification of individual sand and gravel bars and our partial understanding of their sedimentalogical origin and compositions can assist in:

(a) Reinforcing our confidence that landscape topography within the site extents has been reasonably constant throughout its more recent occupation.

(b) Improving our understanding of the potential impact of dewatering on buried artefacts and the sensitivity of the environment to erosion pressures (i.e. by identifying a notable lack of alluvial peat).

(c) Identifying areas of preferential deposition and accumulation within the longer-term formation of the alluvial system (Late Devensian Glacial Maximum to present day).

All of these factors could be used to identify areas of pre-Romano British prospectivity within an investigated landscape such as Shelford and as baseline data from which to produce a more defined series of targeted higher resolution invasive investigations. Such investigations should also be aimed at improving the sedimentological understanding of identified features and dating of the site's depositional history.

7.4 Conclusions

Studies at Shelford have clearly demonstrated that use of remotely sensed data and geophysics can be used to improve the early assessment of sand and gravel deposits both from the perspective of resource potential and archaeological prospectivity. The benefits are increased, however, when such data are available and used in an integrated manner and as part of a tiered approach in which they can be used to focus the collection of more detailed information and to understand the sedimentological and archaeological evolution of similar sites.

From the perspective of resource estimation, the main limitation to its use is that it is difficult to interpret grade and quality information without a degree of site-specific ground-truthing. However, the combined use of remote sensing, terrain analysis and geophysics can assist in the identification and interpolation of distinct features, such as unmapped deposit boundaries (at 1:10,000 or 1:50,000 scales), at an early stage in the site investigation process.

The collation, integration and often first-order assessment of remotely sensed and geophysical data such as that collected in the Shelford Survey also clearly illustrates the potential of these techniques and methodologies to inform the development of archaeologically orientated assessments of both artefact potential and preservation status. However, no one technique provides every answer, even on a reasonably well-constrained site such as Shelford, and the project has clearly demonstrated that the power of such techniques is only fully realised by their integration in a GIS environment.

8 Comparison of Methods for locating Archaeological Features - Shelford.

8.1 Introduction

Attention is focussed in this chapter upon the correlation between the results of a magnetometer survey on the low terrace of Holme Pierrepont Sand and Gravel that extends south-westwards from Shelford Manor towards Shelford village (Figs 8.1 - 8.2), the cropmark evidence revealed on air photographs of this area (Fig 8.4), and the evidence from Lidar and hyperspectral surveys (Figs. 8.12 - 8.17). This provides a useful measure of the effectiveness of these techniques and has drawn attention to some significant discrepancies between magnetic anomalies and plots of cropmarks generated as part of the National Mapping Programme (NMP) and during updating of the cropmark record as part of this project to take account of recent aerial survey data (Figs 8.3 - 8.4). These discrepancies raise a number of issues regarding the fidelity of the cropmark data, which are explored in greater detail in subsequent sections of this chapter.

8.2 Magnetometer survey

The most extensive, high density magnetic coverage at Shelford was conducted with the English Heritage hand-operated caesium magnetometer cart system (Chapter 4, and Linford, forthcoming). This survey covered an area of over 8.5ha using a regularly spaced sample density of 0.125m x 0.5m and a positional accuracy on the ground of approximately $\pm$0.1m. The magnetic response of the site was found to be very good, with anomalies due to the buried enclosure ditches exceeding the background field strength by over 10nT. However, some more subtle anomalies were also detected that produced a response less than 1nT.

The results of the survey are presented as a greyscale image superimposed over the base Ordnance Survey mapping data in Fig. 8.1. In addition, a graphical summary of individually numbered anomalies **[#]** discussed in the following text is provided in Fig. 8.2.

A considerable degree of recent surface detritus was found over the site and this has led to a widespread scatter of intense “iron-spike” anomalies throughout the data. An immovable mechanical excavator was parked close to the NE corner of the survey area and this has also produced a degree of magnetic disturbance. Ferrous material is also evident along the fence-line bordering the road and the responses to passing vehicles have been successfully suppressed where these occurred in the data.

Surface cultivation patterns, due mainly to recent seeding to grass, have also been recorded by the survey and these are most evident as a series of continuous, linear anomalies following an approximate SW to NE alignment. Other modern features visible over the surface of the site have also been replicated in the magnetic data. These include the site of a temporary stabling block, deep vehicle ruts, a line of electric fence stanchions and the limit of the grassed area of the site before it gives way to the ploughed arable field to the south. A series of broad linear anomalies, most likely a ridge and furrow agricultural pattern, runs on a NW to SE alignment across the majority of the survey area. The magnitude of response of these anomalies varies and often appears to be increased in the immediate vicinity of other occupation activity, possibly due to the localised increased of magnetic susceptibility in these areas (*cf* Cole, 1995 #381, Fig. 1).

More significant ditch-type anomalies, apparently forming three large enclosures **[1]**, **[2]** and **[3]**, replicate the main detail found in the aerial photographic (AP) record to the N of the survey area. The largest of these **[1]** forms a polygonal enclosure with 6 sections of ditch visible in the magnetic data and contains a number of both pit-type and rectilinear anomalies that are also evident from the AP. One rectangular ditched enclosure **[4]** with dimensions of approximately 15m x 10m is replicated in the magnetic data from the AP, although a second

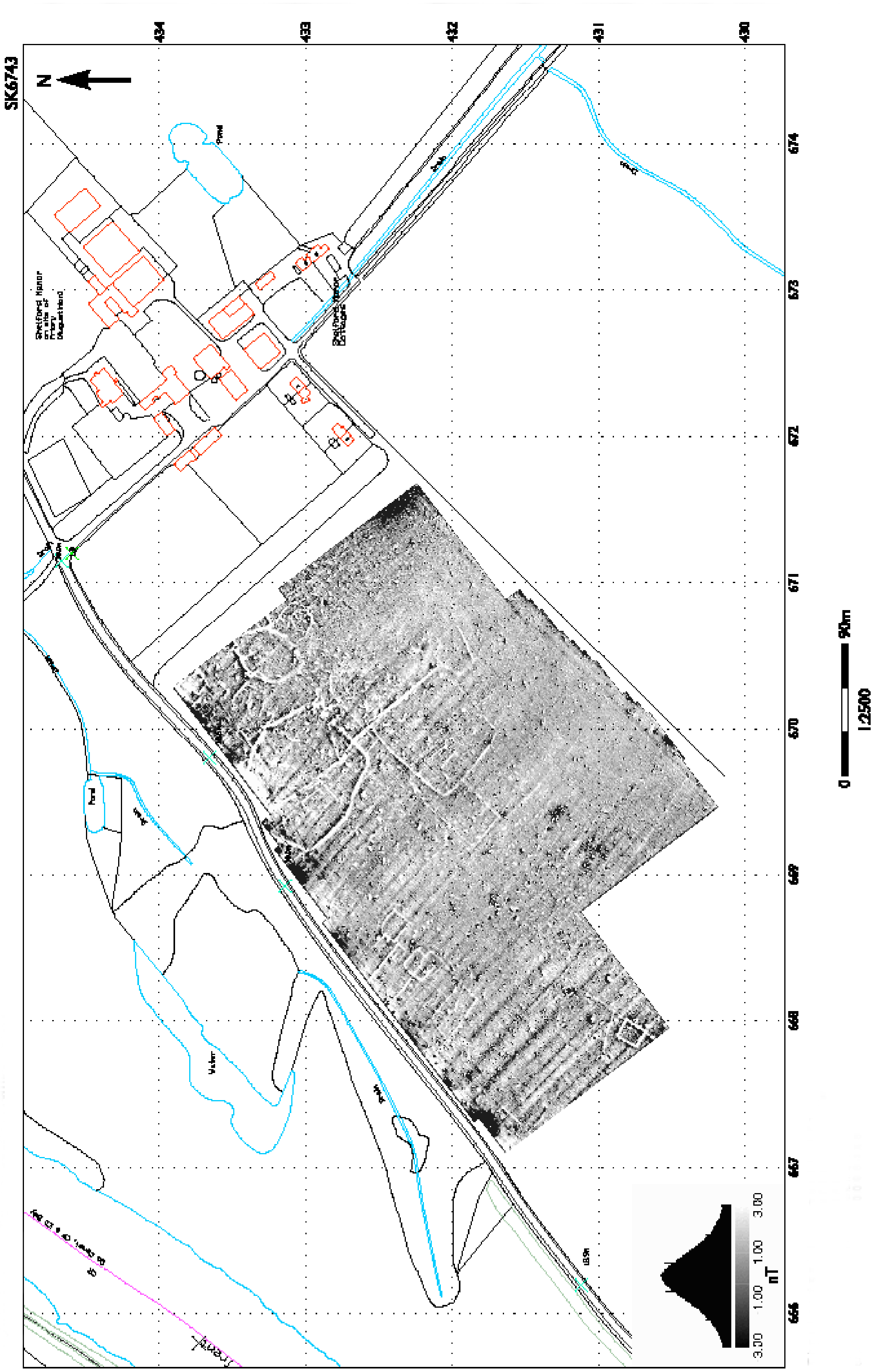


Fig 8.1. Shelford Manor, Nottinghamshire: magnetometer survey, October-November 2007

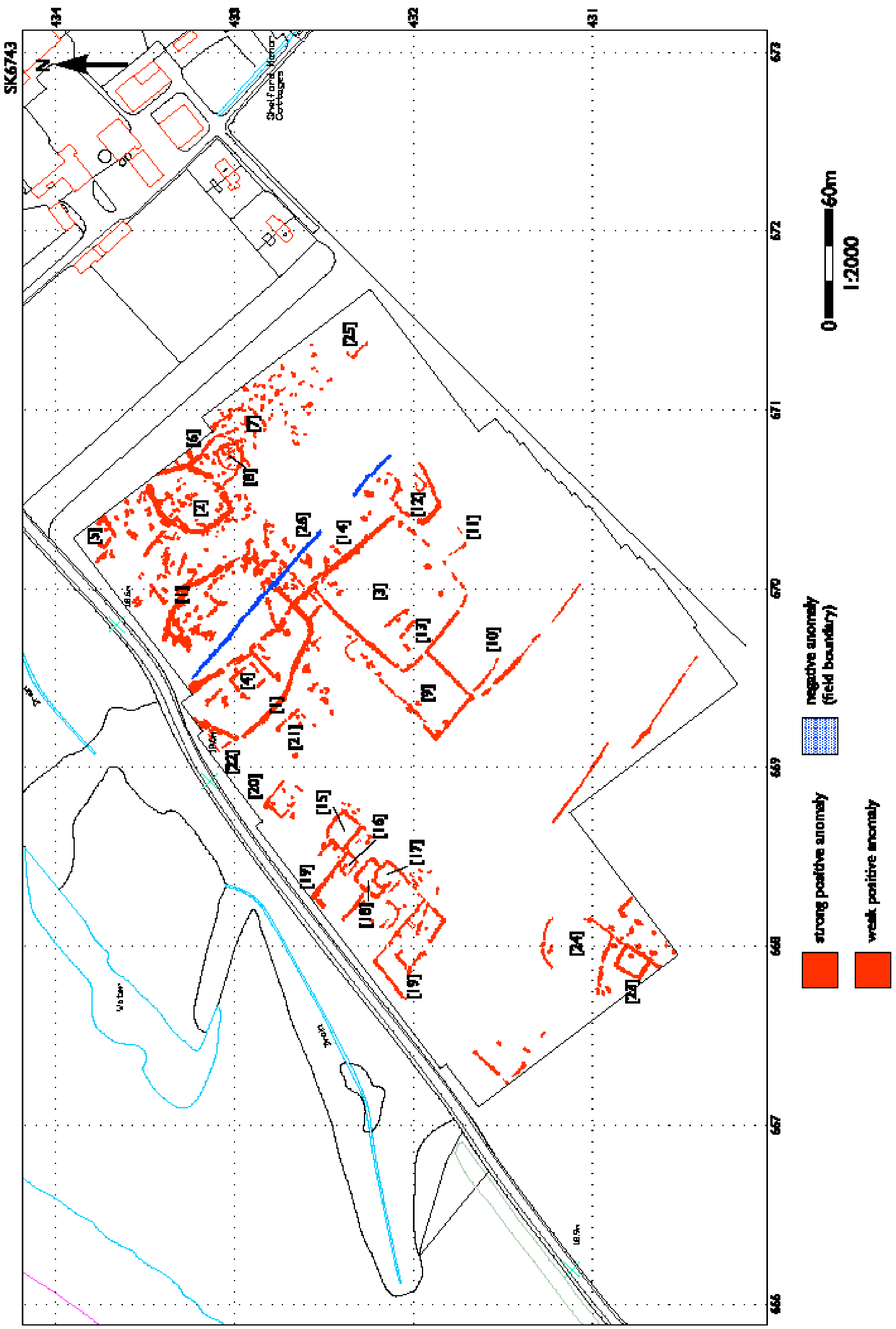


Fig 8.2. Shelford Manor, Nottinghamshire: graphical summary of significant magnetometer anomalies, October-November 2007

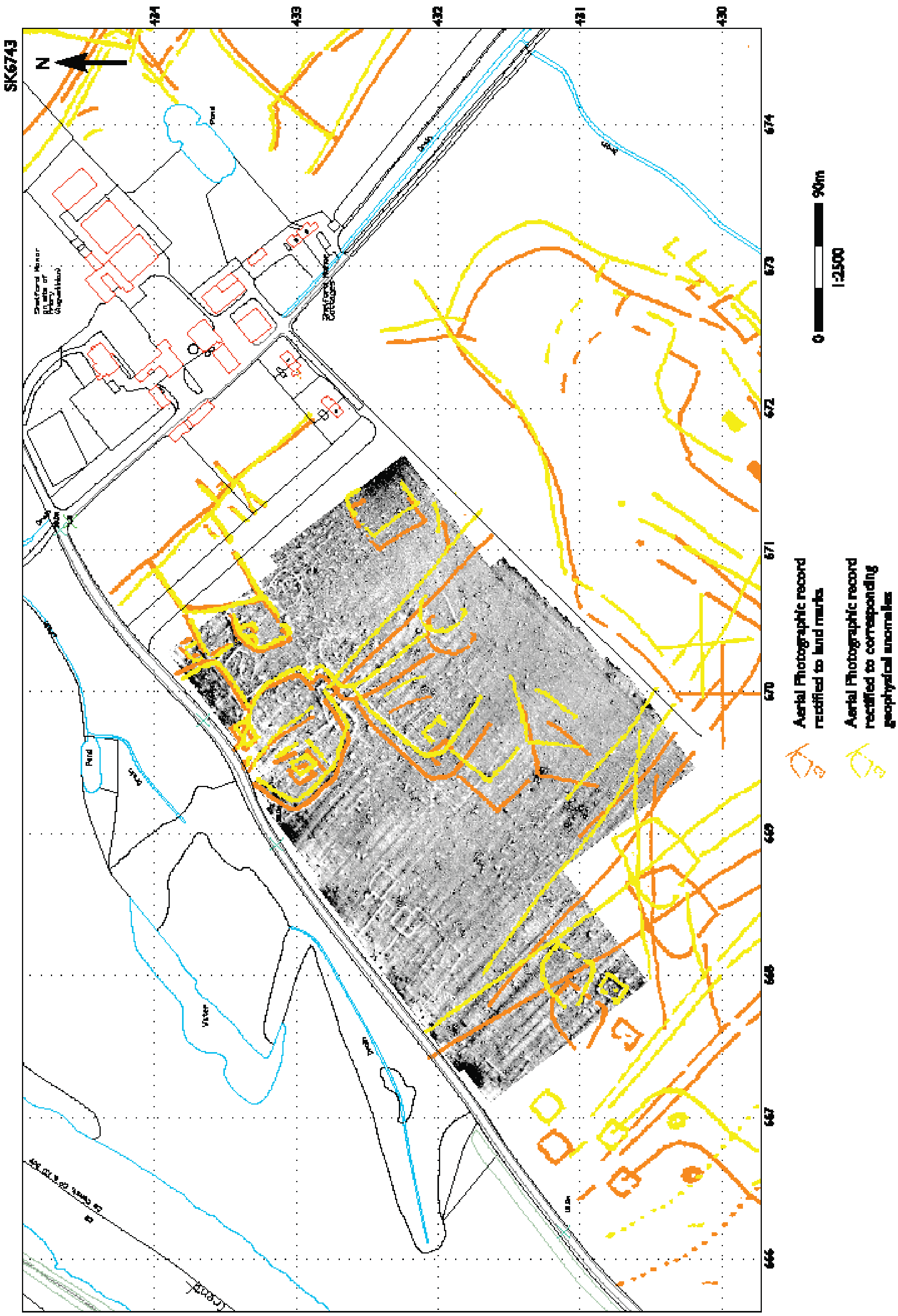


Fig 8.3. Shelford Manor, Nottinghamshire: NMP air photograph transcript superimposed over the magnetometer data

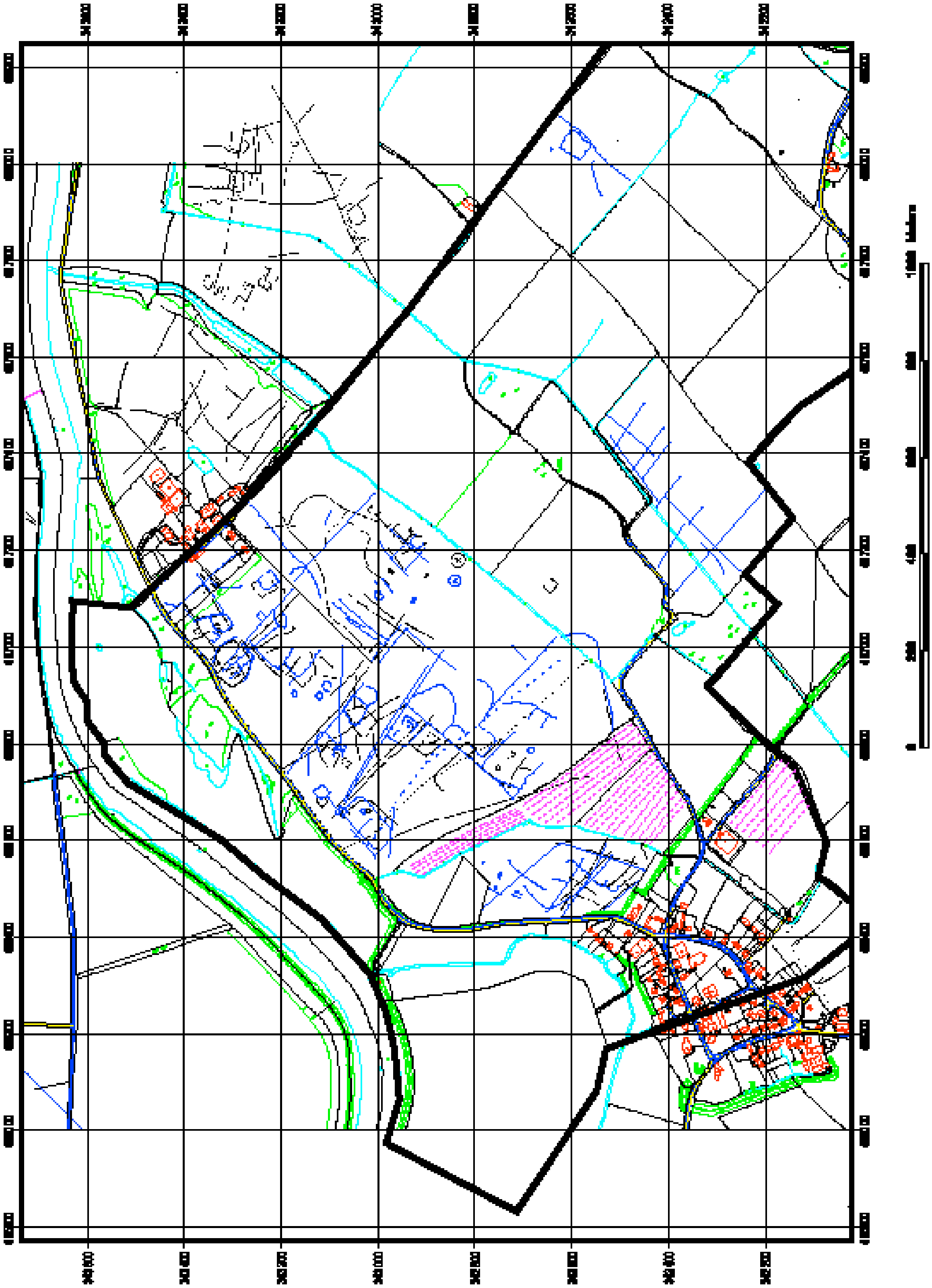


Fig 8.4. Shelford Manor, Nottinghamshire: comparison of NMP and FASTRAC air photograph plots

similar cropmark to the NE is only partially visible **[5]** due to ferrous interference from the field boundary. The anomaly at **[2]** also appears to be polygonal, although the magnetic survey data suggest a more complex structure than the AP with smaller, adjoining enclosures **[6]** and **[7]** immediately to the E, containing more internal sub-divisions including an apparently circular anomaly within **[8]**. In addition, more ancillary activity joining the two enclosures **[1]** and **[2]** is evident from the geophysical data.

The large enclosure at **[3]**, immediately SE of **[1]**, is also more fully represented in the geophysical data. A greater level of complexity relative to the AP record is again suggested by additional rectilinear anomalies abutting and possibly inter-cut with the main ditches. These latter anomalies would appear to include additional large, rectangular extensions **[9], [10]** and **[11]**, a polygonal enclosure **[12]** and a partially represented small, rectangular enclosure **[13]** with similar dimensions to **[4]**. The significance of the high magnitude linear anomaly **[14]**, apparently forming the northern extent of **[3]** whilst also extending E through enclosure **[1]**, is difficult to ascertain fully. This anomaly may well represent a more substantial trackway or boundary apparently respected by **[3]** -suggesting, perhaps, that the polygonal enclosure **[1]** represents an earlier phase of activity.

To the SW of the main enclosures, a distribution of small sub-rectangular ditched anomalies **[15-18]** is found following the approximate orientation of the modern road. Most of these form small enclosures of approximately 15m x 10m with a main grouping associated with additional linear anomalies **[19]**, which do not appear on any of the aerial photography. Similar smaller anomalies have already been identified at **[4]** and **[13]**, together with tentative evidence for additional enclosures at **[20-22]** and a strongly magnetic example at **[23]** that appears on the AP transcript together with a larger enclosure **[24]**, which is only partially replicated in the geophysical survey.

The survey has successfully identified a range of anomalies related to archaeological activity at the site that both complements and extends the extensive aerial photographic record. Whilst any chronology suggested from geophysical data alone should be considered with due caution, the main enclosures at the site are reminiscent of Iron Age / Romano-British activity with what appears to be a later Roman ladder-style settlement following the approximate course of the modern road. A final post-medieval phase is represented by a pattern of ridge and furrow within the magnetic data. This suggests that occupation activity associated with Augustinian Priory to the north did not extend into the current survey area.

Some differences in the magnitude of the magnetic response and the correlation of these weaker anomalies with the AP record are evident in the data. This may be indicative of varying environmental conditions and occupation through a period of rising water levels curtailed by the establishment of a seasonal flood plain. Similar results have been reported from an aggregate extraction site in the Thames Valley, where prehistoric features produced detectable magnetic anomalies, yet activity from the late Bronze Age onwards was obscured by the establishment of floodplain conditions (Linford, 1994 #386; Linford, 2005 #821).

8.3 The Air Photographic Record

8.3.1 Methodology

The air photograph collection preserved in the National Monuments Record was searched for vertical and oblique air photographs showing cropmarks or other features indicative of archaeological remains, as described in Chapter 3.6. Details are provided in that chapter of the methodology employed for AP rectification and the plotting of cropmarks, soilmarks and earthworks. The air photograph plots form part of the project GIS and are reproduced here, together with earlier plots produced as part of the National Mapping Programme (Fig. 8.4). A selection of the more informative air photographs is also included in this chapter by kind permission of the National Monuments Record (Figs 8.5, 8.7-8.10) and Cambridge University Air Photo Library (Fig.8.6).

Fig 8.5. Shelford Manor, Nottinghamshire: view SE across Holme Pierrepont Terrace, showing pit alignment [P] and enclosures [V] and [W] in centre. © English Heritage. NMR Pickering Collection (photograph reference: SK 6642/6; JAP 241)

Fig 8.6. Shelford Manor, Nottinghamshire: view NW across Holme Pierrepont Terrace, showing enclosures [Q] and [R] in centre foreground and enclosures [J] and [K] in centre background. © English Heritage. NMR Pickering Collection (photograph reference: SK 6642/9; JAP 241)

Fig 8.7. Shelford Manor, Nottinghamshire: view northwards across Holme Pierrepont Terrace, showing pit alignment [P] and enclosure [V] with internal pits in centre foreground and complex of ditched enclosures beyond. © Unit for Landscape Modelling, Cambridge University (photo reference: SK6643/11; CAP8387; VK24)

Fig 8.8. Shelford Manor, Nottinghamshire: view westwards across Holme Pierrepont Terrace, showing polygonal enclosure [C] and conjoined enclosures [A] and [B] in centre right. © English Heritage. NMR Pickering Collection (photograph reference: SK 6643/18; JAP 241)

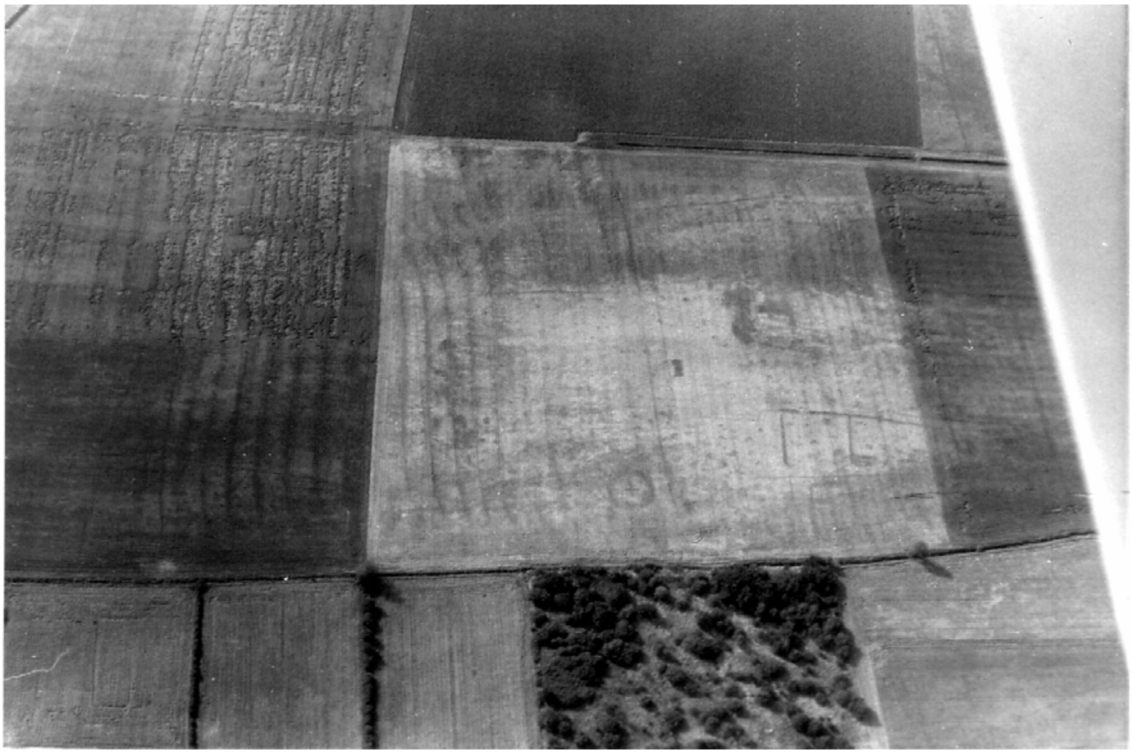


Fig 8.9. Shelford Manor, Nottinghamshire: view NW across Holme Pierrepont Terrace, showing annular ditched enclosure with central cross typical of the cropmarks left by the 'cross trees' of a windmill in centre foreground [S] and rectilinear enclosures [X] in right foreground © English Heritage. NMR Pickering Collection (photograph reference: SK 6742/5; JAP 145)

Fig 8.10. Shelford Manor, Nottinghamshire: view northwards across Holme Pierrepont Terrace, showing river Trent and alluvial floodplain in background and complex of ditched enclosures to SW of Shelford Manor. © English Heritage. NMR Pickering Collection (photograph reference: SK 6743/45; JAP 145)

8.3.2 Classification and interpretation of cropmark data

Air photographic surveys of the sands and gravels of the Holme Pierrepont Terrace have revealed cropmarks of a complex palimpsest of features within the study area, including vestiges of ditched enclosures, linear boundaries and trackways and a pit alignment (Fig. 8.4). Comparisons with excavated cropmark sites elsewhere in the Trent Valley suggest a close association with Iron Age and Romano-British activity, although evaluation excavations would be required to establish more precisely the date, character and level of preservation of these remains. The key features of this cropmark complex are summarised below, noting where appropriate significant correlations with the magnetometer plot. To avoid confusion with the numbered magnetometer anomalies discussed above (Fig.8.2), cropmark features referred to in the text have been attributed alphabetical codes (Fig.8.4).

Magnetometry Survey Area

Although extensive cropmarks may be discerned within the area investigated by magnetometry, plots of these (Fig.8.4) imply a rather less dense distribution of archaeological features than may be deduced from the results of geophysical survey – particularly along the northern terrace-edge in the western part of the survey area, where a series of small rectilinear enclosures recorded by magnetometry **[15-20]** is entirely absent from the cropmark record. In the north-eastern corner of the survey area, cropmarks provide evidence of a densely packed group of single-ditched enclosures abutting the modern terrace edge, relating probably to successive phases of activity. These include traces of a large polygonal enclosure **[C],** adjacent to the road running along the terrace edge, which correlates with a feature that is defined more precisely in the magnetometer survey **[1]**. To the NE of this enclosure **[C]** may be observed a small, irregular, curvilinear enclosure **[B],** correlating with a magnetometer anomaly **[2]** and a complex of linear ditches arranged in rectilinear fashion that may demarcate additional enclosures (e.g.**[A]**) or form part of a network of field boundaries.

To the south and SE of **[C]** may be observed traces of probably three sub-rectangular ditched enclosures **[D][E][F]** that are replicated in the magnetometry survey **[3][9][10]**, a curvilinear ditched enclosure **[G]** corresponding to magnetic anomaly **[12]** and a sub-square ditched enclosure **[I]** that may correlate with a poorly defined magnetic anomaly **[25]**. Two curvilinear ditched structures **[H][I]**, both seemingly of penannular shape and conceivably marking the locations of former round-houses, may be observed immediately SW of enclosure **[E]**; interestingly, neither of these was identified by magnetometry. Close to the western corner of the magnetometer survey area, traces may be discerned of a small square-ditched enclosure **[J]** and, adjacent to this, an irregularly shaped ditched enclosure **[K]** that correspond respectively to magnetic anomalies **[23]** and **[24]**.

Southern Extension of Holme Pierrepont Terrace

A dense pattern of cropmarks has been recorded across the remainder of the sand and gravel terrace, particularly to the south-west of the area surveyed by magnetometry, although these become increasingly difficult to plot south-westwards (compare Chapter 3.6.3). The emphasis in this area appears to lie firmly upon rectilinear ditched enclosures, some **[L]** containing curvilinear ditched structures that might indicate associated round-houses. The boundary ditches of these enclosures are aligned on a predominantly NW-SE and SW-NE axis, in common with several of the rectilinear enclosures recorded in the area surveyed by magnetometry **[D][E][F].** Numerous other linear ditches, some paired and possibly demarcating trackways **[M][N][O]**, and a well-defined sinuous pit alignment **[P]** running fro some 600m across the gravel island may also be observed in this zone. Dating is problematic without excavation, but the predominantly NW-SE/SW-NE alignment of these boundaries raises the possibility of an association with the rectilinear enclosures (to which some appear to have been appended: **[Q][R]**). Similar rectilinear boundary systems have been observed elsewhere in the Nottinghamshire Trent Valley, notably at Hoveringham

(Knight and Howard 2004, 100-101) and around Newark (Whimster 1989), and have been dated predominantly to the later Iron Age and Roman periods. Without further investigations, however, such discussion must remain speculative.

Typological comparisons with sites elsewhere in the Trent Valley suggest that much of the cropmark data from Shelford may relate to intensive settlement and farming during the Iron Age and Roman periods. These features may have been significantly denuded by later ploughing, to judge for example by the widespread ridge and furrow that may be deduced from faint crop- or soilmarks on some air photographs, linear patterning in the magnetometer survey (Chapter 8.2) and extant earthworks close to the village of Shelford (Fig.8.4). Few other obviously medieval or post-medieval features may be observed on air photographs of this cropmark complex, with the exceptions of correlations between some linear features and mapped field boundaries (Fig.8.2: **[26]**; Chapter 8.5) and, most strikingly, by a clearly defined annular ditched cropmark north-west of Moor Close Plantation **[U]**. The latter is some 20m in diameter and preserves a central cross typical of the cropmarks left by the ‘cross trees’ of a windmill.

8.4 Correlations between NMP and FASTRAC cropmark plots

The National Mapping Programme (NMP) plots of Shelford, prepared at a scale of 1:10,000 in 1995, show a broadly similar pattern of cropmarks to that produced in the project GIS, but detailed comparison of the FASTRAC and NMP plots reveals a number of discrepancies that, combined with the variable correlation between cropmarks and geophysical anomalies discussed in greater detail below, raises questions about the fidelity of the cropmark evidence as an indicator of sub-surface archaeology. The imperfect correlation between the cropmark plots may be assumed to reflect in large part the paucity on many photographs of reference points such as hedge corners, particularly on the gravel terrace immediately south-west of the area surveyed by magnetometry. This problem is exacerbated by the severely oblique angles of many photographs and the comparative rarity of vertical air photographs showing cropmarks that may be correlated with features recorded on oblique views (Chapter 3.6.3). The difficulties of plotting precisely the locations of cropmarks suggest that air photography and geophysics should be regarded as complementary techniques, which together can provide a powerful indication of sub-surface features. From the curatorial perspective, the significant enhancement of archaeological understanding that may be demonstrated by combining geophysical and cropmark data at an early stage provides valuable support for arguments that evaluative work should include as a matter of course provision for both geophysical and air photographic research (e.g. Knight, Pearce and Wilson 2007, 45-46).

8.5 Airborne Remote Sensing

Airborne remote sensing data for the study area comprised 2m spatial resolution Daedalus 1268 Airborne Thematic Mapper (ATM) multi-spectral imagery acquired by NERC in June 1996 and 2m spatial resolution airborne Lidar digital surface model acquired by the Environment Agency .

These data were processed using the techniques outlined in section 3.N and examined for evidence to assist in determining general geomorphology and the presence of anthropogenic features archaeological such as cropmark.

8.5.1 ATM

In general both the ATM and Lidar data prove useful tools for assessing the broad geomorphological character of the study area. Best results using ATM data are obtained outside of the visible spectrum (Figure 8.11).

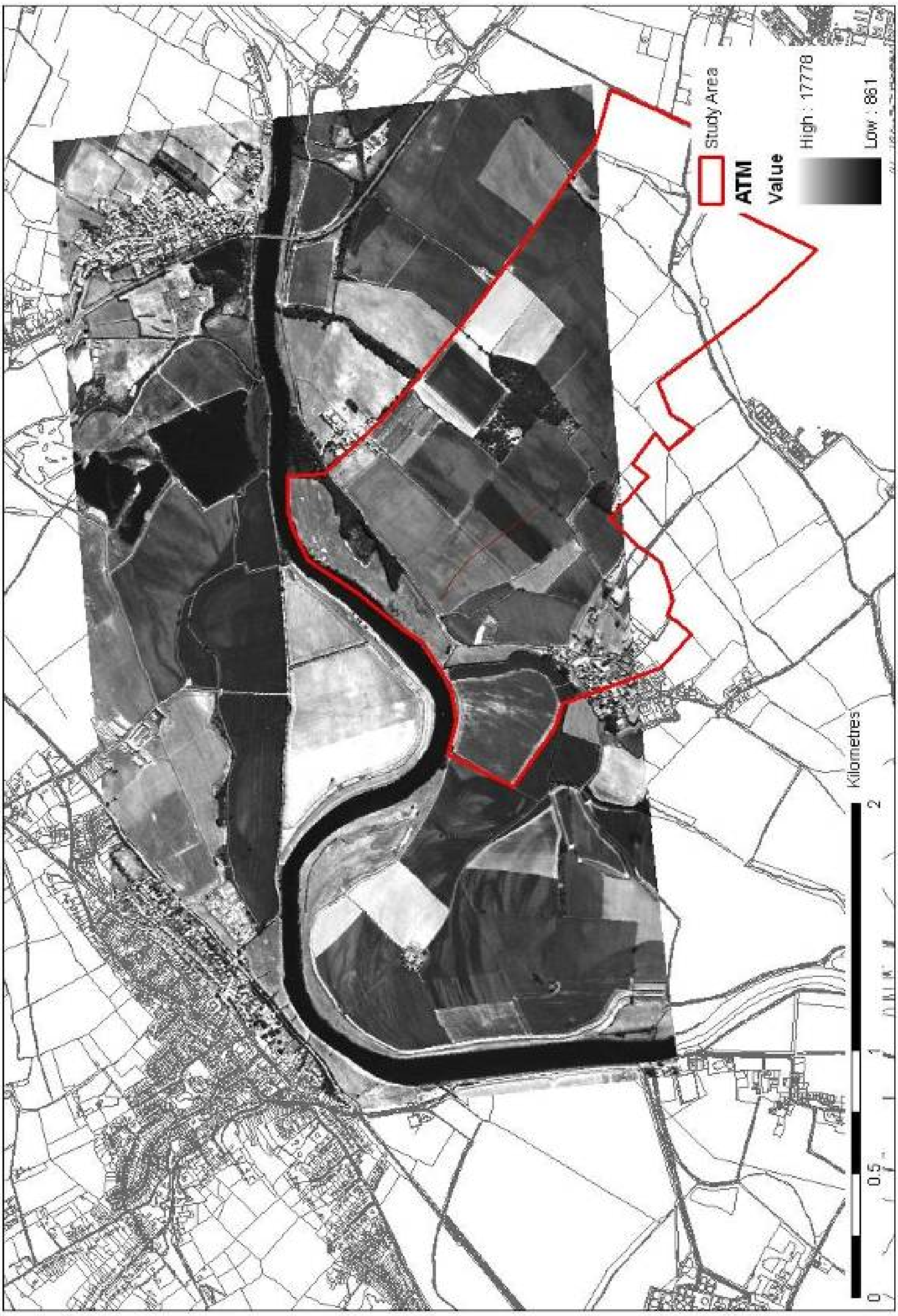


Figure 8.11. Shelford Daedalus 1268 ATM thermal band 11.

Figure 8.12. Shelford, archaeological features plotted from air-photographs.

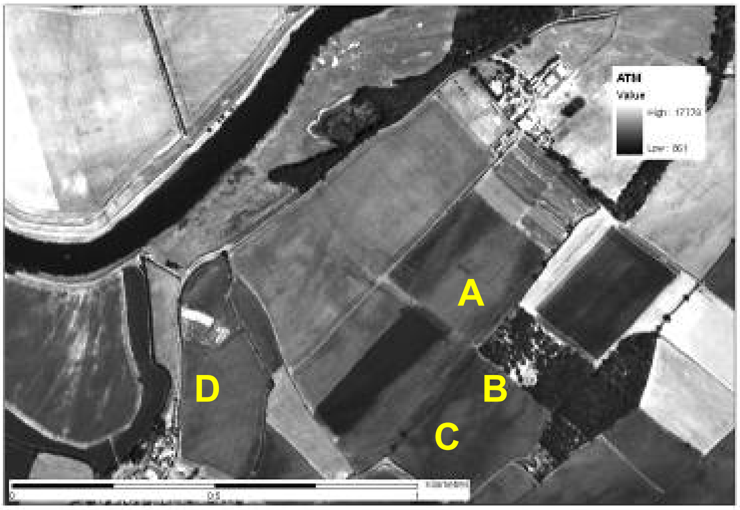


Figure 8.13. Shelford, comparative image of ATM band 11 for area above

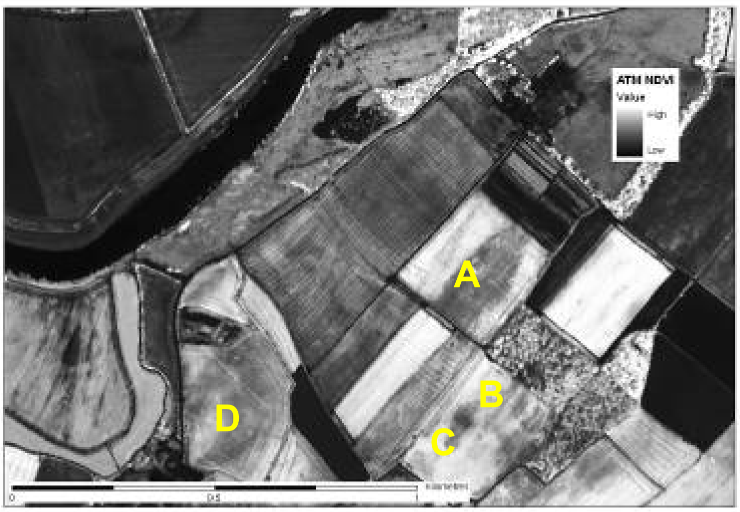


Figure 8.14. Shelford, comparative image of ATM NDVI for area above.

Examination of ATM's thermal band (11; Figure 8.11) highlights variations in the character of the terrace deposits at the centre of the study area (seen in detail on Figure 8.12) as well as the character of the broader landscape setting of the study area, including the complex channel features within the substantial meander to the west of the study area, and a substantial relict channel of the Trent and the terrace –floodplain boundary on the north bank of the present channel. Figure 8.13 shows clearly a terrace fragment with cropmarks indicated by thermal variation at A, channel feature (B) with island of terrace material (C) and further cropmarks to the west at D.

The Normalised Difference Vegetation Index (NDVI; Figure 8.14) provides an improved indicator of the geomorphological features of the site and broader landscape since most are evidenced by cropmarks. This includes impressive detail of the substantial meander to the west of the study area. Within the study the features evident in the thermal band are again clearly visible (Figure 8.14, A terrace with cropmarks; B channel; C island and D further cropmarks. In this image grey tone is equivalent to green vegetation vigour, with pale tines indicating lush green vegetation, largely confined to palaeochannels and anthropogenic cropmarks.

8.5.2 Lidar

Environment Agency Lidar data provide an impressive overview of the geomorphology of the study area and its broader landscape (Figure 8.15) and considerable evidence for anthropogenic archaeological features, particularly when viewed in tandem with cropmarks plotted from conventional air-photographs (Figures 8.16 and 8.17).

The terrace – floodplain boundary towards the northern edge of the study area is clearly evidenced as a marked break of slope in the Lidar elevation data. Individual palaeochannels within the floodplain are clearly evident as sinuous depressions, and the substantial meander to the west of the study area is clearly seen, as is the former channel of the Trent to the north of the modern channel. The character of the terrace within the study area is revealed as essentially a sequence of three east-west aligned gravel ridges separated by broad shallow depressions (A, B and C on Figure 8.16; B and C are also evident in the ATM data, the NDVI image in particular). The island within the southernmost of these channel/depressions is a well-defined topographical feature (D).

Surprisingly, several of the features evident as cropmarks also have expression within the Lidar data. Feature E on Figure 8.16 indicates a long linear bank, running roughly east-west almost centrally within depression B for at least 500m. Comparison with plotted cropmarks shows that this bank lies centrally within a parallel-ditched cropmark interpreted as a trackway. The presence of a central bank between these ditches suggest that it is more likely that the ditch, rather than representing the delineating boundaries of a trackway, served as quarries for the material to form this long linear bank, perhaps more easily interpreted now as a boundary feature. A further linear bank (F) at approximate right-angles to feature E is plotted by the NMR as a similar parallel ditched feature, but is not shown on Figure 8.16.

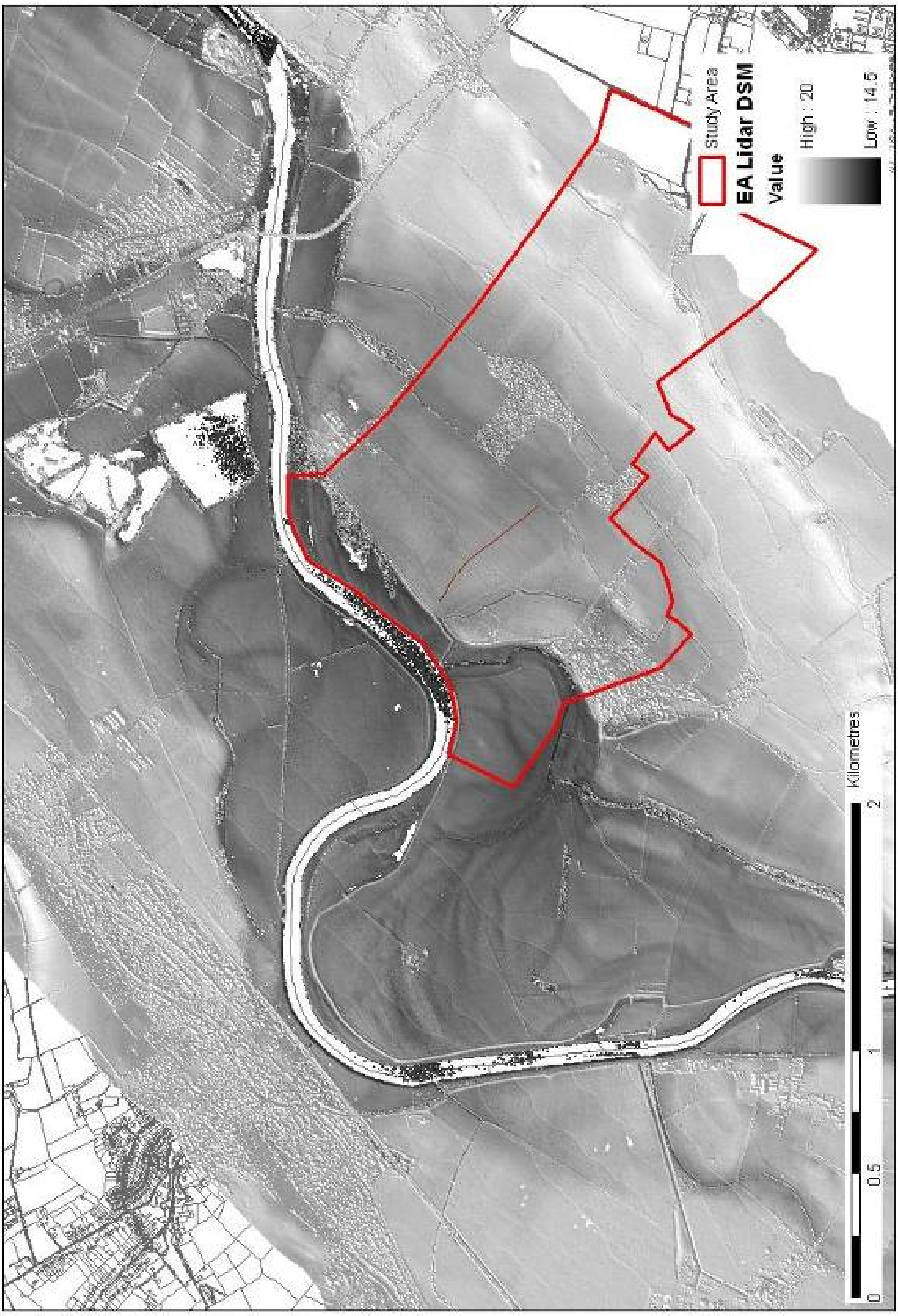


Figure 8.15 Environment Agency Lidar data plot of the Shelford area.

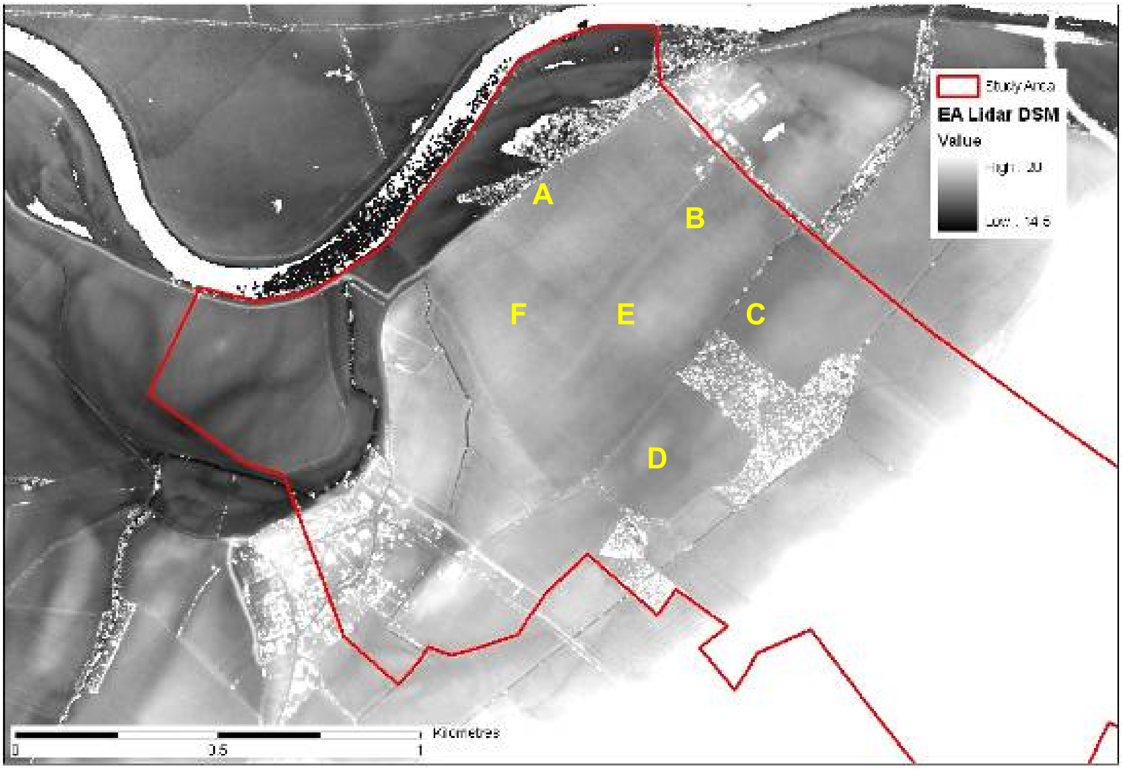


Figure 8.16. Lidar data as Figure 8.15, highlighting features referred to in the text.

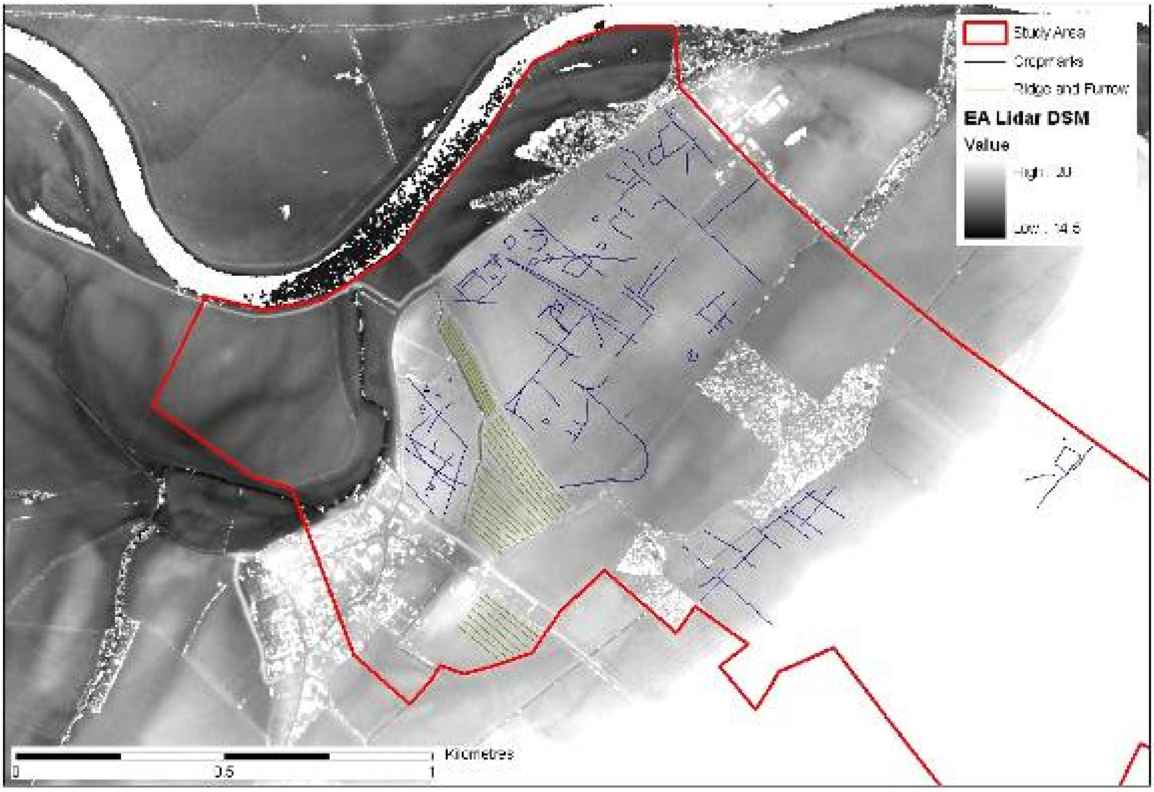


Figure 8.17. Lidar data as Figure 8.15, with cropmark features superimposed.

8.6 Correlations between results of different methods

Comparison of the cropmark plots with the pattern of anomalies revealed during the magnetometer survey carried out to the south-west of Shelford Manor reveals a reassuringly close correlation in the north-eastern half of the area. However, the correlation between cropmarks and geophysical anomalies becomes progressively less strong towards the south-west of the area surveyed by magnetometry.

Within the area surveyed by geophysics, there is a significantly higher density of geophysical anomalies that may relate to buried archaeological features than cropmarks. The reasons for this are unclear, but might include factors such as the masking of features by shallow alluvial deposits, limited differentiation in soil moisture content between feature-fill and the terrace sands and gravels and cropping patterns. Further evaluative investigations would be required to investigate the mechanisms responsible for the variable performance of air photography and geophysics, but whatever the explanation, there is unequivocal evidence that on this site magnetometry has provided the more complete image of the sub-surface archaeology. It must be emphasised, however, that not all potential features were detected by this technique. Attention may be drawn to several cropmark features that have eluded detection by magnetometry (e.g. Fig.8.4: **[H]**), and we would cite this as powerful evidence in favour of combining at the assessment stage both air photographic and geophysical research (compare Knight, Pearce and Wilson 2007).

Figure 8.3 shows an extract of the National Mapping Programme AP transcription information for the Shelford site superimposed over the magnetic survey data. Whilst there is a strong spatial correlation between the two datasets in the vicinity of the main enclosures there is some discrepancy and apparent mis-alignment between geophysical anomalies and corresponding cropmarks to the south and west. Rectification of the AP transcription to the geophysical anomalies improves the correlation between the two datasets, but the correlation remains imperfect. It is of interest to note, however, that a number of more subtle geophysical anomalies that were not used for the rectification, such as the partially replicated enclosure (Fig.8.2: **[24]**), may be shown to correspond directly with cropmarks in the repositioned data set. Even the large enclosure shown as a cropmark falling within the NE extent of the geophysical survey can be found to correlate with a tentative, weak rectilinear linear **[25]** partially obscured by the intense magnetic “shadow” of machinery parked at the edge of the field.

In general, there is a good correlation between the AP record and the majority of the activity associated with the large, polygonal enclosures. The cropmarks correspond well with strong magnetic anomalies, although the series of smaller rectangular enclosures are absent from the AP record with the exception of **[4]**, **[13]** and **[23]**. The response to the presumably medieval ridge and furrow, no longer extant as a topographic feature on the surface of the site, is also more apparent as a series of negative linear anomalies within the magnetic data (cf David, 2003 #1). However, some linear cropmarks sharing the same orientation as the ridge and furrow are evident, including one replicated as a more pronounced negative magnetic anomaly **[26]** that may possibly indicate a more significant recent field boundary or track-way. This latter anomaly does coincide with the boundary of an orchard plantation shown on the 1904 – 1939 epoch of the historic OS mapping.

The analysis of the Lidar data provides a novel and very interesting addition to the overall dataset. While the vertical resolution of the Lidar is seriously challenged by the subtle archaeological effects, there are clear indications that an archaeological signal is present in the data. The combination of the speed of Lidar survey, and the positional accuracy relative to oblique air-photography, make further investigation of the general applicability of this method highly desirable.

Another significant conclusion that may be drawn from the complementary analysis presented here is the ability to enhance the positional accuracy of the aerial photographic record against the corresponding geophysical anomalies. Such a process is likely to enhance the value of the aerial photography both within and, perhaps more importantly, beyond the area of overlapping coverage with the geophysical survey. The apparent discrepancy identified at Shelford between the regional NMP transcription was found to be significant and would certainly influence the success of any invasive evaluation of cropmarks targeted from the AP evidence alone.

9 Case Study – Classification of areas

9.1 Landscape Classification

One outcome of the analysis of remotely sensed data for large landscape areas is often a classification of that landscape into areas of homogenous character. In airborne and satellite multispectral remote sensing that classification often used independent or user influenced computer algorithms to classify images into areas of different land cover based on the distinctive spectral characteristic of those area.

Such computer generated classification of archaeological landscape is problematic. Often the aspects of landscape of archaeological interest present little or no durable surface trace (for example buried archaeological remains may be evident only as scatters of plough-disturbed artefacts, or present no surface evidence). Where underlying archaeology affects surface characteristic such as vegetation or soil, the changes induced are often to slight to distinguished from background values, or insufficiently homogenous is character for automatic extraction from remotely sensed imagery (cf Rowlands 2007).

While extraction of individual archaeological features, or even identification of areas of archaeological significance might be a challenge for remotely sensed imagery, broader landscape classification is achievable (cf Hill, et al, 2002) and might sometimes be of archaeological use.

This chapter presents a summary example of the use of remotely sensed data to generate a qualitative landscape classification of part of the Sturton study area, with the aim of generating an archaeological risk map, the use of which might inform subsequent stages of research.

9.2 Building a Landscape Classification Model

This short study makes use of airborne Lidar elevation and intensity data and Aisa Eagle hyperspectral data to arrive at a simple landscape classification. In river valley environments one of the chief determiners of archaeological and palaeoecological potential is likely to be location within the overall terrace and floodplain structure (cf Howard and Macklin 1999), thus data able to readily identify geomorphology of the study area is likely to be of use.

BGS drift geology mapping (Figure 9.1) provides a basic indicator of the geomorphology of the study area. Eagle hyperspectral data (True Colour Composite; Figure 9.2) while clearly delineating some facets of terrace topography is not uniformly helpful in determining the boundaries of geomorphological units. Lidar intensity data (Figure 9.3) provides little significant information on terrace and floodplain geometry and in this instance Lidar elevation data (Figure 9.4) provides the most useful indicator of terrace and floodplain geomorphology, aspects of which are clearly evident as variations in microtopography.

Clearly the Lidar DSM, while revealing, is too complex to serve as a durable model of the study area; for use as a landscape model the Lidar data require simplification, while preserving the significant boundaries between geomorphological units.

Examination of the Lidar DSM coupled with geological mapping and other data suggested that three classes were achievable and would represent a valid simplification of the original data, with each class likely to exhibit different geomorphological and archaeological characteristics. These were:

1) floodplain
2) terrace margin
3) terrace

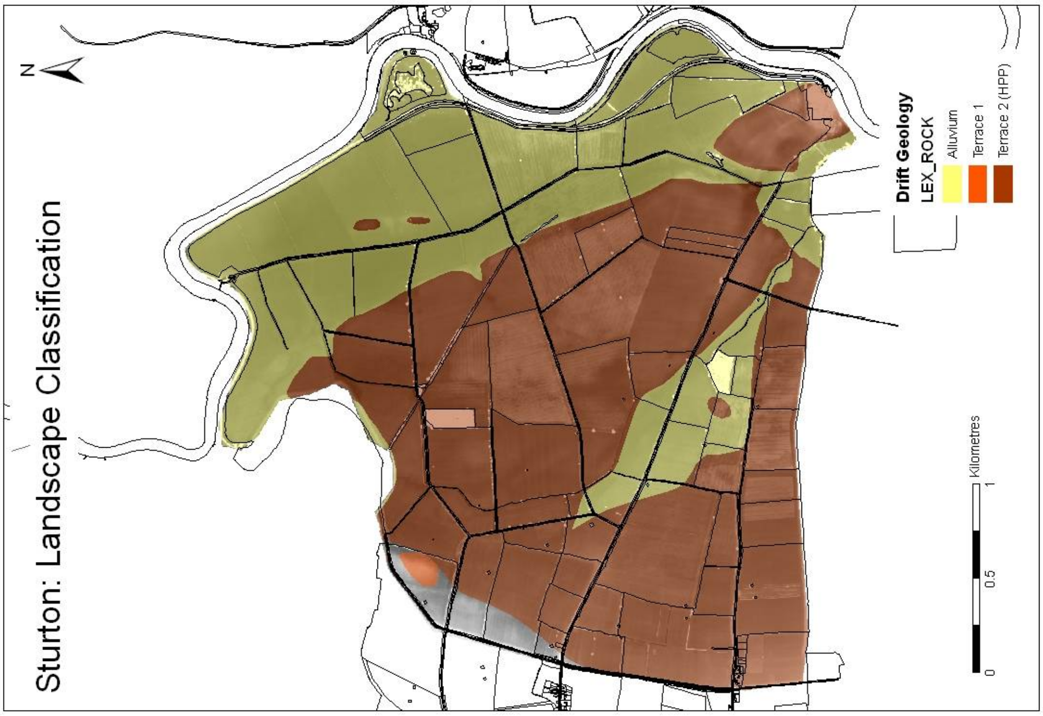


Figure 9.1. British Geological Survey Drift geology mapping

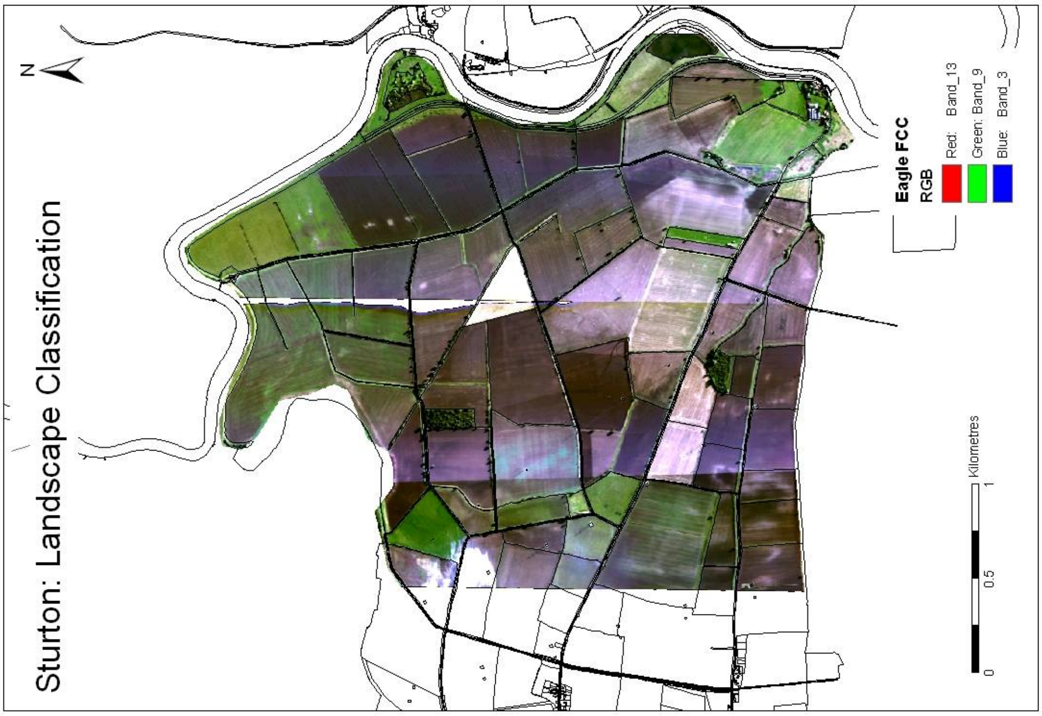


Figure 9.2. Aisa Eagle colour composite

Figure 9.3. Lidar Last Pulse Intensity Image

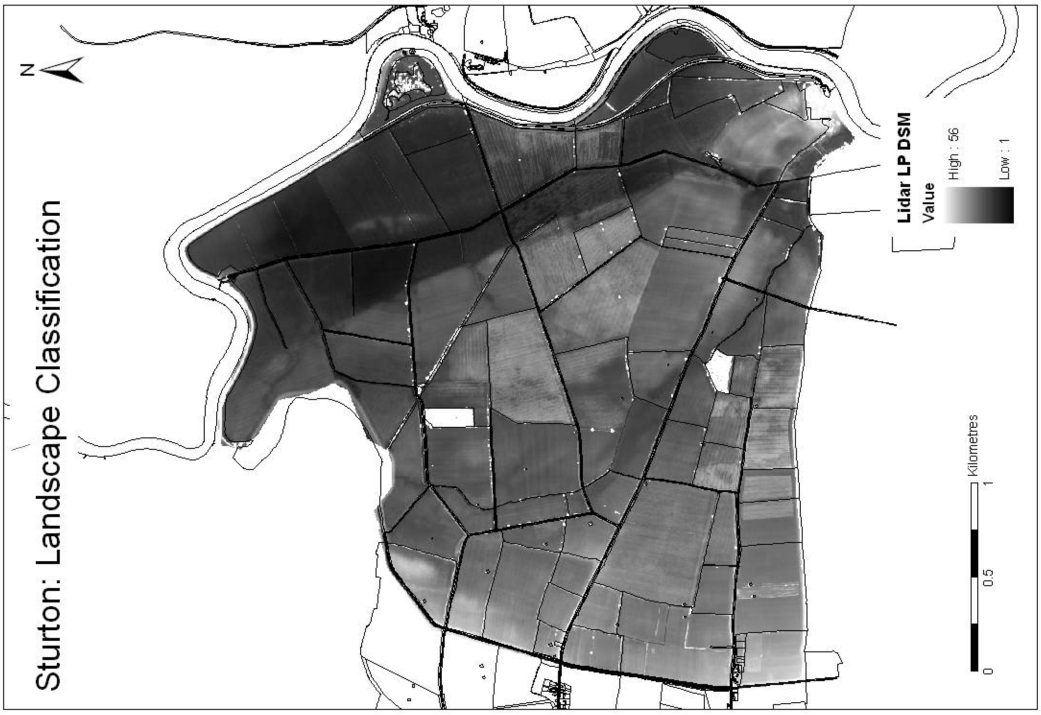


Figure 9.4. Lidar Last Pulse Elevation Model

Figure 9.5. Developing a simplified topography based model. Top, lidar elevation data classified into floodplain, terrace margins and terrace. Middle, simplified 25m gridded model data. Bottom, final model simplified using a No Sort boundary cleaning algorithm.

Figure 9.5 demonstrates one process of simplifying the Lidar data to produce a useful descriptive landscape classification. Lidar data is first density sliced to generate three elevation classes describing different landscape zones. This simplified classification still retains much of the complexity of the original data, particularly at boundaries between classes. The model was simplified generating a 25m grid in which each new cell took the minimum values of the 625 original cells that it contained. These data offer a useable classification of the original topography into landscape classes; this was finally further simplified using a no-sort boundary cleaning algorithm to produce simplified class boundaries suitable for conversion from native raster GIS format into vector data to which further attributes may be added.

Landscape classes were then assigned a score based on their likely archaeological potential in each of three categories:

Surface, i.e. physical remains such as archaeological earthwork preserved *to any degree* at the present land surface

Subsurface, i.e. physical remain *of any period* preserved *to any degree* beneath the present surface *at any depth.*

Palaeoecological, i.e. waterlogged anaerobic deposits likely to preserve artefacts and/or ecofacts of archaeological significance of *any data and at any depth.*

Landscape Class	Common Name	Surface Potential	Sub-surface Potential	Palaeoecological Potential	Significance Score
1	Floodplain	1	4	10	15
2	Terrace Margin	3	3	1	7
3	Terrace	5	10	2	17

Table 9.1. Landscape classification model.

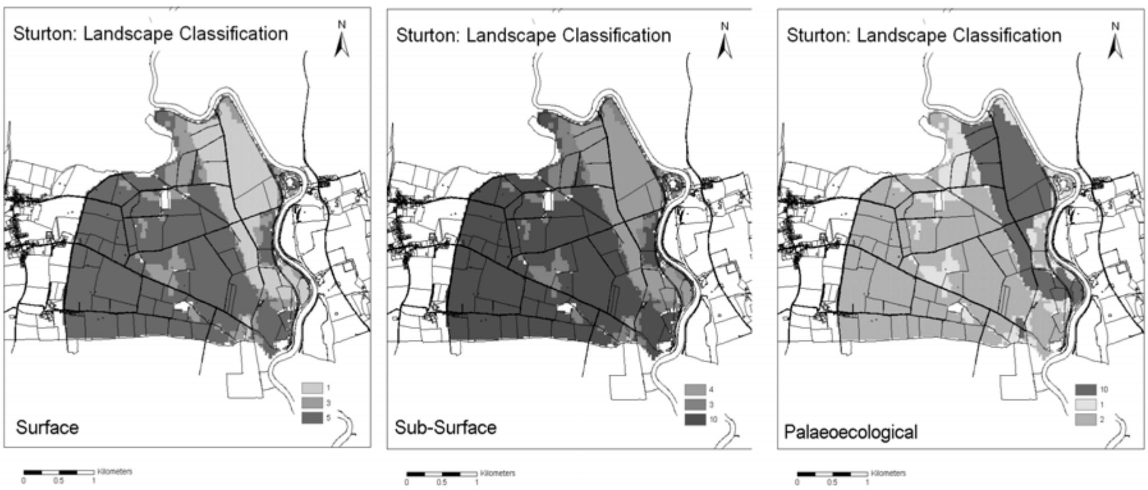


Figure 9.6. Landscape classification model populated with aggregate scores for potential for surface, sub-surface and palaeoecological material within each landscape class.

The model developed from these scores (Fig 9.6) is simple, in that no attempt is made to distinguish age or depth of deposits. Further information, for example from direct observation of boreholes, or from archaeological geophysics might be used to enhance the model by adding a third dimension to the data, while information from archaeological interventions might be used to provide some period based refinement of the classification.

As a simple test, the model was compared with the distribution of surface collected material from a small part of the study area (Figure 9.7) to determine which landscape classes the material fell within.

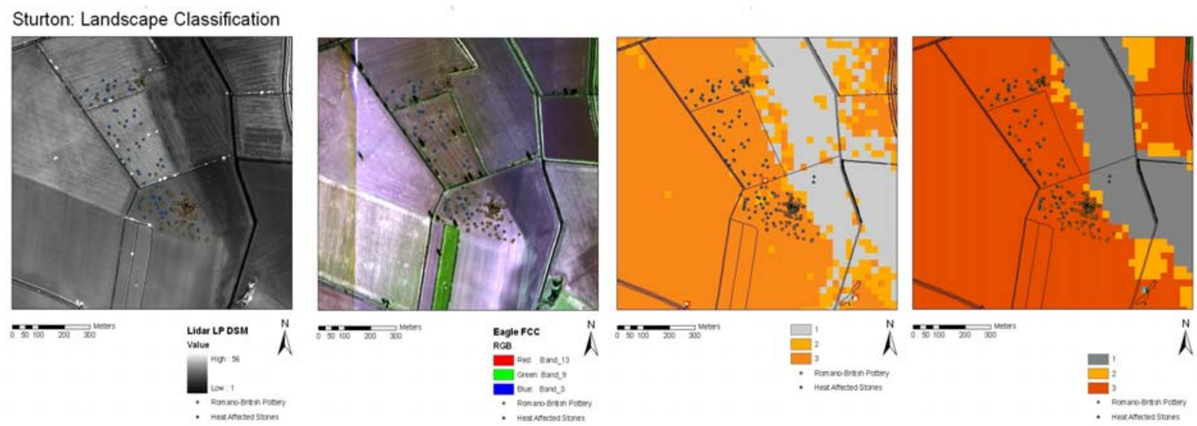


Figure 9.7. Left to Right, Lidar DSM, Eagle TCC, Classified DSM and final model with locations of surface collected archaeological material superimposed. The modelled terrace zone (surface significance score 6) coincides with the artefact locations.

9.3 *Conclusions*

This simple classification and modelling exercise demonstrates one way in which remotely sensed data might be used to construct qualitative models to assist in assessing the potential of aggregate bearing landscapes.

The utility of such models is that they may be quickly adapted to take into account refinements in interpretation, or new information, as and when it arrives, allowing the results of fieldwork from one location to influence the interpretation of larger landscapes and potentially assist in the development of resource management strategies.

10 Project Outcomes & Conclusions

Studies at Shelford have clearly demonstrated that remotely sensed data and geophysics can be used to improve the early assessment of sand and gravel deposits both from the perspective of resource potential and archaeological prospectivity. The benefits are increased, however, when such data are available and used in an integrated manner and as part of a tiered approach in which they can be used to focus the collection of more detailed information and to understand the sedimentological and archaeological evolution of similar sites.

From the perspective of resource estimation, the main limitation to its use is that it is difficult to interpret grade and quality information without a degree of site-specific ground-truthing. However, the combined use of remote sensing, terrain analysis and geophysics can assist in the identification and interpolation of distinct features, such as unmapped deposit boundaries (at 1:10,000 or 1:50,000 scales), at an early stage in the site investigation process.

The collation, integration and often first-order assessment of remotely sensed and geophysical data such as that collected in the Shelford Survey also clearly illustrates the potential of these techniques and methodologies to inform the development of archaeologically orientated assessments of both artefact potential and preservation status. However, no one technique provides every answer, even on a reasonably well-constrained site such as Shelford, and the project has clearly demonstrated that the power of such techniques is only fully realised by their integration in a GIS environment.

10.1 Hierarchy in areal coverage & resolution

In an exploration exercise, whether for mineral resource or cultural heritage, there is a need to focus down from initial assessment of large areas to detailed investigation of local areas of interest. This normally proceeds by a progressive narrowing of the search area by excluding areas which are not of further interest, rather than immediately locating the required detailed targets. As the process develops, the appropriate tools change from those with broad area coverage, to those with detailed high resolution of small areas. Usually there is an essential trade-off between the ability to gain a broad overview, and that of high resolution.

Airborne techniques such as Lidar and hyperspectral imagery provide high spatial resolution data (typical 1m or better) for an entire site, extending to hundreds or thousands of metres, and its even broader landscape setting. Our case studies have demonstrated that such data are applicable in both archaeological and mineral prospection as well as in developing mitigation strategies (i.e. resource impact assessment). These results highlight the importance of optical remote sensing and Lidar as first-pass techniques. Such airborne data are expensive to collect, but increasingly, banks of existing data are being compiled. It is not unreasonable to view their future usage as being similar to accessing databanks of vertical and oblique aerial photography, which are a ubiquitous archaeological resource.

The ability to scan large areas in this way and select areas for searches using geophysical techniques provides a natural hierarchy of methodology. Ensuing geophysical surveying techniques are also developing to provide more precise data in increasingly rapid and efficient ways. The ready availability and relatively low cost of precise GPS provides not only the ability to locate ground and airborne data precisely in 3D, but also allows them both to be located with the same navigational tools, reducing many of the problems associated with integrating multiple datasets.

The ability of the airborne and ground geophysical systems to provide large data volumes rapidly, also requires the development of computing tools to process and present the data quickly on completion of the surveying. The continuous increase in portable computer power, combined with the standardised survey methods and format of the data collected, make this problem at least tractable, if not simple.

10.2 Spatial sampling

Since any form of investigation, from hand excavation to airborne survey, carries significant costs, there is usually a conflict between rigorous, comprehensive survey, and cost. This results in sampling either taking the form of a uniformly even reduction of sample density over a complete area, or taking small sub-areas and sampling only these at a high density. There are obvious difficulties in each approach.

Airborne remote sensing by its very nature removes the requirement to sample. The site, indeed the entire landscape, is the sample. Wide area airborne data can thus provide a landscape context and rationale for more costly ground-based interventions. With the increasing speed and efficiency of geophysical surveying with dense spatial sampling, the necessity for selective sampling in either of the above modes decreases. This is of course highly desirable and facilitates the systematic and progressive focussing of survey effort on specific targets. The advantages of avoiding the need for randomised spatial sampling have already been very clearly demonstrated, notably by the Landscape Research Centre with the surveys of the Vale of Pickering (Powlesland, et al, 2006). Thus ideally the combination of airborne remote sensing and ground geophysics can provide a seamless knowledge-base from the broad hinterland to the context of a specific trench. This concept is equally valid whether the purpose is mineral resource or archaeological assessment.

10.3 Classification

One aim of prospection is to classify the landscape on multiple scales. The objectives of such classification may be diverse, such as mineral quality, overburden depth, archaeological complexity or palaeoecological potential. Such classification contains two essential stages. The first is to identify properties of the landscape which vary systematically within the search area so that it may be divided into sub-areas based on the value of this property. Such classification may be derived from any one dataset, or a combination of several different parameters. The second stage is to identify which of the known parameter set allow a classification which matches the desired ground properties. This latter stage can be carried out by selective ground sampling at locations identified from classifications derived in the initial stage.

Classification raises questions relating to the formation of near-surface deposits and thence the likely impacts of archaeological and resource evaluations. Specific examples would be timescales of likely preservation, degree of reworking of deposits and preservation of the landscape over the last 2000 to 1000 years. This project has demonstrated (Chapter 9) the potential to:

- Define more precisely the boundaries of deposits.
- Identify areas of shallow to very shallow overburden.
- Define areas of prospectivity for both recent and ancient history.

In conjunction with other specific ground-based data such as water chemistry, borehole logs and subsurface water levels, these classifications may allow comment on such detailed issues as the archaeological preservation potential of a site and its variability. In the mineral assessment context, such classification enables gross volumetric estimates on sand and gravels to be made and uncertainties to be characterised.

10.4 Confidence in Interpretation

Confidence in interpretation may be divided into two primary aspects. The first is the spatial accuracy of the location of the feature to be considered. The problems in this area are often more pervasive and less evident than may be supposed. Chapter 8 provides some good examples of the difficulty of establishing reliable locations for some data, particularly oblique aerial photographs. Our case study data, presented in the GIS projects, also illustrate very well the advantages of using precise GPS location to solve these problems. While there are inevitable differences in absolute accuracy between different GPS survey techniques, and different types of equipment, the common and consistent reference frame is hugely beneficial.

While GPS techniques can provide horizontal location to great accuracy, the vertical location is usually poorer. Lidar provides centimetre accuracy terrain models, an essential tool for building reliable assessments of mineral reserves through borehole modelling. For archaeologists, Lidar not only provides the most reliable understanding of the geomorphological context for human activity in most aggregate-bearing landscapes, it also provides an essential tool for interpreting preservation, by detecting upstanding remains. In some instances high quality airborne Lidar might replace ground-based recording as a mitigation tool (e.g. for recording large areas of low significance earthwork remains such as ridge and furrow).

The second aspect of confidence is in relating observed variation in a survey parameter to specific physical properties of the ground. Hyperspectral techniques may be used to describe the physical properties of the earth surface and the data are not only qualitative but potentially quantitative. Sub-surface materials, including rock, soil and anthropogenic deposits, have a wide range of physical properties, and can only be characterised by combining knowledge of several of these properties. Multi-sensor geophysical survey, where several different sensors detect different physical properties of the subsurface, provides an efficient and effective way to relate remotely sensed data to specific properties of the sub-surface. Linking hyperspectral remote sensing and ground-based geophysics potentially allows assessment not just of where a mineral or archaeological resource is, but also aspects of its essential character (e.g. overburden character and extent of waterlogged deposits). Such an ability to characterise uniquely volumes of the subsurface from remote sensing data and geophysical data is still a research objective rather than an established reality. However, the systematic integration of precise survey data which forms the core of this project is the key to future advances in this area.

10.5 The costs, and feasibility of whole-site assessment.

While the research reported here has clearly shown that there are considerable important advantages to performing a whole-site assessment, we have not had the constraint of having to work in a totally commercial environment. If the whole-site assessment methodology is to become a practical tool, it must be cost-effective within the operating constraints of current aggregate extraction. An essential, and attractive feature of the method is that it decreases risk throughout the assessment and development process. This advantage is however gained by increased costs in initial site surveys, which have a negative effect on cash-flow during the early stages of development. Furthermore, many mineral sites are assessed, but for a variety of reasons are never developed. This "wastage" cost increases if the assessment for each of these sites becomes more expensive before the point of rejection of the site is reached.

The gains lie in the combination of factors which follow on from the whole-site assessment. If the deposit is well characterised, and the archaeological and hydrological characteristics better known, the decision to develop or not will have high confidence. Not only will reserve volume estimates be reliable, but quality modelling of the deposit will allow improved estimates of the value of the deposit. Such information will also feed in to the quarry design process and should lead to optimal selection of quarry plant, and minimal wastage of the aggregate deposit. Not only will the increased information facilitate the planning process, but the extensive database will be augmented as production develops, and will provide a useful site management tool throughout the life of the quarry. The main features of these changes of methodology can be listed as below:

Additional costs:

- Data purchase and GIS compilation.
- Whole site geophysics.
- Geostatistics and target drilling.
- A preliminary trial-pit survey.

Potential savings:

- Reduced drilling and sampling costs (targeted instead of grid drilling; joint consideration of mineral resource and cultural heritage).
- Reduced costs of archaeological evaluation (especially high-cost trenching).
- Information transfer and re-use (from the initial assessment to site management).
- Reduced extraction losses and waste disposal.

Potential benefits:

- Improved geological interpretation and models.
- Services location on whole site.
- Geodiversity landform identification.
- Better quality of quarry design.
- Improved economic evaluation and decision making.
- Improved archaeological Schemes of Treatment and enhanced management of cultural resource.
- Improved site management.

An essential component in the economic viability of the whole-site method is the acceptance by planners and county archaeologists that a whole-site approach of assembling remote sensing data and ground geophysical survey will contribute substantially to the total requirement for archaeological assessment of the site. This will require a change in perceived standard practice. In this case the costs of the initial data gathering can be offset against a proportion of the costs that would have been incurred for the archaeological survey required by the planning process.

It also necessitates the availability of some level of Geographic Information System (GIS) software, and training in its use, for both archaeologists and the mineral extraction companies. This in itself also offers another positive advantage. Planners, archaeologists and geologists will be able to share and exchange data within common database formats. There will be benefits here not only in the shared costs of the data preparation, but also in the greater ease of communication, and reduced risk of confusion and error when each sector is using a common database.

The wastage rate on potential extraction sites must also be considered. Many sites are assessed and not taken to successful development. Any new methodology must therefore have a staged approach so that the opportunity is provided to terminate the assessment process as soon as possible to avoid unnecessary costs being incurred. This would necessitate some direct sampling by drilling or trial pitting at an early stage.

Figure 10.1 and 10.2 provide an outline summary of the potential contrasts between the conventional assessment and development procedure for aggregate resources (Fig. 10.1), and the proposed whole-site method (Fig 10.2). One notable feature of the revised flow chart is that decision making on “constraints” is brought earlier in the process, before a major investment is made in costly and invasive investigations.

10.6 Recommendations for Further Research

- To quantify the advantages of the whole-site method, further research is needed to produce a cost-benefit study which conducts a detailed site-evaluation case study by taking a specific aggregate extraction site and following the development cycle through to sustained operation of the quarry.
- There is a requirement to continue to develop methods of geophysical “quality” measurement which are at least close proxies for mineral industry quality parameters, as discussed in Chapter 6.
- The whole-site methodology has the capacity to incorporate hydrogeological investigations in addition to, and indeed complementary to, the other geological and soils assessments. This area has not been dealt with in any detail in this project due to the limited time available, but many of the datasets considered here contain information related to hydrological parameters and this would be another logical development of the system.

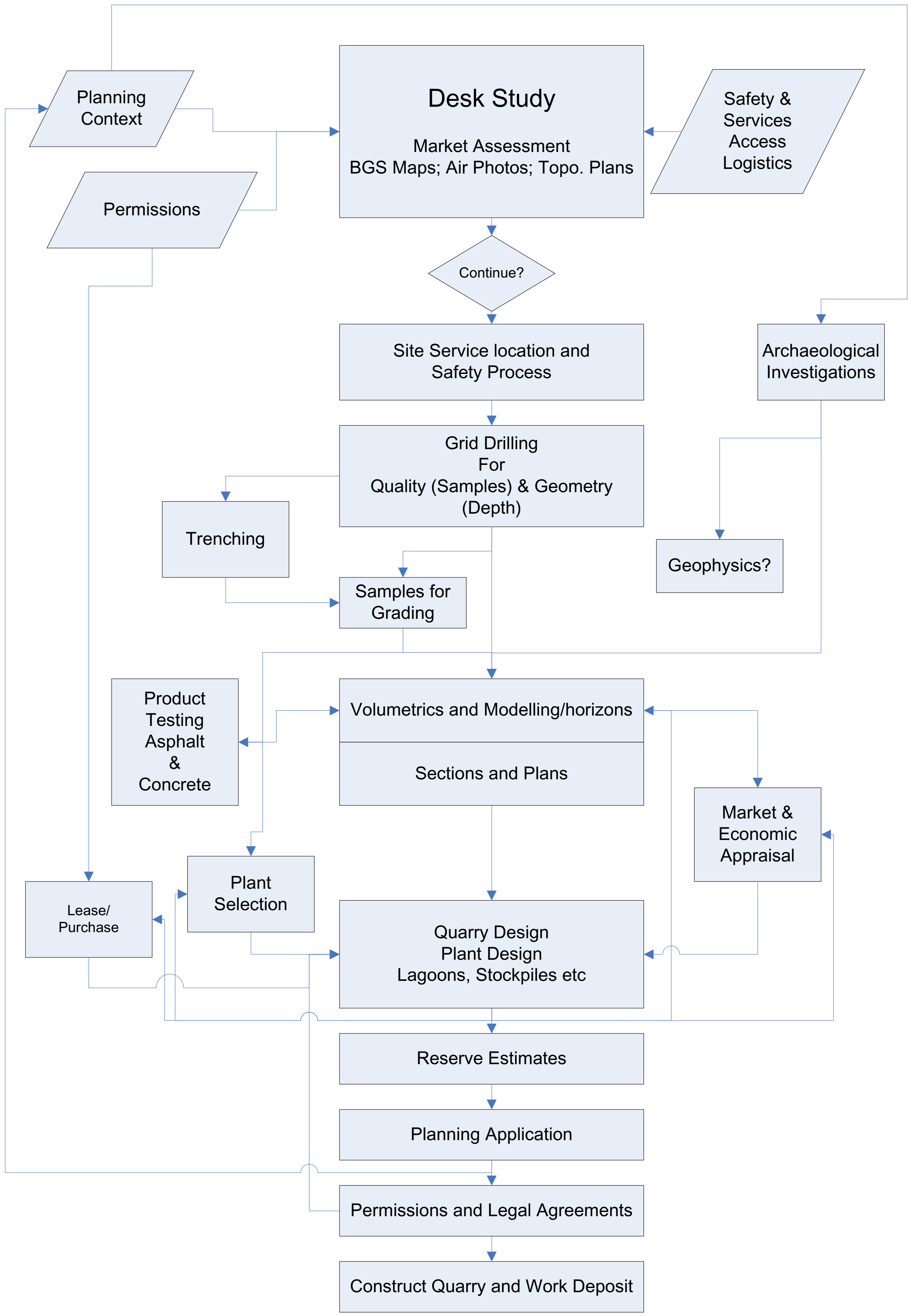


Figure 10.1. A generalised flow-diagram which summarises the information flow and decisions in the assessment and development of a sand and gravel aggregate resource.

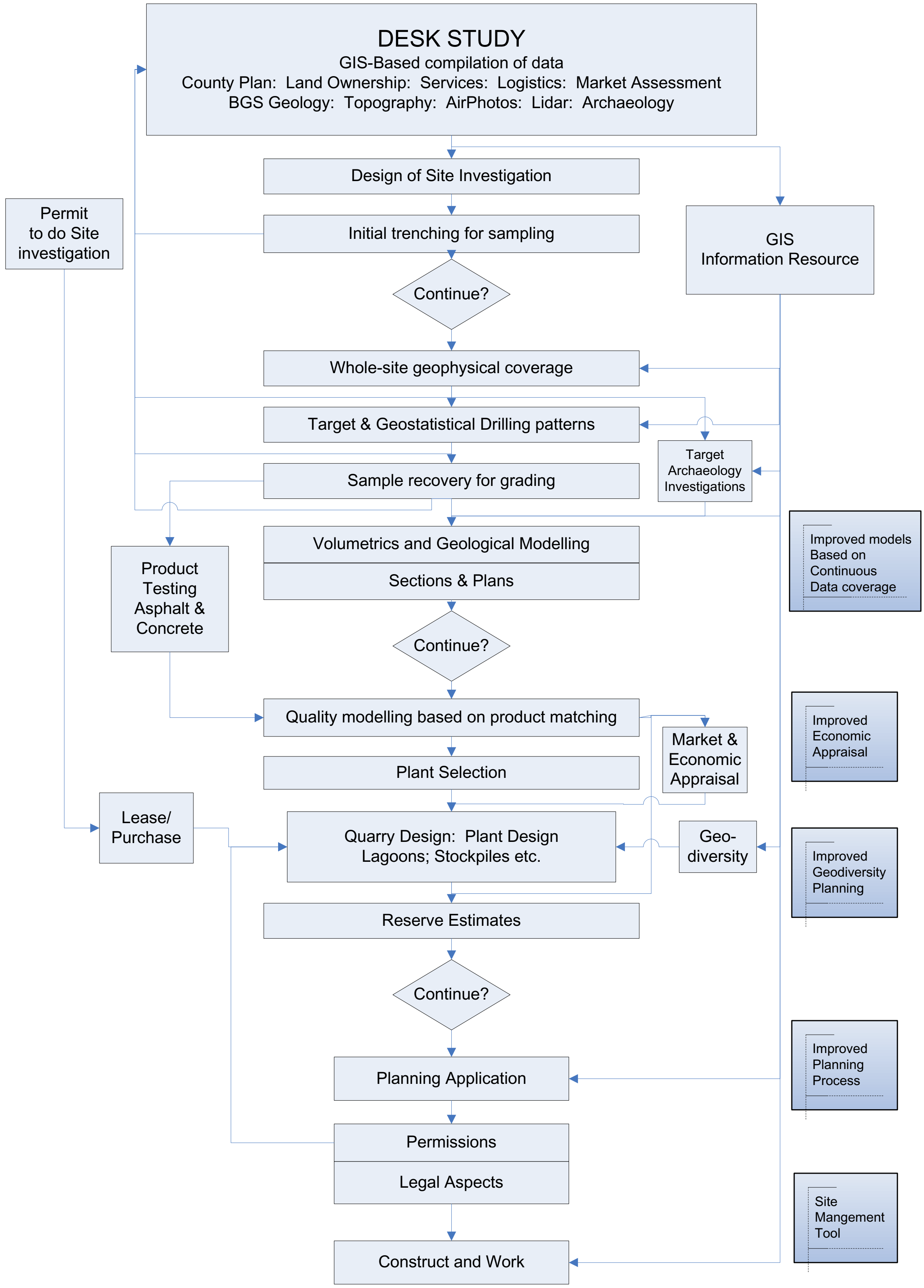


Figure 10.2. A generalised flow-diagram which summarises the potential information flow and decisions in the assessment and development of a sand and gravel aggregate resource based on the whole-site assessment methodology examined in this study (c.f. Fig 10.1).

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4 CS Geophysics

Ian Hill and Neil Linford

5 CS Sturton Terrace

Keith Challis, David Knight, Ian Hill, Lee Elliott and Katy Mee

6 CS Mineral Assessment

Ian Hill and Kip Jeffrey

7 CS Mineral and Archaeology associations

Barry Scott, Mike Raines, David Knight,

8 CS Fidelity of the archaeological assessment

David Knight, Neil Linford and David Walker

9 CS Area Classification

Keith Challis

The report has been compiled and edited by Ian Hill, to whom responsibility for all errors and omissions falls.

11.2 FASTRAC Associated contributors

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11.2.2 British Geological Survey

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Mike Raines has been the major participant in geophysical data collection at Shelford, giving assistance to both Leicester and English Heritage during their respective periods of fieldwork. Support for minor aspects of the geophysical equipment was also given my Oliver Kuras and David Jones.

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National Monument Record

Thanks to staff of the NMR for providing information on aerial photographs and assisting with analysis of air photographic date

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Thanks to Nottinghamshire archives, NMR and Unit for Landscape Modelling, Cambridge University

Other Data sources (external organisations)

Oxford Archaeotechnics (geophysical survey data: Sturton)

University of Leicester Archaeological Services (geophysical survey data: Sturton)

Archaeological Projects Services (geophysical survey data: Sturton)

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Mr R Miller, Beech Farm, Church Street, Shelford;

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1 Data Sources

Here we list the sources used for compiling the data we have used in the GIS projects for each of the study sites. These sources should be regarded as good examples of the data banks available, and the data types they hold. For any other particular area, similar data may be obtainable from relevant equivalent data banks.

We have also had to consider the licence agreements for each data type, so in some instances, though we have used data for the study, we cannot include it on the DVDs of the case studies. Such cases are also described below.

1.1 Ordnance Survey Base Mapping data

Most of the partners in this project have licence agreements to obtain OS mapping products from the EDINA website in Edinburgh. This has been done and such data used in the project. The licence agreement does however preclude us from passing on the raw data. For access to such data, readers are referred to the EDINA website:

http://edina.ac.uk/

With appropriate licensing, users may download the data and add it to the GIS projects provided with this report. The basic structure of the GIS databases does provide folders for adding this data, but they are empty on the DVDs supplied with this report.

1.2 BGS Shelford Data

1.2.1 BGS Originated Data

The following data sets were provided for the FASTRAC project by BGS. These have been collected during the development of BGS's investigations at Shelford overseen by the 3D Modelling Project within the Sustainable Soils Programme. They are currently being written up subject to formal publication and should be referred to as:

K Ambrose, D Entwisle, D Jones, M Strutt, A J Gallagher, C J Jordan, H Kessler, O Kuras, M Lelliott, K McManus, S E Nice, R Palmer, S Pearson, M G Raines, A Scheib, B Smith, D Tragheim, A Tye and J D O Williams (2008). Geophysical and Geological Investigations at Shelford, Nottinghamshire; British Geological Survey, Keyworth, Nottingham.

These data comprise:

a) ERT Geophysics – Electronic images and spatial location of cross-sections

b) ARP Geophysics - Electronic images and spatial location of resistivity maps

c) GPR Data - Electronic images and spatial location of cross-sections

d) Gamma Spectrometry - Electronic image and spatial location of gamma ray spectrometry

e) Magnetic Susceptibility - Electronic image and spatial location of magnetic susceptibility

f) Revised Geological Survey of Shelford Site (including BH locations and logs) as ARCMAP 9.2 Shape file

g) Soil Survey – Including Auger hole logs as ARCMAP 9.2 Shape file

h) Hydrological data – Location and water levels as Excel File together with spatial locations

Use of this data is restricted as per agreements laid down in the project's collaboration agreement dated 5th September 2007 Article 8 – Grant of Rights.

For further information on the availability of this data please contact, The British Geological Survey, Keyworth, Nottingham, NG12 5GG (www.bgs.ac.uk).

1.2.2 NERC ATM Imagery

ATM data based on mission 95/9 (file c177101b.hdf) flown on 25/06/1996 by NERC Airborne Research and Survey Facility (ARSF). Data are provided courtesy of the Natural Environment Research Council, through the NERC Earth Observation Data Centre (NEODC).

1.2.3 NERC Airborne Photography

High resolution Airborne Photography based on mission 95/9 flown on 25/06/1996. Image identifier = 1997_05b_9177_1997-05-26. Data are provided courtesy of the Natural Environment Research Council, through the NERC Earth Observation Data Centre (NEODC).

1.2.4 Site assessment information

Permission was given by Carter Jonas as agents for the Crown Estate Bingham Nottinghamshire to use confidential data for the purposes of the FASTRAC project provided that such data remained as commercial in confidence and would not presented in an identifiable form in this report or passed on to third parties.

1.3 Air Photograph Coversearches: Shelford and Sturton Study Areas

Lists of the specialist oblique and vertical air photographs located during coversearches of NMR records as part of this project are provided in the project DVD. To facilitate use of these records we include here a slightly edited version of the explanatory notes issued by the NMR.

1.3.1 EXPLANATORY NOTES FOR SPECIALIST OBLIQUE LISTINGS.

Researchers wishing to see the photographs or receive photocopies of these should contact the NMR (details below), quoting the NGR Index Number, Accession Number and Frame number. These images are on Open Access.

NGR Index Number

An NGR Index Number is allocated to each oblique photograph. It is made up of a four-figure National Grid Reference and a sequential number. For example, TG1234/5 is the fifth photograph in the collection located within the kilometre square TG1234.

Accession Number

This comprises a letter code which identifies the photography's source, and a film number.

Frame

The frame number identifies images within each film. It must be used in association with an accession number.

Date

This is the date on which photographs were taken.

6 Fig NGR

The six-figure Ordnance Survey grid reference relates to the centre of the photograph. The site or the centre of the site of interest will not necessarily be in the centre of each photograph.

The remaining columns are for internal use.

1.3.2 Explanatory notes for vertical coversearch listings.

The total number of photographs is noted at the end of the listings in the Excel files described in Appendix A5. Researchers wishing to see the photographs or receive photocopies of these should contact the NMR, quoting the Sortie number, camera position and frame number. Each row in the listing gives details for a run of one or more photographs. The site of interest will not necessarily be in the centre of each photograph.

Sortie Number

This is allocated to flights by the source organisation. It must be quoted with camera position and frame number(s) when referring to prints.

Camera Position

These codes indicate the position of cameras on an aircraft and must be quoted as a prefix to frame numbers.

Start Frame/End Frame

The "start frame" is the number of the first photograph in a run; the "end frame" is the number of the last photograph in a run. Where the two numbers are the same there is only one photograph. It is important to determine how many photographs there are in each run before requesting copies.

National Reference Start/End

These are two six-figure Ordnance Survey grid references for the centre of the first and last frames of a run. These can be used to plot runs of photographs onto an Ordnance Survey map.

Date

This is the date on which photographs were taken.

Scale

This is the target scale which the survey aimed to achieve. Each photograph, however, may be at slight variance because of changes in the aircraft's altitude or the height of land covered.

Examples of Scale	Area in photograph	Detail
1:2500	c. 0.13 square miles	Large scale - houses are c.7mm wide, cars and other small objects may be clear.
1:10 000	c. 2 square miles	Houses are c.2mm wide, trees show individually, street and field patterns are distinct,

		footpaths may be clear
1:15 000	c. 4.5 square miles	Medium scale - a village may fit in one photograph, footpath orientation may be clear.

The remaining columns are for internal use.

CONTACT DETAILS

Contact details and more detailed information on air photographic data held by the NMR may be obtained from the English Heritage website:

http://www.english-heritage.org.uk/server/show/nav.1158

2 GIS Database

2.1 *Software requirements*

The ArcMap project files for the two sites are '*Shelford.mxd*' and '*Sturton.mxd*'. These are ArcMap v9.2 project files and cannot be opened in other versions of ArcMap, ArcGIS, ArcView or ArcInfo such v8.2, v8.3, v9.1.

A data free data viewer, ArcExplorer, is available to download from:

http://www.esri.com/software/arcexplorer/explorer.html

It does not have the functionality of the full GIS, but allows data to be explored, layers to be re-ordered etc.

2.2 *Database structure*

The data are organised into 2 separate directories, each with a similar structure of folders and subfolders. The names of the folders reflect the data contents and beneath these are subfolders:

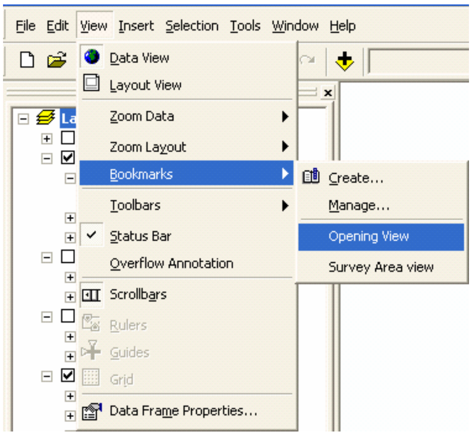
- Archaeology-Cropmarks
- Geology-Boreholes
- Geology-Soils
- Geology-Solid
- Hydrogeology
- Lidar
- Mapping – Current
- Mapping – Historical
- Misc Data
- Multispectral Imaging
- Surface Geophysics – Archaeology
- Surface Geophysics – Mineral Assessment

Views: When the project files (*.mxd*) are opened the initial views have been set. After zooming in and out or panning around the scene the initial views can be returned to:

View > Bookmarks > Opening View

For the Shelford project only 1 bookmark has been set: the Opening View

For the Sturton project 2 bookmarks have been set: the Opening View and Survey Area view



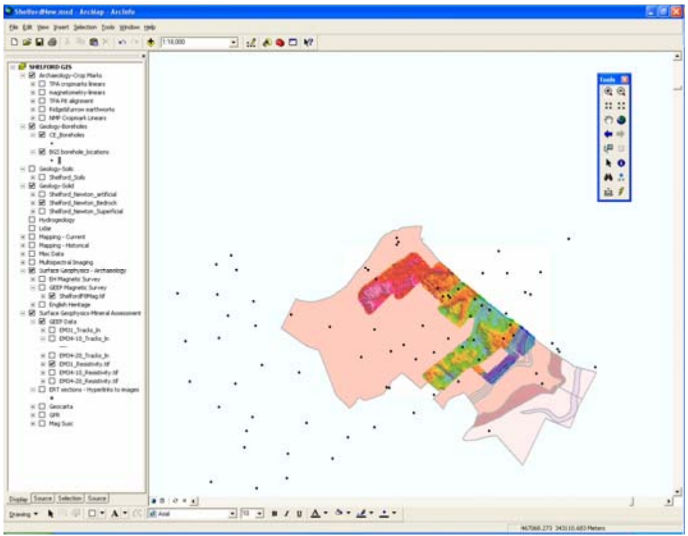
The opening views for both projects are illustrated below.

Shelford Opening View:

Geology Boreholes – CE_Boreholes and BGS borehole_locations

Geology-Solid – Shelford_Newton_Bedrock

Surface Geophysics – Mineral Assessment – GEEP Data – EM31_Resistivity.tif

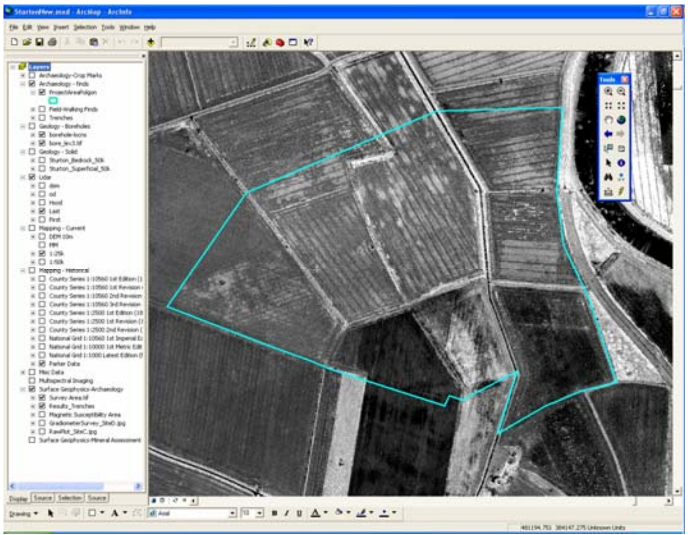


Sturton Opening View:

Archaeology – finds – ProjectAreaPolygon

Lidar – Last

Surface Geophysics-Archaeology – Survey Area.tif, Results_trenches

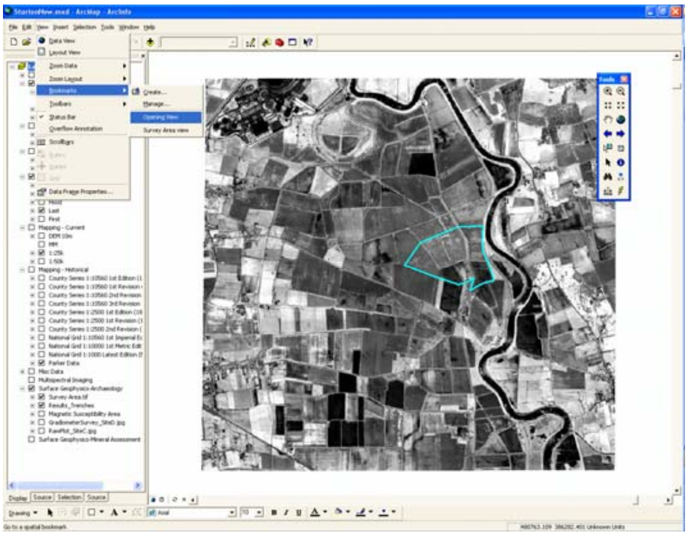


Sturton Survey Area View:

Archaeology – finds – ProjectAreaPolygon

Lidar – Last

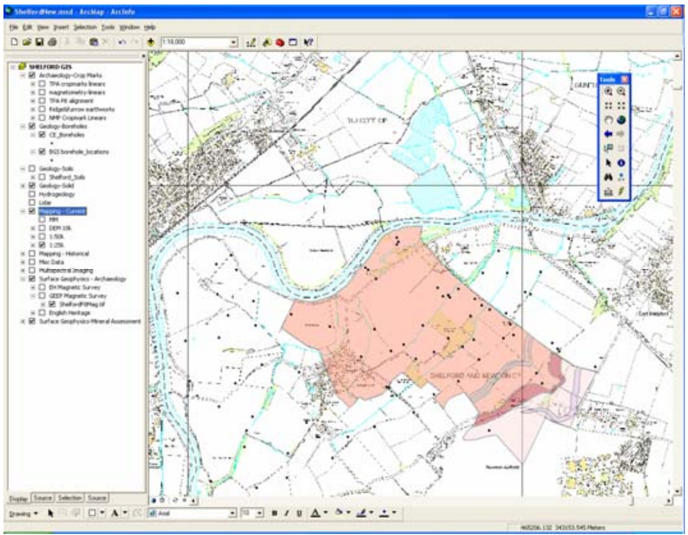
Surface Geophysics-Archaeology – Survey Area.tif, Results_trenches



Data Order: the data display can be altered by re-ordering the data layers. Layers are displayed in the order they appear in the table of contents panel on the left of the map. The layers can be displayed either by turning off layers above or by dragging the layer of interest to a higher place in the list.

For example the Sturton Opening view above has only 2 visible (ProjectAreaPolyon and Lidar – Last) layers even though 4 layers are switched on. In this case the Lidar layer occludes the 2 Surface Geophysics-Archaeology layers.

Similarly in this view of Shelford, the Ordnance Survey 1:25,000 base mapping occludes the Surface Geophysics – Archaeology and Surface Geophysics - Mineral Assessment layers that are switched on



File structure: the file structure on the DVD is similar for each project with folders that mirror the folders and subfolders in the GIS project as described above.

Ordnance Survey data: There are some empty folders due to licensing restrictions, principally those containing the OS 10m DEM, Master Map, 1:25,000 raster base map and 1:50,000 raster base map. These will need to be populated with data downloaded from or supplied to your institution.

2.3 Indemnity Statement

The information and images supplied on the accompanying DVDs are provided as exemplars of the types of data which may be compiled into a GIS, and the chapters of the report demonstrate some aspects of how these may be used. We intend that this will provide a useful background resource to illustrate the specific text of the report.

We make no claim that the datasets on the DVDs are complete, or that all included data is of appropriate quality for mineral or heritage assessment. Indeed we know that the data included are incomplete for at least two reasons:

- There are data to which we have had access but which we cannot disclose.
- There are other data (e.g. Ordnance Survey mapping) which form a key element of any GIS project in UK, but which we cannot distribute for licensing reasons.

We take no responsibility for any actions taken by any parties as a result of, or based on opinions formed by, viewing the data provided.

3 GIS database on DVD

4 Project Outputs, presentations and publications

This appendix lists the range of presentations and publications given, accepted, or proposed by project partners at the time of production of this report, February 2008. The items are listed in time sequence order. Where available, .pdf files of the abstracts, or full texts of papers are included on the DVDs which form Appendix 3.

2007

September:

European Archaeological Association, Zadar, Croatia. Oral presentation. (Ian Hill)

2008

January:

News item in ISAP newsletter.

February:

Submission of final report of PN5366. This includes two case study GIS databases on DVD which would be suitable for publication for wider public availability.

March :

Development of a multi-sensor exploration equipment platform for shallow geophysical applications. First Break, EAGE Journal. (Chris Leech, Ian Hill)

April:

Repeatability of towed magnetic data for archaeological prospection. Symposium on the Applications of Geophysics to Engineering and Environmental Problems (SAGEEP), Philadelphia, USA. Manuscript paper and oral presentation accepted. (Jenny Upwood)

Testing the effectiveness of combining airborne remote sensing and ground geophysics for assessment of sand and gravel deposits and overlying archaeology. I. Hill, K. Challis, C Jeffrey, N. Linford, D. Knight, B. Smith and D. Wardrop. European Geophysical Union, Vienna, Austria. Oral presentation accepted. (Ian Hill)

May:

GEEP system demonstrated at EIGG Equipment Exhibition, May 8th Leicester. (Ian Hill)

June:

Oral paper presented to Extractive Industry Geology biennial conference, Cardiff (Ian Hill)

September:

European Archaeological Association, Valetta, Malta. Oral presentation proposed. (David Knight?)

European Association of Geoscientists and Engineers – Near Surface Geophysics meeting, Krakov, Poland. Oral presentation proposed. (Ian Hill)

December:

EIGG Archaeological Geophysics Meeting, Geological Society of London. Oral presentation proposed. (Ian Hill and Neil Linford)

5 Air Photograph Listings

Coversearches were commissioned from the National Monuments Record (Swindon) of both study areas in August 2007. These searches focussed at Shelford upon an area centred upon kilometre squares SK6642 SK6742, SK 6643 and SK 6743, extending to all adjoining kilometre squares (SK6541, SK6641. SK6741, SK6841, SK6542, SK6842, SK6542, SK6543, SK6843, SK6544, SK6644, SK6744 and SK6844). At Sturton, the search focused upon an area centred upon kilometre squares SK8183, SK8283, SK8184 and SK8284, again extending to all adjoining kilometre squares (SK8082, SK8182, SK8282, SK8382, SK8083, SK8383, SK8084, SK8384, SK8085, SK8185, SK8285 and SK8385). Details were requested of all oblique air photographs for these areas and of all vertical air photographs of 1:10000 scale or larger. The results of this coversearch are presented and provide a record of all photographs curated by the NMR up to 10th August 2007. Most are monochrome prints, but a small number of oblique photographs of the Shelford study area are in colour.

Details of each of these are held in four Excel format files:

ShelfordVerticalAPs.xls

ShelfordObliqueAPs.xls

SturtonVerticalAPs.xls

SturtonObliqueAPs.xls

Details of the file format can be found in Appendix A1.

The files are contained on each of the DVDs accompanying this report.