The York Archaeological Assessment:

an investigation of techniques for urban deposit modelling utilising Geographic Information Systems

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Abstract

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A city such as York offers archaeologists valuable insights into human activity in the past and also, perhaps more importantly, allows the study of *trends* through time as represented by the stratigraphic continua awaiting excavation below the modern streets.

This thesis investigates ways in which the capabilities of computerised Geographic Information Systems (GIS) may be applied to the specific problems integral to studying the multi–dimensional, multi–temporal and basically *crowded* sequence of deposits extant beneath York, and introduces methodologies for exploring the past in more dimensions than the traditional two.

A database gathered for earlier work in the city (Ove Arup 1991) forms the basis of the research, and the methodologies involved in applying this — and other datasets gathered for purposes different from those behind this thesis — are discussed in detail.

Although studying the specific example of York's deposits, the methodologies and case studies discussed herein are of more general interest as they explore issues of data collection, use and analysis of relevance to many practitioners.

This research has demonstrated the value of GIS to urban archaeological research and has shown how the methodology may be applied to the management, analysis and display of disparate archaeological data, as well as to the exploration of specific research questions from the evolving river regime to the development of the town.

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1 × 3½" high density MS–DOS formatted floppy disk, associated with **Appendix D** and attached inside back cover.

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For my mum and dad.

A. Paul Miller
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Following a *viva voce* late in 1996, some changes were made to the thesis which was then resubmitted in the autumn of 1997.

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November 1997

Declaration

I hereby declare the contents of this thesis to be wholly my own work, except where explicitly stated otherwise in text. Computerised data from government associated agencies and from John Bartholomew Ltd are required to be individually cited as below, whereas other data sources are cited in **Appendix C** or in text.

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1. Introduction

> We need not go to the past, for it comes to us
> (Schiffer 1987; 3)

> We should currently be concerned with how little data we need to acquire from excavations to satisfy our conceptual framework.... We should be concerned with which conceptual framework would give us the most reliable, preferably replicable results
> (Wainwright 1978)

The town within archaeology

In contemplating 'The Past', most people turn to the famous sites of the eastern Mediterranean and Near East, to the films of Indiana Jones or to tales of King Arthur, Robin Hood and horned–helmeted Vikings. When asked to name monuments in the British Isles, many will think of Stonehenge and, perhaps, Westminster Abbey or York Minster.

Despite a perception that our better preserved towns and cities are of value and, in some way, special, few actually recognise them as relics of a time before the present. In reality, towns and cities actually represent the main spaces in which the public interact with the past, although often they will do so without realising.

In a nation where the countryside has been transformed by large open fields and the road network has been supplemented by modern swathes of motorway, the past has continued to exert influence upon the development of urban space, despite the best efforts of developers and planners alike. In a city such as York, for example, the extant city walls control the manner in which the urban core can grow and force communications routes to respect the lines of ancient defences. In developing areas of the city, designs are constrained by neighbouring older buildings and the ancient lines of essentially Viking streets and property divisions. Even where relics of the past lie buried, they continue to exert an influence in the present, whether as walls of a Roman building causing instability beneath York Minster or as lines of a property boundary upon a map of the city.

The archaeological resource within towns and cities is a valuable and essential element of the surviving heritage, and offers many valuable insights into the growth and development of the State, as well as evolution in technology, demographics, and belief.

Unlike rural landscapes, evidence within the urban sphere is highly concentrated within a small geographic space, and often extends downwards for several metres, providing clear stratification over several centuries. Where soil conditions are appropriate, as in York, Dublin, or Ribe, anaerobic conditions prevail and the deep strata contain evidence of organic remains as well as the more usual post holes and pottery. Although necessarily complemented by the very different evidence to be found on rural sites, urban archaeology offers some of the greatest challenges and opportunities to modern archaeology, whether in terms of the methodological issues to be addressed in adequately exploiting the resource or in the rich rewards to be gained in doing so.

Understanding 'The Town'

As illustrated below, data derived from the investigation of urban spaces are both numerous and complex. Data collection through time has by no means been uniform, and the vagaries of archaeological thought (*e.g.* Trigger 1989) and practice (Barker 1982) have served to further add to the difficulty of integrating past archaeological work due to problems of comparing data gathered under such different — even near incomparable — theoretical and methodological conditions.

Their very complexity makes it difficult for the urban archaeologist either to consider a particular excavation in its wider context or, more importantly, to address archaeological questions relating to the functioning of an urban space in its entirety, as a series of competing forces in some form of symbiosis.

The advent of computers in archaeology, and the growing power and affordability of Geographic Information Systems (GIS), offers the urban archaeologist a potentially powerful tool capable of storing and manipulating the diversity of urban data in such a manner as to facilitate exploration of important archaeological questions.

This thesis explores the manner in which use of GIS techniques can aid the archaeologist in exploring the urban past, and uses the City of York to provide data for a series of case studies outlined in **Chapter 5**.

Proposing the premise that GIS may be a valuable addition to the urban archaeological tool kit, — a premise which may be thought to have some validity, given the number of urban archaeological projects now making use of GIS in some form — a number of key issues were identified for research throughout the thesis, each of which is briefly outlined below and further expanded upon throughout the body of the thesis. Each issue highlighted below represents a major research thrust during this work, and together they build up to form the basis of the overall research agenda and its exploration of the role to be played by GIS in understanding and exploring urban archaeology.

Data

Urban archaeology generates a wealth of data, much of it represented solely in analogue form, and often of less than ideal quality. The thesis explores a number of the problems associated with using imprecise real–world data in conjunction with computers geared towards rather more absolute world models, and encounters the added complications brought about by use of mixed origin data, gathered over several centuries for many purposes, and never intended for integrated use such as that attempted here. Experimental use of the Kriging technique (**Chapter 4**) illustrates a graphical means by which potential imprecision in spatial data may be represented. **Chapter 4** also contains a discussion of issues relating to the effective design of databases for urban archaeology, where the relational database model employed to hold data during this research is compared with less flexible models such as that used by projects funded under English Heritage's Urban Archaeological Database programme (English Heritage & RCHME 1993*a*, 1993*b*).

A Town–wide Approach

Rather than merely considering each urban excavation in isolation, it is necessary to gain a broader perspective upon the urban space if we are truly to understand the forces at work throughout the past. The concept of *polis* is introduced in **Chapter 2** as a means of expressing this notion of a town–encompassing construct, and underpins all that follows, whether explicitly or implicitly.

Given the wealth of data generated by modern urban excavations, it is impossible for any one individual to grasp the complexity of the urban space, and computer–based techniques such as GIS therefore offer a powerful means by which the researcher may extend their ability to model sufficient data for patterns to be discerned. GIS–based techniques offer the potential to hold *all* archaeological information available for a particular urban space, bringing the power of a town–wide approach that much closer for functions such as research, data management and development control.

A number of case studies are undertaken using data from the City of York, and are reported in **Chapter 5**. These case studies succeed both in demonstrating the great potential of GIS and the diverse problems associated with attempting to utilise archaeological data such as those available today. If GIS is to become an effective part of the urban archaeological tool kit, effort will need to be expended in enhancing or documenting existing data, and thought will need to be given to more effective means of capturing useful data in future.

Geographic Information Systems

Although increasingly prevalent within UK archaeology, the Geographic Information System (GIS) was relatively unheard of at the outset of this research. As such, it was necessary at the time to consider issues now so commonplace as to be not worth mentioning in a piece of academic research, and time was also spent in developing tools since superseded by the onward march of technology and the release of new versions of software.

Originally intended to some extent to justify the use of GIS in urban archaeology, this thesis has since been overtaken by events and now simply uses **Chapters 4** and **6** to outline a number of the major issues associated with utilising archaeological data within a GIS.

Implemented within an environment such as that offered by the City of York Council's planning department, and kept up–to–date through the required deposit of data collected during the development control process, a GIS such as that discussed throughout this thesis would, as explored in **Chapter 6**, offer great benefits to the planning process itself, as well as being a powerful tool for integrating other, existing data sets such as museum collections and research corpora for use by practising archaeologists, museum curators and members of the general public.

Changing approaches to urban archaeology

The practice of archaeology in British towns and cities has changed greatly in the past fifty years or so, both in response to external pressures such as widespread redevelopment or government reform as well as because of changing modes of thought within the profession itself.

It is impossible, of course, to isolate changes within archaeology from the external pressures of society as a whole, as changes in one undeniably have a — sometimes unquantifiable — effect upon the other. The expression of archaeological thought in the practice of urban archaeology is itself little more than one manifestation of underlying trends in society and the two may therefore be seen as inextricably linked.

Changes in archaeological practice have significant effects upon data which are captured, as well as the manner in which these are recorded. An awareness of such changes is therefore important for a project attempting to integrate data sets collected at different times, in different ways and for different purposes. These changes are therefore outlined briefly, below, and certain of the resulting issues are addressed further throughout **Chapters 4** and **5** where they impinge directly upon this project's methodology or the selected case studies.

RESCUE

In the 1960s and early 1970s, urban regeneration at an unprecedented rate began to seriously threaten the surviving urban fabric on a scale not seen since the bombing campaigns of the Second World War. The nature of development — primarily tall office blocks in the very hearts of long–lived urban centres — meant that, perhaps for the first time, deep strata were threatened as much as the extant resource above ground. Deep foundations cut through even the most deeply buried deposits, and long piles pierced through the clay beds which had kept the riverine deposits of sites such as York and London's Walbrook wet and anaerobic, leading to desiccation and destruction, even in areas not directly attacked by bulldozers.

Recognising the threat, and forecasting imminent destruction for the whole resource, archaeologists reacted by forming urban archaeological units up and down the country, and by convening the pressure group, RESCUE, to argue for protection. Through the 1970s, the precepts of RESCUE and the philosophy of preservation by record held sway, with expensive — often publicly funded — large excavations undertaken in a large number of cities where potential threats were identified. In the race to 'preserve' from the onslaught of development and regeneration, archaeological responses within British towns and cities were rarely proactive in nature, instead attempting to react to each and every perceived threat by excavating as much as possible, recording as much as possible, and depositing the whole in an archive in order to preserve the site for posterity.

Urban archaeology was at its height, excavations were large, and most commonly undertaken in response to threats to a particular plot of land, rather than as part of any considered strategy for a larger part of the urban space. Archival practice at the time was poorly defined and unconstrained either by documented good practice or even guidance such as that offered by a later English Heritage publication (1991). As a result, archives from this period prove on the whole to be difficult resources for re–use today.

Ancient Monuments & Archaeological Areas Act, 1979

The Ancient Monuments and Archaeological Areas Act of 1979 (HM Government 1979) led to a tightening of archaeological legislation relating to both urban and rural sites, including an enhancement of the scheduling process by which 'monuments' could be designated and protected. More importantly for York, the concept of an Area of Archaeological Importance (AAI) was introduced with York as one of the few cities granted this designation. AAI status for York entitled archaeologists of York Archaeological Trust (as the nominated archaeological contractor) access to any potential development site, although money for necessary archaeological work was not guaranteed.

Towards PPG 16

With the publication of EC directive 85/337/EEC in 1985 (European Community 1985) and its local implementation within the Town & Country Planning Act's environmental assessment legislation three years later (HM Government 1988), the concept that 'polluter pays' began to enter urban archaeology and public money decreased to — in theory — be replaced by largely voluntary contributions from site developers. In cities such as York with the protection of Area of Archaeological Importance designation (HM Government 1979), extra powers were available to the archaeological authorities in bargaining with developers, but even here the transfer to developer funding was far from smooth.

As the graphs in **Chapter 3** show, the environmental *assessment* model of the Town & Country Planning Act led to a decrease in the size of excavations and an increase in the number of trenches as developers paid for prospection on sites, or restricted excavations increasingly to the strata directly threatened by the current development. In short, the processes of evaluation and mitigation taken towards their logical conclusion within the current legislation enforced by York City Council (York City Council 1992*b*), began to evolve in the late 1980s, with cities such as York leading the way in moving towards a new style of archaeology.

A model such as this marked a significant change to the way in which archaeology was undertaken, with monolithic excavations running for extended periods of time, and often undertaken by the same organisation in any one area, increasingly replaced by short–term, small–scale evaluations of the resource, each tendered for in a commercial market and awarded to any one of several archaeological contractors. Importantly, the rapid provision of archaeological reports became more commonplace, as many of these evaluations were tied intimately to the development control process and proof of archaeological assessment was increasingly a requirement for planning considerations to proceed, especially after the publication of *Planning Policy Guidance* note 16 (DoE 1990). This process was not wholly advantageous to the researcher wishing access to data from archaeological interventions as, although the weighty — and invariably tardy — site report of the 1970s and early 1980s had largely been replaced by more promptly produced and fact–rich evaluation documents, the wealth of the single archaeological archive became somewhat diluted.

Many British cities gained urban archaeological units during the early days of RESCUE in the 1970s, and these units were normally responsible for the large majority of archaeological work within any one city. As such, these units maintained both a body of expertise related to the city's archaeology and a comprehensive archive within which the results of their work over several years were available for study. With the rise of competitive tendering for archaeological evaluations, however, it became possible for contractors far removed from the city itself to gain contracts to undertake archaeological work, leading to increasing dispersal of both expertise and archival information, with different elements of a single archive now potentially held at numerous locations around the country.

It has been argued (*e.g.* Biddle 1994*a*, 1994*b*) that the over–zealous interpretation of guidance such as PPG 16 (DoE 1990) and its Scottish equivalent (Scottish Office 1994*a*, 1994*b*) has had a detrimental effect upon the conduct of archaeological *research*, with the proper conduct of research excavations replaced by formulaic application of 'assessment', 'evaluation' and 'mitigation' processes (*e.g.* Biddle 1994*b*; 4–5).

Rather, and as alluded to by Carver (1994), assessment and evaluation should be seen as essential elements in archaeology's development of effective research agendas (**Chapter 2**) for the better exploration of the urban past. Far from marking the end of archaeological research, PPG 16 offers an opportunity for the profession to garner a better understanding of the surviving urban record, to construct models of that which we *know* and that which we *expect*, to construct research agendas based upon that which we wish to *learn*, and to move forward to a future in which we direct the progress of archaeological endeavour, rather than continually reacting to the latest commercial developments. Working towards such an environment, this thesis makes use of archaeological archives and modern computer technology in order to explore the ways in which models may be constructed that are capable both of answering current archaeological questions and of aiding in the construction of research agendas for the future.

The Rose, and other stories

As proof that the transition from public to developer funding was progressing far from smoothly, and that tensions were often high between archaeologists, developers, local authorities and national bodies, several high profile fiascos made headline news in the late 1980s, including London's Rose theatre (Biddle 1989) and the Queen's Hotel in York (Hall 1988*a*, Brann 1988, 1989*a*, 1989*b*). The importance of both sites had been predicted long before development began, but adequate steps were not taken to preserve or record the resource, even after the importance of the buried remains had been shown. That a site of the richness of Queen's Hotel could have been predicted and then stood derelict and unexcavated for fourteen years highlighted the flaws within the system to many, and led to a search for new solutions. English Heritage responded by commissioning Ove Arup and York's Department of Archaeology to produce the *York Development & Archaeology Study* (Ove Arup 1991), and an internal consideration of policy leading ultimately to the publication of a Planning Policy Guidance note on archaeology (DoE 1990). York City Council collaborated with English Heritage in the commissioning of the Ove Arup study and appointed a Principal Archaeologist to implement more effective procedures within the Local Authority structure.

The *York Development & Archaeology Study* (Ove Arup 1991) included the production of a computer database recording information on archaeological contacts across the city, which was used to produce models of York's topography for the major periods of the city's past. This thesis records the results of research intended to enhance the potential of the data collected for the Ove Arup study. Using GIS software, the data were integrated with map and topographic resources to produce a complex model of the deposits buried beneath York. Whilst not attempting to produce a full GIS holding information on all of York's archaeology, the project discusses theoretical and design issues that are equally valid to the small subset studied here as to a model for all of York or any other urban space. It is hoped that the methodologies discussed herein will be of as much value to those developing similar solutions elsewhere as the study of a number of archaeological questions will be to those working with the archaeology of York.

Thesis synopsis

The remainder of this thesis is structured in such a fashion as to provide necessary historical, theoretical and methodological background to a series of case studies presented in **Chapter 5**. Following these studies, certain of the issues arising from the previous chapters are summarised and presented along with some thoughts both on how changes in the world of GIS make their adoption more plausible within archaeology and the possible impact of such adoption on the way in which urban archaeology is understood.

Chapter 2 introduces issues related to the consideration of archaeological deposits, a fundamental foundation to this work as to others. The basic — and presumably unassailable — scientific principles of deposition and stratification are introduced, along with discussion of the pioneering work in stratigraphic studies of antiquarians such as Nils Steensen (Garboe 1954) and J.J. Worsaae (1849).

Building upon the scientific evidence and the earlier work of others, Harris' Laws of Stratigraphy (Harris 1989) — namely *superposition*, *original horizontality*, *original continuity*, and *stratigraphical succession* — are discussed, and minor amendments are suggested in the light of archaeological realities.

Moving on to highlight other theoretical foundations for the research, **Chapter 2** also examines problems associated with the inherent multidimensionality of archaeological strata which, after all, manifest themselves both in three–dimensional space and in the fourth dimension, time. All too often, this dimensional complexity is simplified to the extent that the third dimension of elevation is effectively ignored whilst the fourth dimension of time — a continuum — is represented merely as a series of 'slices' through the stratigraphic column. This simplification, it is argued, greatly reduces the value that may be gained from the rich topographic data potentially available from many excavations. **Chapter 5** also explores similar issues with Case Study 3, although here the current methods for capturing topographic data on site are shown to be largely ineffectual in the construction of three–dimensional stratigraphic models.

The often–confused, although increasingly topical, issues of archaeological *quality* and *value* are defined for use throughout the thesis, and Carver's (1996) notion that value is a result of the modification of deposit quality with reference to a valid research agenda is introduced. The data available to a GIS such as the one discussed herein are capable of allowing for the creation of models depicting the quality of extant deposits across a city such as York. For such models to be transformed in order to represent notions of the value such deposits are perceived as having within society, it is necessary for a consensual research agenda to be applied to the available information as, for example, the best preserved deposits (those of high quality) need not necessarily meet the current interests of the archaeological community (therefore being seen as of low value). A Research Agenda should never be seen as static, but should rather evolve rapidly in the light of new discoveries or of changing interests within the archaeological community or society as a whole.

As discussed above, archaeologists need to move away from a site–based approach to urban studies and towards a town–wide approach capable of drawing upon the results of archaeological — and other — work across a wide area of urban landscape. **Chapter 2** alludes to this need, and introduces the concept of *polis* as a useful term capable of encompassing the physical and conceptual aspects of urban space which together make up a 'town'. The *polis* concept underpins all further considerations of urbanism throughout the thesis, and serves to reinforce the importance attached to the undertaking of landscape–style studies within the urban sphere.

In order to place work on the city of York within its unique historical context, **Chapter 3** opens with a detailed synopsis of York's history from its foundation in the First century AD until the ravages of Twentieth century redevelopment.

Changing archaeological practices have always affected the manner in which archaeological data are gathered, whether defining those periods of the Past which are considered 'worthy' of recording or merely specifying the level to which the location of individual artefacts should be recorded. In a project such as this which relies upon re–using data collected for many purposes over several centuries, it is important to be aware of these changing practices and of the limitations they imply about individual data.

Chapter 3 describes these changing practices, from the antiquarian efforts of those such as Drake (1736) to the more systematised present–day work of York Archaeological Trust and the City of York

Council. Time is spent specifically examining the ways in which these changes impinge upon the understanding of archaeological deposits, and earlier city–wide explorations of these deposits (Andrews 1984, Ove Arup 1991) are assessed in order to judge their value to the study of York and their potential contribution to the current research.

A valuable benefit of compiling information on archaeological interventions across the city in a computerised form is that information on excavated areas may easily be extracted from the computer. **Chapter 3** closes by illustrating the ways in which the changing practices of archaeological excavation discussed from **Chapters 1–3** have actually impinged upon excavation practice within the city. Clear trends may be observed in such statistics as the mean number of trenches opened during each excavation (Figure 6) or the total area excavated per annum (Figure 4) and convincingly related back to earlier discussions.

In **Chapter 4**, the methodologies underpinning this research are introduced, and issues associated with the use of computer–based techniques are introduced in a manner suitable for an archaeological audience.

The area of study (Figure 13) is introduced, and the primarily pragmatic rationale for its selection is presented, along with a detailed discussion of the data sources (see also **Appendix C**) available for integration. The project sought to integrate archaeological data from the Ove Arup (1991) assessment project (Table 1) and its York Archaeological Trust enhancement (Table 2) with cartographic data from the Ordnance Survey (Figure 11) and elevation data from Ordnance Survey, Ove Arup, the National Rivers Authority and Yorkshire Water (Figure 19). Each data set brought different problems, and the issues of integration are discussed at some length. Other data sets, such as those offered by aerial survey, were also considered and the reasons for not including them are explained.

Although constrained to a large extent by limitations in the available data, **Chapter 4** discusses the effort expended in developing a powerful and flexible database design (Figure 14) capable of storing the diverse data in a fashion suitable for graphical display in the Geographic Information System as well as more traditional database search and retrieval. The definitions of each field in the database are discussed in detail.

This flexible, modular, and relational design is compared to the more inflexible systems developed around the same time for the Urban Archaeological Databases (English Heritage & RCHME 1993) and the urban section of the Monuments Protection Programme (Darvill 1992), and the different approaches adopted for York and other urban areas are also explored.

The Geographic Information System is defined and explained, along with a brief introduction to the *Arc/Info* system actually used within this research. Within the constraints of available data and selected software, issues related to integrating maps with database are explored, along with examples (*e.g.* Figure 16) of simple GIS queries. The practicalities of constructing models of past topography are explored in detail, with discussion of the various technical possibilities available, and examples of the manner in which increasing sophistication (Figure 25) enhances the model. The limitations of archaeological data are introduced, to become increasingly apparent in **Chapter 5**.

In **Chapter 5**, five case studies are presented in order to illustrate the application of the available data to a number of different archaeological questions. Throughout these examples, limitations in the available data — discussed in more detail in the chapter — constrain the results, but it remains possible to see the potential benefits of such techniques. Following discussion of the rationale for selecting the five case studies actually included, the first examines the applicability of GIS–based techniques to analysis of the changing river regime in the late Roman period.

Although insufficient data and the use of a relatively simplistic flood model prevented analyses as complex as those undertaken by Gillings (1995) in Hungary, it was possible to show the ease with which computer–based techniques could be applied to resolving debates such as those surrounding Herman Ramm's 1971 proposal that Roman occupation in York was curtailed by catastrophic flooding. A model of the Roman topography is used to examine the effect of rising flood levels, and strategies are suggested for re–examining excavated sites in and near the potential fluvial zone.

Case study 2 tackles questions of differential deposition, based upon the premise that areas of increased deposition may potentially represent increased activity in the past. The question of differential use of the intra– and extra–mural fortress area in the immediate post–Roman period is tackled, although even in this relatively well studied area, problems with data affect the results. It would appear, though, that the results show a greater level of deposition inside the fortress than without, and the reasons for this require greater archaeological consideration.

Applying similar techniques to the city as a whole, the case study goes on to explore degrees of deposition across the city from one period to the next. Overlaying the results upon modern street maps (*e.g.* Figure 42) it becomes possible to see at a glance the areas in which significantly greater or lesser deposition has occurred and archaeologically derived reasons for these patterns may then be explored.

A third study addresses the application of GIS–based techniques to site–level topographic analyses and shows that whilst GIS techniques may be well suited to certain analyses on site (*e.g.* Biswell *et al* 1995), the topographic modelling techniques employed herein are poorly suited to such small areas, where the serious limitations of the available data become overly apparent. This case study discusses the problems of extracting topographic data from archaeological archives and suggests methods by which such data may be more usefully gathered on site.

The fourth study returns to hydrologically–related issues in an exploration of ways in which potentially anaerobic sites might be pinpointed; a useful capability enabling forward planning to either preserve the site with a strategy designed to minimise desiccation or budget adequately for pumps and conservation techniques suitable for dealing with organic material likely to be uncovered during excavation. The case study demonstrates a simple procedure whereby a topographic model of the known modern water table is subtracted from a topographic model of the presumed Roman ground surface, thus creating a new topography in which the Roman ground surface is classified as lying either above or below the water table. Computer simulations are compared statistically with excavated Roman sites classified as either wet or dry, with the computer's predictions being found significant; the technique is therefore shown statistically to be of use.

The final case study is very different from the others, and considers some of the issues involved in facilitating access to a tool as powerful as GIS for those with a purely archaeological training. Such users might undeniably benefit from GIS techniques, but they do not necessarily have the time to learn how to use such complex software.

The approach adopted is modular, and geared around the creation of small, self–contained, tools, each of which is designed to do a tightly delimited task, to allow the user maximum flexibility within the bounds of that task, and to minimise their contact with GIS commands and non–archaeological terminology. The example application demonstrated in case study 5 is of a borehole simulation tool which allows the user to select a point on a map and see the computed elevations (and associated deposit thicknesses) for the Modern, Medieval, Anglo–Scandinavian, Anglian, Roman and 'Natural' topographies of York. These notions of modularity and ease of use are then carried forward into **Chapter 6**.

Chapter 6 explores a wide range of issues associated with the archaeological adoption of Geographic Information Systems, including the problems of applying GIS retrospectively to existing projects such as the Urban Archaeological Databases, and relevant developments in the wider GIS community. The growth of 'desktop GIS' — capable of running on almost any computer rather than only the most powerful workstations — is addressed, as are a number of the national and international standards likely to impact upon GIS work in the near future.

This chapter also addresses some of the factors involved in implementing such a GIS for real in an environment such as a Local Authority, and briefly explores technological, methodological and human requirements for such a system to operate effectively.

As elsewhere in the thesis, problems with the crudity of the underlying data are emphasised, and some of the potential risks arising from misinterpretation of these data are outlined.

Chapter 7 offers a series of conclusions to be drawn from the work, and alludes to the great potential of urban archaeological GIS in an environment where higher quality data become increasingly readily available.

A number of Appendices detail the hardware and software utilised throughout this research, as well as offering a comprehensive **Bibliography**.

Possibly unfamiliar terms are defined in the detailed **Glossary**, and a **List of Abbreviations** expands each abbreviation used in the text.

The attached computer disk contains copies of the main Arc Macro Language (AML) scripts used in programming the computer software to produce the figures reproduced, below.

2. *Archaeological Deposit Modelling*

> All archaeological techniques grow out of two rules so simple that many a lecture audience thinks them funny. They are: (1) If soil layer **A** covers level **B**, **B** was deposited first, and (2) each level or stratum is dated to a time *after* that of manufacture of the most recent artefact found in it. These are the laws of stratigraphy, and in theory they are never wrong.
> (Hume 1975; 68)

Deposit Theory

The process of soil deposition

In studying archaeological deposits, it is important to have some concept of the ways in which these deposits form and change over time. Generic soil formation is more the domain of pedologist than archaeologist (Limbrey 1975), but the basic principles are of importance to archaeology and will be addressed below in order to place later discussions of deposition in some form of supra–disciplinary context.

Over extended periods of time, rock is naturally broken down by processes such as frost shattering and aeolian action to form soils. Once formed, these soils are supplemented by decaying waste from plants which take root in the newly formed soil and the soil deposits gradually increase in depth and complexity.

Many of the formation processes leading to the creation of soils in the first place continue to act upon the deposits, with wind and gravity carrying soil off high and exposed regions to deposit it lower down the slopes in sheltered corries or valleys. Where water flows, soil particles are carried downstream and deposited along river beds or in the sea. In spectacular cases, the alluvial fans from Alpine meltwater streams or the rich organic deposits at the mouths of major river deltas such as the Nile are clearly visible from the air, or even from orbit, but these processes are constantly underway across the planet on a far more modest scale, helping to shape the soil chemistry in complex and far from fully understood ways (Schiffer 1987).

Deposited soil horizons continue to interact almost symbiotically with the flora and fauna above, with changes to one having readily apparent effects upon the other. Amazonian deforestation, for example, rapidly leads to leaching of soil nutrients and the breakdown of the extremely fertile soil chemistry so sought after for agriculture, leading to the rapid failure of the farms and plantations for which the whole process was begun and inciting a further round of deforestation, farming, and eventual desolation. Without tree roots to bind the soil and rotting foliage to replenish soil nutrients, the soil rapidly becomes worthless and the very reason for removing trees in the first place is itself destroyed.

The ground surface is modified in a multitude of ways, ranging from the gradual to the cataclysmic, and the efforts of humanity in shaping the landscape to their requirements are but a part of a larger and more long term process which has been underway for millennia, and is likely to continue for many more. There is an inclination — not merely within archaeology — to categorise the depredations of humanity as in some way different from the so–called natural processes underway around us, yet when examined from the perspective of deposition many, if not all, of the processes at work are in fact the same.

At the most basic level, all deposition processes may be classified as either *additive* — where the quantity of material above the underlying rock strata increases at a given point — or *subtractive* — where the quantity of material decreases. In each case, one is reliant upon the other as the principle of conservation of mass requires that the finite quantity of material available on Earth be preserved. For soil to be deposited at one point, it must first have been removed elsewhere.

Deposit recording

Just as the laying down of rock beds over millennia forms strata for study and classification by the geologist, so more recent actions in the deposition — whether by human action or other agents — of soils, organic waste products and other materials forms identifiable stratification for study by the archaeologist in search of evidence for past human activity.

Study of deposition processes has advanced greatly since the nineteenth century assertions of Sir Charles Lyell that geological strata were evidence of the aftermath of the Biblical Flood (Lyell 1865), and many of the original geological concepts have been refined for the different requirements of modern archaeology, but many of the processes involved are still not as well understood as some (Schiffer 1987) might imply.

Early deposit recording

According to Harris (1989; 1), some of the earliest work with stratification was that of the Dane, Nils Steensen, in Italy during the seventeenth century. Steensen made the important step of associating fossilised teeth, or 'tongue–stones', found in the Maltese chalk with the teeth of modern sharks observed in the waters of the Mediterranean:

> since the shape of the tongue stones is like the shark's teeth as one egg to another; since neither their number nor their position in the ground speaks against it; it appears to me that they cannot be far from the truth who assert that the tongue stones are shark's teeth
> (Steensen, quoted in Garboe 1954; 45)

From this observation, the concept that rock deposits might have been laid down over time — and might incorporate evidence of earlier life — gradually evolved, although still within the constraints of Biblical time and Bishop Ussher's creation date of 4004 BC (Greene 1983; 99).

The great advance in archaeological understanding of the stratigraphic process was again initiated by Danes, with the work of C.J. Thomsen (Daniel 1943) and J.J. Worsaae (Worsaae 1849). Thomsen was the first director of the Danish National Museum in Copenhagen, which opened in 1816 (Greene 1983), and he made effective use of the Three Age system of classification in displaying the museum's collections to visitors. Under the Three Age system, the past began to gain a degree of obvious progression from the earliest stone tools, through bronze, to the most recent iron artefacts. Although now much subdivided, the basic concept enshrined in Thomsen's classification (1848) remains in place today. Thomsen's work was further enhanced — and firmly linked to the stratigraphic process — by his successor at the National Museum, J.J. Worsaae, who excavated several Danish bog deposits and was able to show a clear stratigraphic progression along the lines of Thomsen's model. Even this work, however, was constrained by the prevalent Biblical chronology, and it was not until the publication of *The Origin of Species* (Darwin 1859) that chronologists were freed to extend their work many thousands of years back into the Past.

The laws of stratigraphy

Archaeological concepts of stratigraphy continued to develop into the twentieth century, and finally began to grow apart from the underlying geological principles (Harris 1989; 5) of *superposition*, *original horizontality*, *original continuity* (Woodford 1965; 4) and *faunal succession* (Dunbar & Rodgers 1957; 278). An important addition to the conceptual framework surrounding archaeological stratigraphy was the formalisation of the *interface* between strata, and the recognition that this interface equalled the strata themselves in importance (Kenyon 1952). Although readily accepted today, the conceptual leap required in order to define *and record* a theoretical construct such as the archaeological 'cut' (a non–physical construct, defining the interface between that which has been dug into and that which fills any resulting hole) alongside the tangible deposits themselves was a remarkable and important one.

Drawing from the geological literature and the work of earlier archaeologists, Edward Harris has defined four laws of archaeological stratigraphy, thus:

> **The Law of Superposition:** In a series of layers and interfacial features, as originally created, the upper units of stratification are younger and the lower are older, for each must have been deposited on, or created by the removal of, a pre–existing mass of archaeological stratification.
> (Harris 1989; 30)

> **The Law of Original Horizontality:** Any archaeological layer deposited in an unconsolidated form will tend towards a horizontal position. Strata which are found with tilted surfaces were originally deposited that way, or lie in conformity with the contours of a pre–existing basin of deposition.
> (Harris 1989; 31)

Although strictly true, this law is perhaps misleading in its insistence upon a tendency towards horizontality. The law derives from the geological principle of original horizontality which was formulated primarily to describe the settlement patterns of lacustrine and sea–bed sediments. Conditions affecting archaeological strata are very different from the idealised model of a loch bed, and the likelihood of horizontal archaeological deposits is so remote that the law might better be reworded as *Any archaeological layer deposited in an unconsolidated form will tend towards non–abrupt interfaces....* In other words, no matter what the deposition alignment of a given deposit, that deposit will tend to conform to the alignment of deposition, except where acted upon by external factors.

> **The Law of Original Continuity:** Any archaeological deposit, as originally laid down, or any interfacial feature, as originally created, will be bounded by a basin of deposition, or may thin down to a feather edge. Therefore, if any edge of a deposit or interfacial feature is exposed in a vertical view, a part of its original extent must have been removed by excavation or erosion, and its continuity must be sought, or its absence explained.
> (Harris 1989; 32)

> **The Law of Stratigraphical Succession:** A unit of archaeological stratification takes its place in the stratigraphic sequence of a site from its position between the undermost (or earliest) of the units which lie above it and the uppermost (or latest) of all the units which lie below it and with which the unit has a physical contact, all other superpositional relationships being redundant.
> (Harris 1989; 34)

Archaeology in n*–space*

> by reducing space to a statistic it loses its descriptive force
> (Green 1990; 4)

Despite the inherently multidimensional nature of the archaeological record, modern archaeological recording techniques remain firmly situated in two–dimensional flatland, with the recording of heights on excavation plans in reality little more than a poorly considered extension of existing two dimensional techniques into the complexity of Tuftean three–space (Tufte 1990) and beyond. The conceptual framework of space within which archaeologists operate is well defined by Renfrew and Bahn, who write in their description of archaeological excavation that

> Very broadly we can say that contemporary activities take place *horizontally in space*, whereas changes in those activities occur *vertically through time*. It is this distinction between horizontal "slices of time" and vertical sequences through time that forms the basis of most excavation methodology.
> (Renfrew & Bahn 1991; 90)

Such a perception of deposition processes greatly simplifies reality and, while simplification for operational reasons is not unreasonable, *this* simplification exacerbates the prevalent trend towards considering spatial continua and temporal snapshots, or slices. The fourth dimension exists as a continuum in the same way as do the first three, and the artificial process of subdividing time into arbitrary slices prevents the researcher from truly grasping the fundamental relationships in *all four dimensions* between components of an excavation (Reilly 1992; 164–168, Harris & Lock forthcoming).

The role of the third dimension on an archaeological site further complicates the task of enhancing recording techniques in order to better comprehend the stratigraphic sequence and the temporal relationships between strata. This complexity is perhaps partly responsible for the fundamental two–dimensionality of archaeology, a two–dimensionality which is present despite the 3– and 4–dimensional aspirations of many excavators and researchers.

The third dimension on any excavation is the elevation of any point above a given datum. This elevation is recorded to varying degrees and with unpredictable frequency, depending upon the excavator and conditions on site, but it is used to record both the topography of the site (z) *and*, implicitly, the site phasing (t) which is theoretically the preserve of measurements of the fourth dimension. Measurements of the third dimension provide stratigraphic phasing information by way of Harris' Law of Stratigraphical Succession (above).

In reality, the stratigraphic sequence is more often derived solely from purely stratigraphic relationships, and the relative elevations of individual strata are rarely considered. Nevertheless, room for conceptual confusion exists in this dual role for the value of z.

The primary objective in collecting measurements of z should be to build an understanding of the changing topography on a site over time. While UK urban archaeology has developed detailed procedures for the recording of horizontal space through the single context plan and proforma context recording sheets (*eg* Spence 1990), the extension of these plans towards the multidimensional reality of the site is often left very much to the individual excavator with a lack of consistency in recording even within individual trenches on an excavation. The implications of elevation recording on two York sites are explored in more detail in **Chapter 5**, but some of the more general concepts at work are outlined here.

The way in which archaeological layers are recorded has changed greatly, even during this century. The first major recording technique discussed here was the box grid style of excavation espoused by Sir Mortimer Wheeler in his excavations around the world (Greene 1983, Renfrew & Bahn 1991). This grid technique relied upon the detailed recording of the four sections in each grid square, but has been widely criticised (Barker 1982, Harris 1989) both because of the impact the baulks between squares had on any comprehensive understanding of the site, and because of the manner in which plans were drawn of the excavated layers. Many excavators using this technique recorded the three dimensional locations of artefacts in detail, but recording of heights for individual contexts was erratic.

The grid excavation gradually evolved towards the open area excavation, where large areas were opened up and emphasis was placed upon the drawing of site plans rather than recording sections.

Sections were still used where necessary, but these were placed across features of interest rather than being tied to the edges of a square box trench (Biddle & Kjølbye–Biddle 1969). The recording of height information, as a rule, was little different from that under the box trench technique.

Evolution beyond the open area technique came with the widespread implementation of the single context plan, where contexts were recorded individually on separate recording sheets only after their upper horizontal extent had been fully defined by the excavator (Harris 1989, Pearson in Harris 1989; 101–102). The number of elevations recorded for each context increased significantly, with excavators attempting to crudely define the topography of each context. The amount of time invested in elevation recording therefore increased, but the results in **Chapter 5** would suggest that little new information of real value to the surface modeller was introduced into site archives by this practice.

Quality and Value

The twin concepts of deposit quality and value are occurring with increasing regularity in the archaeological literature, but their meaning and application appear to be the cause of some confusion amongst writers. The two terms are often used interchangeably within the literature and definitions vary between — and even within — publications.

The concepts as used in this thesis draw upon the work of Martin Carver (most recently in Carver 1996), and his definitions are assumed as the starting point for further discussion.

Deposit quality

Even in an archaeologically rich environment such as York, the buried deposits are of varying quality. In other words, their *physical* preservation can vary greatly, and this level of preservation has an effect upon their potential value to any research programme.

At a simplistic level, the definition of a 'good' or high quality deposit is straightforward and probably obvious to any archaeologically aware individual. Such a deposit will be well preserved, probably in anaerobic conditions, it will be deep, and it will be part of a long sequence of earlier and later deposits, although preferably little intercut by them. This description of the high quality deposit is presented visually by Carver in *Underneath English Towns* (Carver 1987; figure 88) and in the Ove Arup document (Ove Arup 1991; figure 3.1).

In projects such as the *York Development & Archaeology Study*'s deposit database, a measure of deposit quality was constructed by recording a number of variables from deposit thickness to whether or not the deposit was anaerobic (Ove Arup 1991; Appendix A). This database forms the basis of the work discussed herein, and is examined in more detail in **Chapter 4**. Although many of the variables are recorded on a simple two–point scale, it would be possible to construct a more complex coding scheme and thereby arrive at a single value for deposit quality at any given point by combining the different values in some way. Such a project would require a complete reassessment of archaeological archives rather than simply drawing upon the Ove Arup database, and was therefore beyond the scope of the current research. The implications of such a project in the future are discussed in **Chapter 6**, as well as an assessment of the obvious dangers inherent in providing planners and politicians with a simple numeric scale for quality and, by implication, value.

Deposit value

> value... [is]... the product obtained by matching the deposit quality with the research agenda: the knowledge desired with the knowledge available. In framing this definition it was accepted that neither the deposit quality nor the research purpose had any permanent status; the first was impermanent because the model of the underground resource was continually refined with every new contact made with it; and the second because the concept of what should be on the agenda was continually being revised in the light of new discoveries and new ideas.
> (Carver 1993; 15)

Whatever the quality of an individual deposit, its importance in terms of input to a modern excavation should be defined with respect to its value under the current research agenda for the area. Before approaching excavation in an area such as York, it is important that the excavator formulates (or complies with, if one exists) a research agenda in which archaeological questions and concepts deemed to be of importance are defined. A research design should then be implemented in order to address the means by which data fit for the purpose of answering the research agenda's questions may be captured. If operating effectively, both research agenda and research design will evolve over time as new data are uncovered, as new techniques emerge, and as new questions gain prominence. A static research agenda will quickly become worthless as those enforcing it lose touch with academic, popular, legislative and methodological reality. A purely reactive research agenda is also in danger of descending into mediocrity as excavators and planners are forced from one area of interest to another with each new discovery. The effective research agenda should, of course, be flexible in taking new discoveries on board, but it should also be capable of setting priorities and forcing the direction of archaeological work rather than merely reacting to current opinion or serving as a justification to the current projects of the excavating agency.

Deposit value is derived from a combination of deposit quality and the requirements of the current research agenda. The Medieval deposits of York's Coppergate/ Ousegate area, for example, are undoubtedly of extremely high quality, yet would hardly feature at all in a research agenda interested in the development of the Roman fortress area. Under such a research agenda, these high *quality* deposits would have a low *value*.

Deposit prediction

Given the low proportion of the archaeological resource visible above the ground, a degree of prospection has always been important in archaeology, whether the relatively crude gathering of evidence by Schliemann in order to identify Hisarlik as the probable site of Troy in the nineteenth century (Wood 1985), or the more advanced scientific prospection as employed at Sutton Hoo (Carver & Evans 1986) or, more recently, at Wroxeter (Gaffney *pers comm*).

With decreasing excavation budgets and a rapid increase in the applicability of remote sensing techniques and computer–enhanced analyses, archaeological prospection has increased dramatically, especially in North America. As part of this general trend, the deposit prediction techniques developed during the 1970's in towns such as London (Biddle *et al* 1973), Stafford and Worcester (Carver 1987) have become more important, and their use continues to spread to urban areas such as London's Southwark (Miller *pers comm*), Newcastle upon Tyne (Graves *pers comm*), Lund and Uppsala (Beronius–Jörpeland 1992) and even into the rural landscape in regions such as Wessex (Shell *pers comm*).

Site prediction techniques have been widely applied within the GIS field, although far more so in North American archaeology (Allen *et al* 1990) than in Europe, even five years on (Lock & Stancic 1995). The capabilities of modern GIS lend themselves well to the combination and manipulation of multiple variables necessary for generating these red flag models (Altschul 1990, Carmichael 1990, Hasenstab & Resnick 1990, Marozas & Zack 1990, Warren 1990*a*, 1990*b*, Zubrow 1990), and the complexity of modern computer–based models far exceeds the earlier manual techniques.

> The importance of predictive models of archaeological location to the growth of GIS in North American archaeology cannot be overemphasized.
> (Kvamme 1995; 3)

Little effort has been expended on either side of the Atlantic in turning the predictive capabilities of GIS modelling to an investigation of the urban sphere and it is in fact the arguably environmentally deterministic nature of so many models (*eg* Gaffney in Gaffney & van Leusen 1995) that reduces their value to the urban researcher.

In the days before the advent of archaeological GIS, complex assessments of urban deposit potential were undertaken on paper and although the data may not always have been as precise as the resulting output would imply (Brinklow *pers comm*), the results are all impressive. Of major UK projects, the early *Future of London's Past* (Biddle *et al* 1973) and the work of Martin Carver and the Birmingham University Field Archaeology Unit (Carver 1987) stand out as pivotal. Given the age of these projects, it remains remarkable that more modern assessments (*eg* Darvill & Gerrard 1994) ignore many of the lessons learned, and avoid consideration of the deposit in favour of a flawed emphasis upon 'monuments' and discrete units within the urban space (see page 82).

Occurring at about the same time as uncontrolled growth led to the Esher report on conservation in York (Esher 1968). and amidst a backlash against widespread destruction resulting in the formation of RESCUE, the *Future of London's Past* is an extremely pessimistic report in many ways more concerned with the amount of destruction than with the remaining resource. An earlier CBA report (CBA 1966) goes a long way towards capturing the feeling of the time with

> the old deserves to be saved not merely because it is old, but because it possesses qualities of permanent value to humanity.
> (CBA 1966)

Such a statement seems naïve and untenable in the 1990's, where the past is considered as simply one resource among many, and where proponents of studying the past must present a clear case for money being spent upon the investigation or preservation of a particular location. It is unlikely that many modern archaeologists would seriously consider arguing for the near unquestioning preservation of archaeology suggested in the CBA document, as such a stance would be seen as both anti–development and, arguably, anti–research.

Urban Theory

In approaching the study of urbanism, archaeologists borrow a great deal from other disciplines, such as anthropology and urban geography. Urban archaeologists are too frequently primarily concerned with individual excavation sites, with an urban overview only occurring within summarising works of synthesis (*eg* Ottaway 1993, Hall 1994) or, increasingly, in the development of research agendas or Urban Archaeological Database–driven urban assessments (English Heritage 1992) such as that in Newcastle upon Tyne (Heslop 1992).

In situations where wider issues are considered, many archaeologists have difficulty in conceptualising an urban whole, and tend to break the urban space down into a series of discrete elements, or 'monuments' as advocated by English Heritage (English Heritage & RCHME 1993*a*, Carver 1996, **Chapter 4**). Such divisions, although easy to legislate for and categorise, fail to adequately describe the essential coherence of urban space, and ignore the important fact that a major consideration when investigating urbanism is the relationship between components of the whole. Drawing essentially upon a rural model of discrete sites — a model which is losing credence within landscape studies (Chartrand & Miller 1994) — this monument–centric approach cannot succeed in considering urban spaces in a manner suitable for deposit led research.

The *polis*

Throughout this thesis, an emphasis is placed upon the consideration of an *urban space* rather than a discrete series of monuments grouped together in order to form a 'town' or 'city'. This approach is close to that espoused by Martin Carver (1996), but directly opposed to the monument–centric recommendations of the relevant national agencies (English Heritage & RCHME 1993*a*) discussed in greater detail below (page 82).

In considering the growth and development of a town, one of the most important factors is the interaction between components and the processes occurring between and within these components at any given point in time. The deposits comprising, beneath and between these identifiable components are as vital to a true understanding as any extant 'monumental' structures, and analytical techniques should therefore be geared towards a consideration of the deposits within a wider context rather than as blocks of stratigraphy lying beneath arbitrarily defined areas of interest.

This approach may seem obvious and, indeed, merely builds upon the earlier work of others (*eg* Carver 1987, Ove Arup 1991), but it is important to state the underlying premise clearly in order to differentiate from the more prevalent monument approach espoused by the national agencies.

In order to clarify the 'deposit and component approach' (as opposed to the 'monument approach'), a definition and label were sought in order to allow easy and clear reference to the technique and its philosophy without the need for lengthy justification such as this in every context where the approach is referred to. Although the detail of this concept, as outlined below, is not necessary for the deposit modelling methodologies adopted in this thesis, the two (wide-area deposit modelling as opposed to the identification of individual monuments and the notion of an urban whole in preference to consideration of aspects of urban space in isolation) evolved side-by-side during the conduct of this research. Archaeological deposit modelling may be undertaken by anyone with access to suitable data, regardless of theoretical persuasion. Nevertheless, it was thought useful to introduce readers to the manner in which urban space is perceived by the author in order, perhaps, to aid their understanding of why wide-area modelling is seen by him as being of value.

Over a period of time, the *polis* concept was developed by the author, with original inspiration from the works of James Lovelock (1987), and continual input and comment from the many subscribers to the `URBAN-L` electronic mailing list. The definition finally arrived at, and accepted by the list members in late 1994, was:

> a conceptualisation of coherent urban space. The *polis* encompasses both the mapable extent of the physical manifestation of urbanism and the conceptual urban sphere, within which a series of discriminable components combine to form the whole

Similarly to Lovelock's *Gaia* hypothesis (1987), the notion of *polis* emphasises the belief that an effective — in this case, urban — unit is more than the sum of its parts; housing, industry, administration, services, *etc.* are all possible in isolation, yet when combined in a single — urban — space, they interact with one another both to facilitate further growth and to create a sense of place, whether ephemeral and invisible archaeologically, or as a potentially quantifiable node within the landscape, exerting influence upon the flow of goods, people, ideas, and power for large distances into the hinterland.

Whilst suggesting that a notion of the urban space is valuable in tempering archaeological research into towns, it appears unfeasible that a *single* model is sufficient to describe the detail of all towns at all points during their life as active urban spaces. The model influencing those who constructed the Alfredan *burhs* of southern England (Biddle 1976), for example — or that formulated by those *studying* the same settlements today (*e.g.* Carver 1987; 48–49) — is different in many instances from models formulated for the creation or study of a Roman *colonia* (*e.g.* Wacher 1975, Carver 1987; 25).

Attempts have been made by archaeologists in the past to define that which is urban (Hodges 1989*a*; 20–25), with such attempts tending to be dominated by criteria–based classifications such as that for a medieval town from the *Erosion of History* (Heighway 1972);

1. defences
2. a planned street–system
3. a market(s)
4. a mint
5. legal autonomy
6. a role as a central place
7. a relatively large and dense population
8. a diversified economic base
9. plots and houses of urban type
10. social differentiation
11. complex religious organisation
12. a judicial centre

Such criteria may be mechanistically applied to evidence gathered from suspected towns, and are capable of acting as a check–list for the identification of urban–like attributes, yet they fail to necessarily recognise the required inter–relationships between these otherwise isolated — and un-urban — 'monumental' features. The *polis* concept is more closely allied to geographical notions of urbanism (*e.g.* Wheatley 1972) than to these essentially functionalist notions;

> It is impossible to do more than characterise the *concept* of urbanism as compounded of a series of sets of ideal–types social, political economic and other institutions *which have combined in different ways in different cultures at different times.*
> (Wheatley 1972; 623, emphasis added)

The *polis*, therefore, represents a pragmatic recognition that the 'town' may not be definable consistently across time and space, whilst serving as a convenient label for the conceptual model lying behind this research, wherein urban spaces must be considered in their entirety — spatially *and* temporally — if they are truly to be understood.

Despite the conflict between a suggestion on one hand that the *detail* of urban definition is not constant across time and space and, on the other, that towns should be considered where possible as a whole rather than as spatial (*e.g.* a 'monument) or temporal (a 'period') snapshots, this tension in itself serves to remind the practitioner of weaknesses within their data and of flaws within the model they are choosing to apply; a model which, like all others, is incapable of capturing the full reality of that which is modelled, and which often engenders more faith from the modeller than is perhaps deserved.

In searching for a suitable name to describe this concept, words in frequent modern usage were considered too loaded with associated meaning to be of any value, and it was felt important to avoid use of the three letter acronyms (TLAs) and extended three letter acronyms (ETLAs) so prevalent in modern technical writing.

The writings of Lovelock on Gaia (1987), although much misunderstood and misrepresented, are in many ways similar to the concept of the *polis* seeking, as they do, to document interactions between different elements within a wider whole (in Lovelock's case, the Earth's Biosphere). The Nobel laureate, Sir William Golding, turned to the classical world in searching for a suitable label for Lovelock's concept and settled upon the Greek 'gaia', the Earth goddess. This word, once known only to classical scholars, has re–entered modern English and is now associated primarily with the popular (mis)conception of Lovelock's work and with the wider environmental movement.

Although neither expecting nor seeking similar widespread adoption, the reasons for choosing *gaia* apply equally to the requirements for a term suitably capturing the *polis* concept, and the Greek *polis* was chosen over the Latin *urbs*, which was felt to be too closely associated with 'urban' and the connotations of skyscrapers, overcrowding and sprawl.

Even where not directly referred to in the following text, the *polis* concept underpins all consideration of urbanism and the urban space related to this research. Reading of the following chapters should therefore be undertaken with the definition of *polis* in mind.

Temporal Theory

Notions of time continue to concern GIS professionals, with a great deal of effort expended (*e.g.* Castleford 1992, Langran 1993, Halls & Miller 1996) in the search for an effective means of representing the temporal continuum in a meaningful manner.

A project such as this, however, is forced by the realities of archaeological data to contend with far less complex notions of time, and is constrained by these from devoting attention to more esoteric questions of temporality.

As outlined in **Chapter 4**, data for this project were collected as part of an earlier study (Ove Arup 1991) wherein archaeological contacts were defined merely as 'Natural', Prehistoric, Roman, Anglian, Anglo–Scandinavian, Medieval or Post–Medieval. No further granularity was offered, and the temporal spans of the periods were not clearly defined.

The use of such sweeping terms for defining periods of time has the potential to disguise underlying trends in data, and certainly makes it difficult to identify short–term changes such as those explored in **Chapter 5**'s case study 2. Other problems also arise in the application of named periods of time; those of cultural associations with the selected name and difficulties in clearly defining the interface between one period and the next.

Despite the problems outlined in detail below, it remained necessary for this project to use the temporal units of the core data (Ove Arup 1991), even with their limitations. Discussions of a temporal nature throughout the body of the thesis should therefore be read with a consideration of the issues below in mind.

Temporal resolution

Developments in and around York, even in the short duration of this research project, show how quickly human development is capable of transforming existing topographies and serve as one illustration of the information lost in grouping long temporal spans together because of possibly spurious cultural associations. The Ove Arup database (1991), for example, defines a period of over 300 years as 'the same', merely because of some continuity in the cultural grouping within which York was defined as existing at the time. Yet archaeological and historical evidence (*e.g.* Ottaway 1993) for the early first millennium AD clearly shows great change throughout this period, both within York and in the wider culture of which it was a part. These changes *within* such a period may, on occasion, be greater than those *between* one period and the next, but such diversity tends to be suppressed by the rigorous application of chronology to the past.

If it is to be possible for such change to be detected and represented in a system like that developed in the following chapters, then data must be captured with sufficient resolution for underlying trends to be isolated and modelled.

Individual excavations in a city such as York tend to produce notions of phased development on a site (*c.f.* Table 12) that transcend crude period groupings such as those of the Ove Arup report. In generalising results across the city as a whole, however, such site–specific detail is invariably reduced to the lowest common denominator and basic period groupings re–emerge.

Adoption across an urban area of a temporal coding scheme such as that illustrated in Table 7 (and elucidated further in Chartrand & Miller 1994) would allow for the recording of temporal characteristics of objects, events and strata in as much detail as was available at any given time, whilst also making it easy for future users to generalise such precision if necessary for their purposes. Importantly, the coding scheme actively encourages the categorisation of temporal spans to the nearest century, and offers an easy means by which dates may be expressed to the level of a single year. To record such precision from the outset allows generalisation where necessary, but the obverse is untrue, as a date of 'Roman' may never be refined to 'AD 306' without the input of further information.

Given the data available, dates in the project database (**Chapter 4**) were only expressed using the numeric equivalent of Ove Arup's (1991) period names, but the database structure is constructed in such a fashion that new data might easily be recorded with greater temporal precision.

Cultural associations and temporal labels

Archaeological periods are often named after cultural groupings of prominence at that time, such that the time span of the Roman empire is known as the Roman period, *etc.* Although useful in appending well understood constructs of the past to a particular temporal duration, these named periods do not bear close inspection and actually require a degree of imprecision perhaps not always recognised by those making use of the terms.

The simple application of cultural labels to temporal periods is largely untenable, partly because an entity such as the Roman empire changes in size over time and partly because, even while notionally within such an entity, large areas of land are unlikely to be much affected by any change of control amongst the elite, with an Iron Age farmer potentially remaining a largely unchanged Iron Age farmer, even if his farm is drawn within a sphere of influence or control designated as Roman.

Perhaps the greatest difficulty with the use of culturally determined labels such as 'Roman' is the fact that the term is necessarily associated with different temporal durations across the spatial extent of its use. Thus, while 'Roman' may sensibly be applied to the entire span of Roman Republic and Empire in central Italy, it is perhaps only relevant to the first four centuries of the first millennium AD in southern England, and to an even shorter span in central Scotland, where Imperial control was exerted for a shorter time still. Indeed, the term is likely to have different connotations and a different temporal duration at nearly every point in the empire, and is further confused by the degrees of Romanisation potentially associated with, for example, trade, clientship, and conquest.

The terms as used in Table 7 are notionally correct for the environs of York, but even here are open to some debate and are thus merely provided as convenient labels with which to associate the more objective numeric codes.

Towards the edge: when is a Roman not a 'Roman'?

Chronologies applied to the past tend to reinforce certain interfaces, whether absolute (years, centuries, millennia) or cultural (reigns, empires, periods) in nature. Whatever the nature of these interfaces, they tend to be reinforced by the chronologies in common usage, such that one century is seen as 'different' from the next, for example.

Whilst significant changes do often occur in the *duration* of a century, the notion that events at the *interface* — occurring on 31 December in one century as opposed to 1 January in the next — are somehow different is patently ludicrous. Similarly, such interfaces as the 'end' of Roman Britain in the fifth century do not lead overnight to changes, but rather merely mark one point in a process of change started long before the 'end', and likely to continue long after.

In this respect, case study 2 in **Chapter 5** is constrained by the Roman/Anglian interface inherent within the temporal recording of the data used. More usefully for this case study, as for other research, the data might be recorded with as much precision as possible — and free of culturally determined period constraints — in order to enable researcher and GIS to explore the data in search of the relationship between changes visible in the archaeological record and the cultural labels to which they are often too closely aligned. As it was, and as **Chapter 5** demonstrates, the coarseness of the underlying data prevented such an analysis from taking place.

Time for a change?

Notions of temporality are at the heart of much archaeological work, and representations of time are a key research topic within the wider GIS community, although one in which there have so far been few breakthroughs of note.

Within archaeology, temporal labels tend to be applied with less care than perhaps they might and, although this thesis perpetuates the use of such labels, it is with an awareness of the many problems involved.

In order for temporal information to be of more value to those researching multiple data sources, it is necessary for dating information to be uniformly recorded with greater precision and *without reference* to highly subjective period labels. With such precision available, it becomes possible for the researcher to generate period divisions of relevance to the patterns within the data, and to tie these patterns to the widely understood — but loosely defined — culturally determined period labels in order to enable discourse with a wider audience. Such flexibility was not, however, forthcoming from the data used in this research, and the results should be read accordingly.

3. The development of York

> York possesses archaeological deposits some of which are of outstanding importance. These deposits rank in importance alongside streets such as the Shambles and Stonegate and match the landscape and environmental quality of areas such as Museum Gardens and the Strays.
>
> (York City Council 1992*b*; par. 2.3.1)

Background

Whilst this thesis is not the place for a detailed discussion of the archaeology and history of York, a background to the changing circumstances of the city through time will allow the reader to better understand both the need for detailed mapping of the resource, and the selection of the specific case studies discussed later. The history of York is outlined and certain areas are discussed in greater detail to provide a flavour of the subsurface remains. References cited in text should be consulted for more specific data.

Lying at the confluence of two rivers, and on a narrow band of terminal moraine traversing the Vale of York (Figure 1), the city of York occupies a position of strategic importance both militarily and commercially; an importance recognised and exploited for at least the last two thousand years.

Whilst there is little evidence of pre–Roman activity in the immediate vicinity of the Roman fortress and later medieval city (Hanson & Campbell 1986), aerial photographic evidence (Addyman 1984, Jones 1988) clearly indicates the presence of native settlement in the surrounding area, much of which dates prior to the construction of the Roman fortress towards the end of the first century AD. The name given to the Roman settlement, *Eboracum*, has been suggested as native rather than Latin in origin (Wellbeloved 1842; 44, Hanson & Campbell 1986) and given the normal Roman tradition of naming fortresses after rivers (Hartley 1971) as at Chester, where the fortress of *Deva* stands on the modern river Dee, an earlier native settlement on the site has been proposed. Some writers (Hartley 1971) have even suggested York as the central place of the Brigantes, and capital of Cartimandua. Given the positive identification of Iron Age remains at the huge 243 ha site of Stanwick (Wheeler 1954), and the lack of any identifiably pre–Roman structural evidence from York (Hanson & Campbell 1986; 76), this seems an unlikely hypothesis.

Recently examined evidence from the City Garage site on Blake Street (Monaghan 1993) and from the Museum Gardens (Cool *pers comm*) points to a possible Roman presence some years before the documented advance of the IX legion. It is suggested (Cool *pers comm*) that this assemblage may be military in origin, but firm evidence of pre–fortress military structures remains elusive.

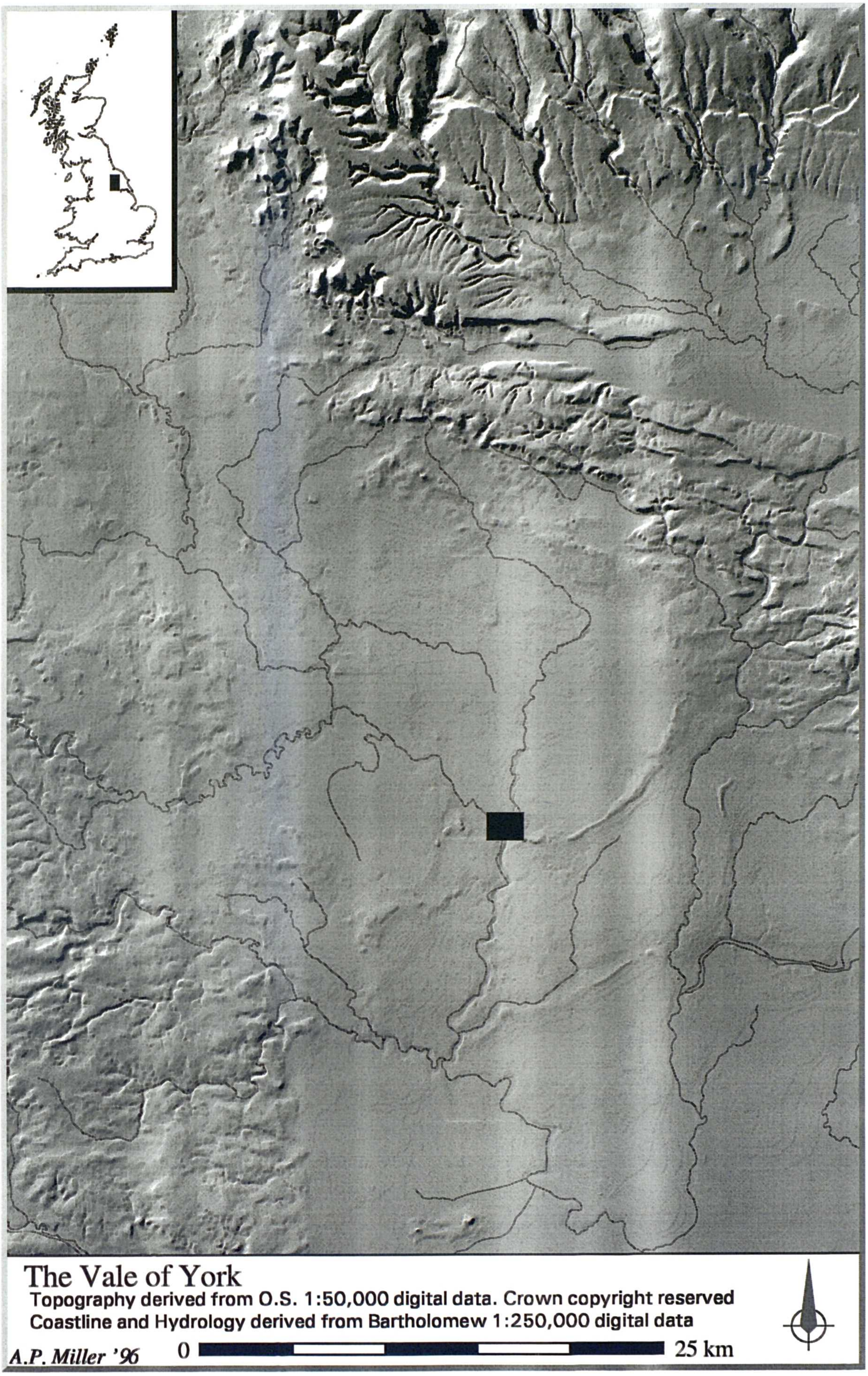


Figure 1: The Vale of York

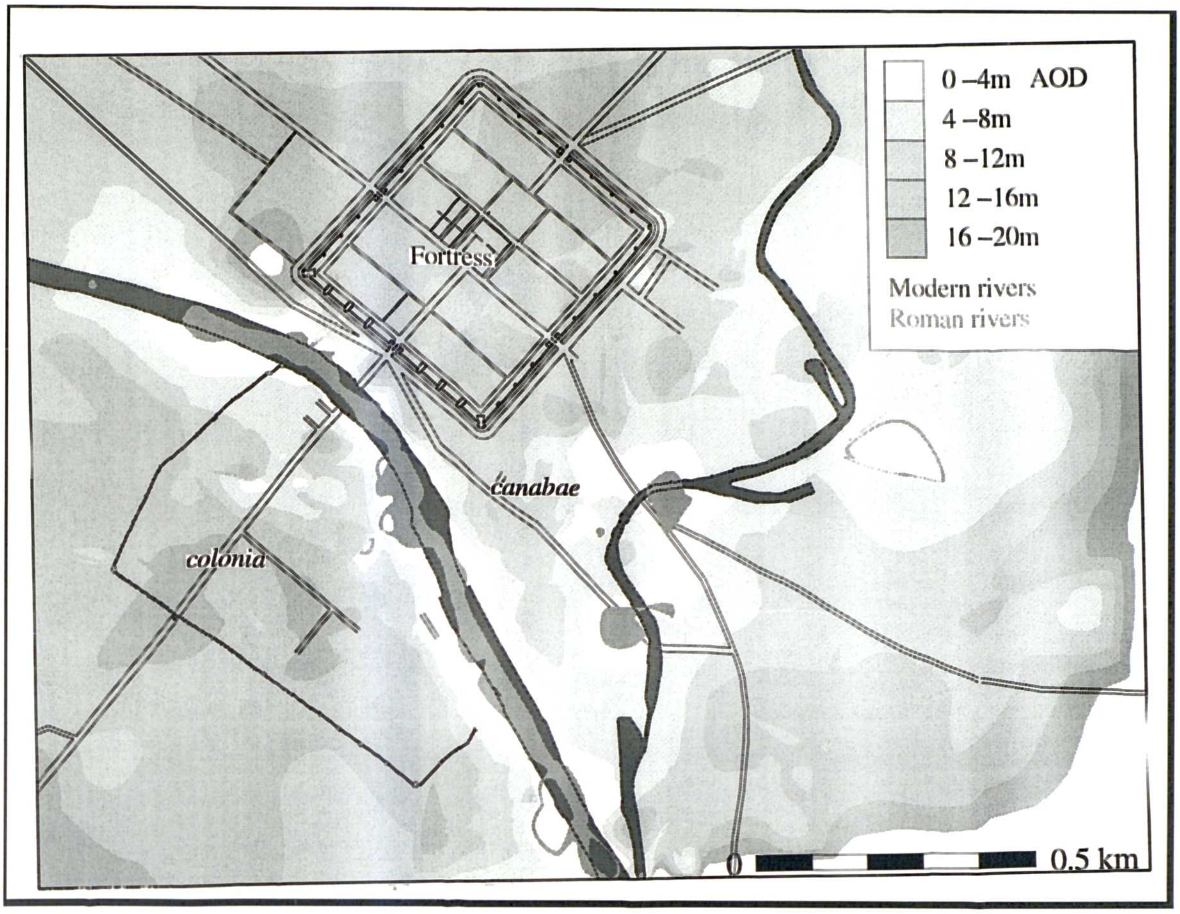


Figure 2: *Eboracum* with underlying computed Roman topography and hydrology

With the advance of the Roman IX legion under Petilius Cerialis in AD 71 (Wenham 1971*a*), York was recognised as an ideal place for the situation of a legionary fortress due to its topographic advantages and position in relation to the two native tribes of the Brigantes and Parisi. It has been suggested (Addyman 1984) that the band of moraine visible in Figure 1 would have formed an important routeway across the wide Vale of York, and area that was probably less well drained, and thus wetter, in the past than now (Manby 1980). This important routeway would have served as an interface between the west and east sides of the Vale, and thus between the Brigantes in most of Yorkshire and the Parisi in North Humberside (the modern East Riding). Communications up and down the Vale along the tidal and navigable Ouse would also be controllable from York and the naval base at *Petuaria* (Brough) on the Humber (Wacher 1971, Wenham 1971*a*; 9).

A timber fortress was constructed between the two rivers (Figure 2) and became the new base for the IX legion, which moved from Lincoln (Wenham 1971*b*) to facilitate expansion of the fledgling province northwards into Brigantian territory and beyond. As a legionary fortress the site was of great importance within the province of Britannia, serving as the base for legions operating along Hadrian's Wall and further north into Scotland. Throughout the Roman occupation of Britain at least three emperors visited York and two — Septimius Severus in AD 211 and Constantius in AD 306 — died there (Wellbeloved 1842). Outside the fortress, there is evidence of settlement on both sides of the river, and possible wharves and cranes (Ramm 1971, Ordnance Survey 1988*a*) on both the Ouse and Foss point to commercial use of the river system.

The earliest extramural buildings appear in the strip of land between the south–west gate of the fortress — the *Porta Praetoria* — and the River Ouse. This *canabae* (Ottaway 1993; 67) shows evidence of granaries (Brinklow *et al* 1986) in the Coney Street area and unidentified stone structures in Coppergate (Hall 1984). These granaries are identified as stores for tithes, collected from the native population and gathered at York for shipment down the coast to London or mainland Europe. On the south west bank of the Ouse, the Royal Commission (1962) suggests that first century wooden structures also exist in the area to the north west of the main Roman road from the south. This area between Toft Green and the railway station must have been fairly small as it is constrained by the main road to the south east and a cemetery to the north west. Ottaway (1993; 72) suggests that the rest of this zone south west of the river may well have been kept clear for military reasons, as there is little evidence for structures earlier than the second century.

With an increasing population, the civilian settlement at York expanded, probably encompassing the walled area of the later medieval city on the south west bank of the Ouse by the third century (Ottaway 1993; 72–73). Some time in the early third century (*c.* AD 210), York became both a *colonia*, the highest ranked of Roman civilian settlements, and capital of the new province of *Britannia Inferior*, or northern Britain (Ottaway 1992; 83). These developments and the archaeological evidence for growth in the civilian settlement (RCHME 1962) would suggest that York was recognised as being of more than merely military importance within the province by this time. From a military point of view, the major advance for York was in the fourth century when it became base for the *Dux Britanniarum*, a poorly understood military position which seems to have been responsible for the control of the military in northern Britain (Benson 1911). At about this time parts of the fortress wall appear to be refurbished, with the most notable rebuild being that of the south west wall of the fortress — the section facing the civilian settlement (Ottaway 1993; plate 10, Robertson 1995).

By the fifth century, Roman government in Britain was in terminal decline, with the oft–cited letter of Honorius in AD 410 usually equated with the 'end' of Roman Britain. Decline in York itself is identifiable earlier than this date, with town houses on Bishophill being converted to factories for processing fish (Briden *et al* 1986), and the Roman fortress wall possibly patched with a crude repair — the so–called Anglian tower (Buckland 1984) — yet it is impossible to identify any specific date for the final abandonment of the fortress and civilian settlement; if, indeed, they were ever truly abandoned.

Even the confusing evidence of the later Roman period in York is more useful to a study of urban development than the dearth of concrete data for the Anglian period (defined as AD 400–800 in **Chapter 4**, Table 7) where archaeologists struggle to find dateable material. It seems unlikely that the strategic importance which first drew Petilius Cerialis and his legion to York would be overlooked in the immediate post–Roman period as central authority and the weight of Roman military control crumbled, leaving opportunities for new societal groupings to form and struggle for advantage in the new climate. In any newly formed polity, the very fact that York had been an important Roman centre would doubtless have been used as a means of legitimising the new order by demonstrating a continuity of settlement, and therefore authority.

Despite an extensive and ongoing programme of excavation undertaken by York Archaeological Trust, evidence for York in the immediate post–Roman period remains unforthcoming. Other than cemetery sites around the Roman city at Heworth, the Mount, and on Bootham (Addyman 1994), fifth, sixth and seventh century York is almost invisible archaeologically. Previously misleading evidence from beneath York Minster has recently been reinterpreted (Phillips *et al* 1995) and sheds some light upon the core of the Roman fortress in this period, providing information on the living inhabitants of Anglian York, rather than merely their dead. The Venerable Bede refers to the baptism of Edwin of Northumbria in York in AD 627, but it is unclear whether this baptism took place at York because it was an important royal or ecclesiastical centre of the period, or because it had been the diocesan centre for *Britannia Inferior* during the Roman period and was thus perceived as a suitable centre for new religious practice.

In the later Anglian period, good archaeological evidence survives for the trading settlement, or *wic* (Kemp 1987), and documentary sources point to an ecclesiastical and royal presence somewhere in the city at the same time, although these have yet to be located archaeologically (Morris 1986). This *Eoforwic* lies to the south of the Roman fortress by the confluence of the rivers Ouse and Foss and dates to the eighth and ninth centuries with clear evidence of a planned street layout and international trade. The extent of the settlement is unknown, but Anglian evidence has been discovered as far east as Walmgate Bar, suggesting that the settlement may spread in that direction.

In AD 866, York was captured by the Danes and became capital of the Viking Danelaw (Hall 1994). Known during this Anglo–Scandinavian period as *Jorvik*, the city became a thriving commercial centre and left incomparable evidence of this boom in the archaeological strata of the Coppergate/Ousegate area, which are deep, well stratified, and anaerobic. During the Anglo-Scandinavian period, settlement again becomes apparent within the walls of the old Roman fortress, and some areas of the defences are apparently reinforced. New defences may also have been constructed between the east angle tower of the Roman fortress wall and the river Foss, enclosing an expanse of the Roman extramural zone (Addyman 1994; 112).

This period marks a major reorganisation of the city, with the street grid being largely redefined to approximate its modern form. A major shift is apparent away from the old line of the Roman road running approximately from Micklegate Bar to Lendal Bridge — the site of the old Roman bridge — to a new alignment down Micklegate itself to Ouse Bridge — where a new bridge was constructed by or during the Anglo-Scandinavian occupation. This change is also reflected on the north east bank of the Ouse opposite Micklegate, with the laying down of a complex of streets and planned plots in the Coppergate/Ousegate area (Hall 1988*b*). Other new streets were also laid down across the city, as the suffix *–gate* (from ON *gata* meaning street) in many York streetnames suggests, but the commercial focus would appear to be in the Coppergate/Ousegate area (Hall 1994).

After the Norman Conquest of England in 1066, York remained an important regional centre, with two castles erected, and a massive rebuild of the Minster church begun. Clifford's Tower and Baile Hill were erected within three years of the Conquest (Benson 1911), and one of the city's seven shires was flattened to make space for them. The two motte and bailey castles were set on either side of the river Ouse to the south of the city, and were apparently intended to control access to and from the city by river, as well as to control and protect the populace (RCHME 1972*a*). It is perhaps a measure of the problems York posed for the Normans that the city had two castles built at such an early date. Even with these strongholds, the populace repeatedly caused problems and attacked the castles at least twice before William himself returned to the city, ravaging both it and its hinterland in the 'Harrying of the North' (Addyman 1994) and rebuilding both castles. As part of the Norman strengthening of the defences, the river Foss was dammed to provide a moat for York Castle (Clifford's Tower). This so–called King's Fishpool was a major alteration to the landscape, and constrained development in the eastern portion of the city for centuries until the Foss was canalised in the 18th century. These alterations make it almost impossible to discover the pre–Conquest course of the Foss without an extensive coring programme, and the problems posed to the YAA terrain modelling programme may be clearly seen in many of the models, below. The defences around the rest of the city were also enhanced, with the earthworks being heightened, and eventually topped with a stone rampart. In the twelfth century, the defensive circuit was also extended to include the Walmgate area (RCHME 1972*a*). In the 1080's, Archbishop Thomas of Bayeux began a major rebuild of the Minster, and altered its alignment to conform with the east–west alignment expected by the Church (Phillips 1985). This imposition upon the essentially Roman street plan in this area of the city caused some reorganisation of the surrounding streets, and is still clearly visible in the modern city plan (Ordnance Survey 1988*b*).

The twelfth to fourteenth centuries marked the heyday of York, with rapid expansion of the population (RCHME 1972*b*, 1974, 1981), and the foundation of a number of religious houses such as the Benedictine nunnery of St Clement and the Gilbertine St Andrew's priory. Churches all across the city were enlarged or improved, and new churches were established in the city centre. From 1246–1337, York was frequently capital of England during the wars with Scotland.

The wealth and power of York as a trading centre began to fade in the later fifteenth century with the growth of the West Riding textile industry, the waxing influence of the Hanseatic League (Andrews 1984) and the increasing shift of shipping from York downstream to the more accessible Kingston upon Hull (Esher 1968). This downturn in the fortunes of the secular community was soon matched within the Church with the Dissolution in the early sixteenth century, and the suppression of all monasteries and friaries within the city from 1536–9. Despite the availability of large tracts of land within the city following the destruction of religious buildings, little new development took place; a sure sign that the city was in decline (RCHME 1972*b*, 1974, 1981). In line with this economic and spiritual decline, the city's population plummeted from *c.* 15,000 in the fifteenth century to a mere 8,000 in the mid sixteenth century (Andrews 1984; 183). The Civil War and the Siege of York in 1644 did not help the ailing fortunes of York, as the city backed the losing royalists and was eventually forced to surrender to Cromwellian troops in July of 1644.

The eighteenth century marked a period of some regeneration, with the creation of grand new buildings such as the Assembly Rooms (1730), but it was not until the coming of the railways in the nineteenth century that York again began to boom; now as a tourist centre. The city walls and many other monuments were restored by the Victorians, and large development programmes were initiated in the extramural areas resulting in the extensive housing visible today. This development, especially the provision of the railway, resulted in a population explosion from *c.*16,000 in the census of 1801 to *c.*36,000 in 1851 (RCHME 1974). The Irish potato famine of 1845 and the resulting exodus to cities such as York, Liverpool and Glasgow contributed to the rapid expansion. The chocolate factories that were later to make York famous were also established at this time, providing a source of employment for the growing population.

Into the twentieth century, York continued to grow, with the developments of the 1960's and 1970's impacting most visibly upon the archaeology of the city due to widespread development in the intramural area and the construction of the Inner Ring Road (Esher 1968). Local Authority emphasis in the 1980's on attracting government departments and other large organisations to York (York City Council 1992*a*) has resulted in the construction of headquarters buildings for the National Curriculum Council — now the Funding Agency for Schools — and the Ministry of Agriculture, Fisheries and Food, as well as a new regional headquarters for General Accident.

Early Archaeological Investigation

The changing practices of antiquarian and archaeological work within the city reflect well the altered social, ideological and academic circumstances influencing workers in York across the centuries. A clear progression may be charted from the antiquarian investigations of writers such as Drake (1736) to the tightly legislated work of the PPG16–dominated 1990's (DoE 1990, Ove Arup 1991), and on to the proactive interventions that might replace current reactive solutions in the future (Carver 1993).

As with the discipline as a whole, aims and aspirations have changed throughout the study of this city, and the development of new methodologies and hypotheses have altered the way in which archaeology is investigated and results interpreted.

The earliest antiquarians were concerned mainly with the remnants of Roman York, and with relating York to the wider context of Imperial Rome. Given the growing role of Britain as an imperial power at the time, and the predominantly high status of these early antiquarians, interest in York's previous imperial incarnation is hardly surprising. Throughout the eighteenth and nineteenth centuries, Anglian and Anglo–Scandinavian remains in the city and elsewhere were largely ignored, where they were even identified at all. Remains of Roman structures, however, were recorded in some detail and often appear in issues of the local newspapers, as well as learned journals such as that of the Yorkshire Philosophical Society, founded in 1823.

Archaeological work in this period was undertaken on a largely *ad hoc* basis, where identifiable remains were struck by construction projects and an interested individual happened to be either in the area or known to the workmen. Many of the early finds in the Micklegate area, for example, are attributed to the fact that an early curator of the Yorkshire Museum lived outside Micklegate Bar and walked that way to work each day (Roskams *pers comm*). A prolific source of Roman artefacts was the station area, where the construction of numerous railway lines and two stations cut through a large Roman cemetery and the western edge of the *colonia*. The finds from this area are detailed in the Royal Commission volume, *Eburacum* (RCHME 1962).

The study of medieval York concentrated largely upon the standing buildings themselves and the documentary sources, rather than upon the application of excavation to the buried remains. Standing remains such as the City Walls were consolidated during the nineteenth century, and the ruins of St Mary's Abbey were incorporated within the gardens of the Yorkshire Philosophical Society.

In the twentieth century, larger projects began to appear, with locals such as Peter Wenham from the College of Ripon & York St John undertaking excavation work in the city (Wenham 1968). Work at this time was still largely reactive and concerned primarily with high visibility Roman remains.

In line with other areas of the country, the rapid development of the 1960's caused unparalleled — and largely unquantifiable — damage to the archaeology of York. Large construction projects were undertaken in the very heart of the city at sites such as 65–71 Goodramgate, the Stonebow, and 11–17 Spurriergate with little, if any, archaeological work undertaken. Emergency work on stabilising the central tower of York Minster and the resulting archaeological excavations (Phillips *et al* 1995, Phillips 1985) marked a welcome change to the far less structured approach to recovering many of the threatened deposits beneath the city. Amid growing concern as the old city was torn apart, the Esher report was commissioned (Esher 1968) to assess the implications to York of continued development. It should be noted that archaeology itself goes unmentioned in the report, although many of the conservation issues raised apply equally to archaeology as to the historic buildings *etc* actually discussed.

Even with the creation of a professional Unit in 1972, archaeological work in the city remained largely reactive in nature, with excavations undertaken in advance of destructive development. This unit, the York Archaeological Trust (YAT), has been responsible for the vast majority of the excavations in York and has added hugely to our knowledge of York's past. Given the constraints of rescue–led government funding through much of its history, the levels of research (as opposed to mere recovery) managed by YAT are remarkable.

According to Peter Addyman (1994), YAT is attempting to work to a research programme within the constraints laid down by funding and lack of free access to excavation sites. The aims of the programme are nine–fold:

- to determine the pattern of pre–Roman landuse, and discover the pre–urban topography
- to determine the Roman urban plan
- to discover the steps by which Roman York evolved to the present
- to excavate a representative series of buildings from all periods
- to extensively explore certain districts deemed representative of larger areas of the city
- to show the impact of urban population on the environment
- to study environmental conditions in the city through time
- to explore exploitation of resources
- to investigate the importance of trade

The results of these investigations are well documented in the *Archaeology of York* series and in the popular periodical, *Interim*, and YAT would appear to be achieving many of the stated research aims. As well as the large number of small and short–term interventions around the city, the Trust have been involved in a number of larger projects spanning several years. These large excavations have been pivotal in adding to our detailed understanding of York archaeology, and sites such as Coppergate (Hall 1984) are famous worldwide. As well as the primarily Anglo–Scandinavian excavations at Coppergate from 1976–81, large excavations at Wellington Row from 1987–91 (Ottaway 1993) and Back Swinegate from 1990–91 (Pearson 1990*a*, 1990*b*) have shed important light on the Roman bridgehead and fortress, and the long running Bedern site (Richards 1993) has illustrated medieval life in the very heart of the city.

The work YAT has undertaken through the Environmental Archaeology Unit at York University, and published in volume 14 of the *Archaeology of York* series, has been important in shedding new light on the past environment, and has provided new information on everything from the post–Roman use of the fortress (Kenward *et al* 1986) to changing levels of pollution in the rivers (Jones *pers comm*).

Throughout much of its history, YAT was, like the majority of urban units in Britain, driven by the beliefs of rescue and 'preservation by record'. Excavation was undertaken on the majority of threatened sites and most of the money was supplied by government. Recent changes of policy and a number of studies carried out both centrally (DoE 1990, Darvill 1992, English Heritage 1992) and locally (Ove Arup 1991) have led to a change in emphasis away from recording all threatened sites towards preserving archaeology *in situ* wherever possible. It is widely believed that large excavations such as Coppergate will never be funded again, and that the future of excavation in urban areas is largely a future of small keyhole investigations in advance of piling, in association with an array of non–destructive techniques such as remote sensing (Stove & Addyman 1989, English Heritage 1995) and deposit mapping (Richards 1990, Miller 1995*a*, 1995*b*, forthcoming, Miller & Oxley 1994).

Applying deposit modelling to York

As discussed in **Chapter 2**, the use of deposit modelling techniques in this country developed almost wholly from *The Future of London's Past* (Biddle *et al* 1973) and the work of Martin Carver and the Birmingham University Field Archaeology Unit (BUFAU) in the Midlands during the 1970's (Carver 1978, 1980*b*, 1981). Despite the apparent value of these studies, little further use has been made of deposit modelling within British towns other than York. Indeed, the Monuments Protection Programme manual for urban areas (Darvill 1992) describes deposit modelling as useful, but not essential, in the study of towns and cities. At the 1994 IFA conference, an English Heritage spokesman advocated the 'SMR approach' whereby information was collected and stored on individual monuments rather than the techniques, including deposit modelling, which make up a siteless approach to the town (Thomas 1994).

The Andrews report

The earliest serious attempt to analyse deposits beneath York as a coherent entity was that undertaken by Gill Andrews in 1982 (Andrews 1984).

As Saunders suggests in his introduction to the report (Andrews 1984; 173), the motivation behind this study was primarily financial; it was an attempt by the then Inspectorate of Ancient Monuments to assess the value of expensive urban excavation and to pinpoint, if possible, areas of the city most worthy of future funding. Although written over a decade ago, this report still forms possibly the most comprehensive single description of past archaeological work in the city, and makes an essential introduction to any review of archaeology within York. In terms of the current research, the main failing of the Andrews report — and, perhaps, a missed opportunity for the Inspectorate — is that it omitted the question of *where* or *why* archaeological work should be undertaken in the city, preferring merely to identify areas where excavation might be possible or where post–depositional development was felt to have destroyed the buried archaeology. The maps of destroyed deposits produced by Andrews — and reused by the Ove Arup study — form an important guide to the areas of the city unlikely to produce new results if excavated. Discussion with YAT (Brinklow *pers comm*) suggests that more scientific study of the deposits is required before confidence may be placed in such a map, produced largely from an empirical knowledge of the deposits rather than accurately measured investigations.

Essentially, the Andrews report provides a most useful summary of the history of York and archaeological work therein up until the early 1980's, drawing as it does from many published and unpublished sources. The report fails, though, to address the question of where future work should be undertaken, or which areas of the city are most likely to address current research issues. With the supremacy of the preservation by record philosophy at the time the report was written, it was undoubtedly an important and effective summary, allowing the Inspectorate of Ancient Monuments to easily identify the *types* of archaeology likely to be destroyed by proposed development, but it fails to address the issues of deposit quality and value, or relevance to a stated research agenda that are so important in York today.

The Ove Arup report

In the aftermath of embarrassing mistakes made in York and elsewhere (Biddle 1989) in the late 1980's, the City of York and English Heritage jointly commissioned a study into the ways in which archaeological preservation and research could better be integrated with modern development. This report was produced by the civil engineering firm Ove Arup (1991) and York University's Department of Archaeology, and formed the basis of the City Council conservation policy for archaeology (York City Council 1992*b*).

The purpose of the Ove Arup report was seen as

> to update knowledge of the City's archaeological resource and to provide a framework for ensuring the development of sites is secured in a way which can conserve the most outstanding archaeological resources.
> (Ove Arup 1991; 1)

In order to achieve this goal, the report undertook to investigate two separate objectives; an engineering study of piling strategies capable of minimising archaeological damage; and a review of past archaeological work resulting in the construction of a computerised database of archaeological contacts and deposit models showing the topography at different times in the past.

The first resulted in the generation of piling strategies designed to support many different building designs, while only destroying a maximum of 5% of the buried resource (Ove Arup 1991; 6–7). Doubt has recently been cast upon this model (Biddle 1994, Gabby *pers comm*) due mainly to the danger of waterlogged deposits being pierced and therefore drained by the deep piling necessary to reach firm subsoil. Further work is necessary to assess the damage which piling actually does to buried deposits (Stockwell 1984). A major step proposed by the Ove Arup study was for piling diagrams to be stored centrally so that future buildings on a site may use existing piles where possible, rather than requiring further piling (and, presumably, the loss of a further 5% of the deposits). The practicality of this suggestion will obviously not become apparent for some decades.

The second of the two objectives, construction of the database, resulted in a database of over one thousand entries (see page 61) for archaeological contacts across York over the past few hundred years drawn from sources ranging from the Royal Commission volumes on York (RCHME 1962, 1972*a*, 1972*b*, 1974, 1981) to the archives of York Archaeological Trust (Ove Arup 1991; Appendix A). As discussed further in **Chapter 4**, data were collected on the height of deposits above sea level, and some effort was made to assess factors such as waterlogging, quality, and anaerobic properties. A programme of boreholes was also used to construct a separate database of information on the underlying geology. The gathered data were utilised to construct computer models for York deposits using the *UNIRAS* package (Richards 1990), and provided the inspiration for the current work. As with the Andrews report (Andrews 1984), the Ove Arup study succeeded in achieving its objectives and provided an excellent case study for the importance and potential of deposit modelling within urban areas, but the computer based modelling did have certain limitations which the current work would hope to resolve. These limitations were a result of the software available to the researchers, and the specific nature of the project brief which did not require much of the flexibility now considered important. In terms of the deposit models themselves, the software was incapable of satisfactorily merging the modelled topography with features of the built or natural landscape, whether modern or historic. Early attempts to drape the walls of the Roman fortress, for example, resulted in unsightly stretching of the lines down into folds of the terrain.

The report provided several important recommendations for the ways in which archaeological work should be conducted in the city. It suggested that all proposed developments should be subject to a site evaluation which, although primarily desk based, could include limited excavation or remote sensing. Importantly, *only* those sites which were felt to have a large contribution to make towards current research objectives should then be excavated. This contrasts markedly with the recommendations of PPG16 and its 'presumption in favour of... preservation' (DoE 1990; par. 8).

Based upon the results of the deposit modelling, prior archaeological knowledge and the engineering input of Ove Arup, the city was divided into twenty archaeological zones (Ove Arup 1991; Appendix B). Sites within those zones were then evaluated to discover the best means of mitigation from one of five options;

1. Preservation under piling. *Normally* less than 5% destruction of deposits
2. Full excavation over 3–4 years — cost *c.* £1,000,000
3. Full excavation through floor of new building either during construction or at a later date
4. Preservation in view
5. Watching brief during construction. Deposits not felt to be worthy of preservation, so no constraint upon foundations

As guidance, the zonation and assigning of levels of mitigation is useful to the developer and planning authority, but with knowledge of York's archaeology still patchy, it is dangerous to assume that we are able to zone areas of importance at different periods without even knowing what lies beneath the ground. The Anglian settlement discovered beneath the Redfearns National Glass factory in Fishergate (Kemp 1987) is a case in point as, prior to the excavation, this area would have been considered of low importance for any study of pre-Norman York. Of the zones, 6 (30%) are felt to be of 'high quality', 4 (20%) are of 'medium quality', and 50% are felt to be too poorly understood to be quantified (Ove Arup 1991; 2). Therefore, even if the zonation is assumed to be correct for all potential developments within a zone, half of the city centre is unquantified and in urgent need of further study. The problems of even beginning to address quality itself are widely recognised (*eg* Carver 1993).

There are inconsistencies within the report, such as the major discrepancy between

> The archaeological deposits of the city of York are a cultural resource of international importance and *shall be preserved whenever possible*
> (Ove Arup 1991; 6. emphasis added)

and the premise that the most important sites should be investigated by means of a research excavation (Carver 1993), but these appear resolved in the application of the report to real situations in the City Council policy (York City Council 1992*b*).

City Council policy

Based upon the recommendations laid down in the Ove Arup report, the new Principal Archaeologist for York City Council embarked upon the task of creating a workable policy for management of the archaeological resource in the face of development demands. This document (York City Council 1992*b*) lays down the policies adopted by the council, and advises developers and archaeological contractors of the procedures to be followed during the development process. The aims and objectives are summarised as

> To promote development
>
> To conserve the archaeological resource
>
> To manage the archaeological resource
> (York City Council 1992*b*; par. 2.1)

and the mechanics of the development and planning process are intended to alleviate conflicts which arise between these three.

Importantly, this document lays down the stipulation that archaeological evaluation shall be *required* prior to any development on an archaeologically important site, and states that the City Council will be prepared to refuse planning permission for a development proposal failing to adequately minimise damage to the archaeological resource within its mitigation strategy. An unusual stance is taken in that archaeological excavations other than those required by mitigation would themselves be subject to the planning system, and required to apply for planning permission in the same manner as any other change of use. This novel approach to managing 'research' excavations has yet to be tested by the passage of an application through Planning Committee.

Within the Policy, York City Council recognises that management of the archaeological resource requires more than simply processing planning applications and assessing mitigation strategies. The City acknowledges the need for a coherent research framework and sees itself as pivotal in the creation of a York research agenda in consultation with other interested parties. Within this research agenda, priorities shall be set for future research, and key areas of interest or importance will be identified for study where the opportunity arises. This moves beyond the recommendations of the Ove Arup report (1991) and suggests a structured and centrally regulated approach to archaeology within York in the future.

Changing practices

Excavation practices have evolved in York — as elsewhere — over the past twenty years, reflecting changes in financial and research objectives nationwide. It should be possible to chart these changes as they are reflected within the planning and execution of archaeological excavations across the city, and to go some way towards evaluating the true impact of these changes upon the fieldwork aspect of archaeological research in an urban context.

Drawing upon the computerised outlines of their excavations between 1972 and 1992, provided by YAT, and the list of sites and excavations (YAT 1993*a*), it is a simple matter for the GIS to calculate basic information such as areas excavated in any one year, and these data may be used to explore trends within the city over a twenty year period. This information is important in aiding the evaluation of our current knowledge of York; how is this acquisition of knowledge affected by factors such as the size and placement of excavations?

As Figure 3 shows, the general trend in York has been for an increase in the number of excavations underway in any one year, but it is clear from Figure 4 and Figure 5 that both the total area excavated each year and the actual area of each site is decreasing; excavations are becoming smaller but more numerous.

The apparently anomalous results for 1981 in Figure 4 are caused by the huge Coppergate watching brief (`siteno 1981.22`) which covered an area of 11,335m^2. This is the largest single unit ever examined archaeologically within the city, although only a fraction of the total area was actually uncovered under archaeologically advantageous conditions.

In line with the move away from large excavations and towards small evaluations, it should be possible to recognise an increasing number of trenches per excavation and a related drop in the size of trenches. The results in Figures 6–8 would appear to support this hypothesis, showing a 2–3 fold increase in the average number of trenches per excavation — as well as a real increase of similar proportions in the total number of trenches excavated per annum — towards the end of the 1980's, a few years later than a marked decline in the size of excavation trenches, beginning around 1984.

The evidence from York would appear to support the hypothesis of a move away from large excavations towards evaluation and small-scale fieldwork suggested by so many authors, but the data would appear to show this trend beginning several years before the publication of the supposedly causal PPG16 in 1990 (DoE 1990). For any definitive conclusions to be reached, it will be necessary to monitor the changing trends as PPG16 becomes better established than it was at the end of 1992 and to examine the changes brought about in working practice as the development sector moves out of recession and begins once more to undertake large scale projects in urban areas.

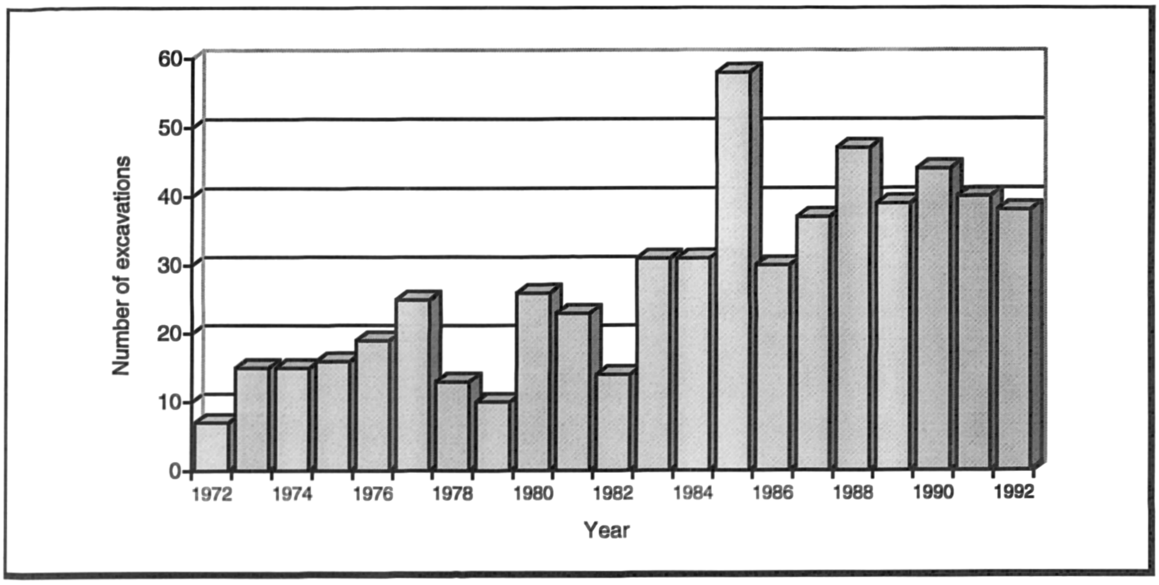


Figure 3: Number of YAT excavations underway per annum, 1972–1992

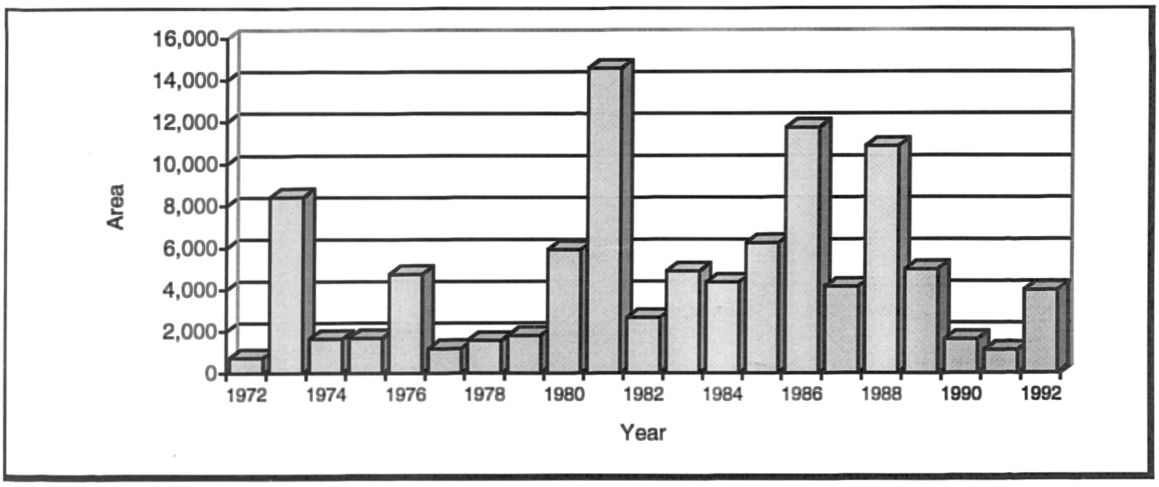


Figure 4: Total area (m^2) investigated per annum, 1972–1992

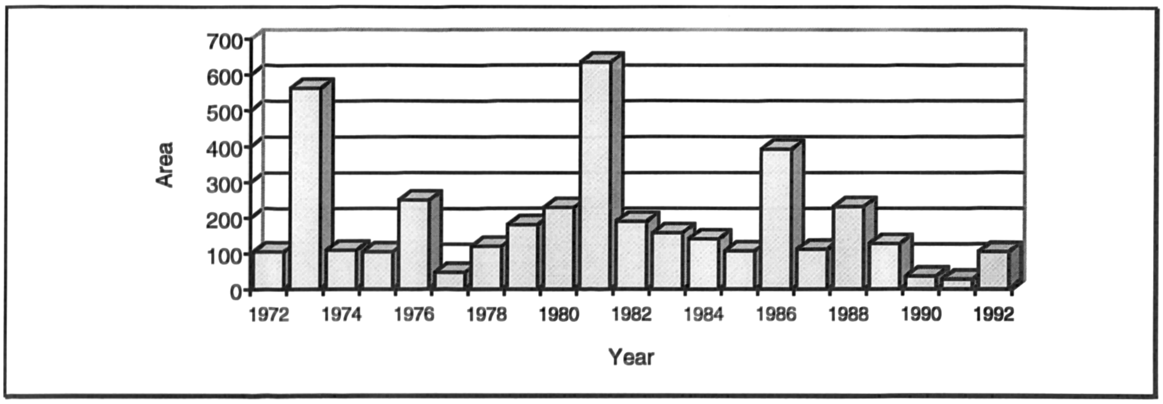


Figure 5: Mean area (m^2) investigated per excavation, 1972–1992

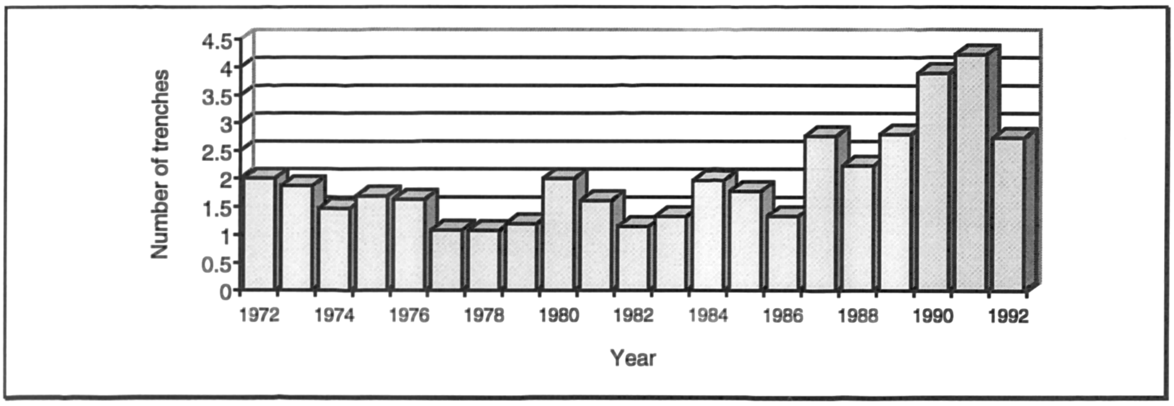


Figure 6: Mean number of trenches per excavation, 1972–1992

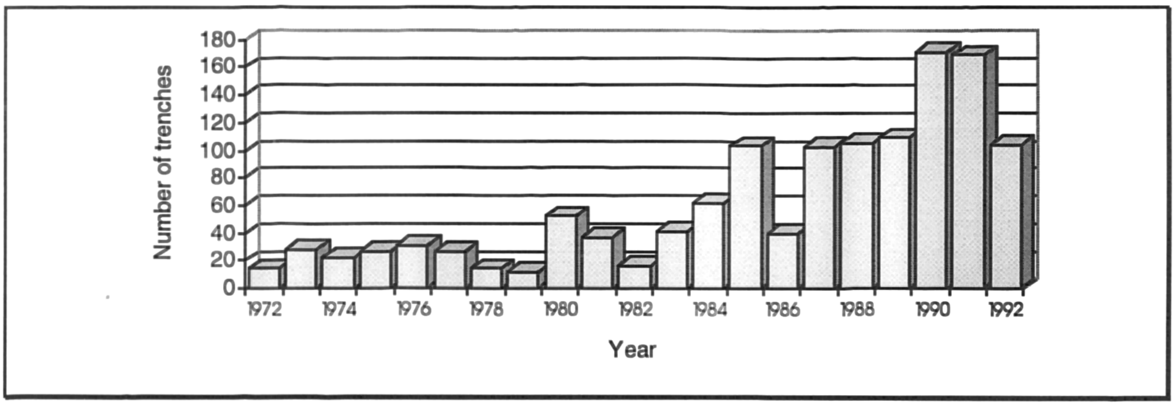


Figure 7: Actual number of trenches excavated per annum, 1972–1992

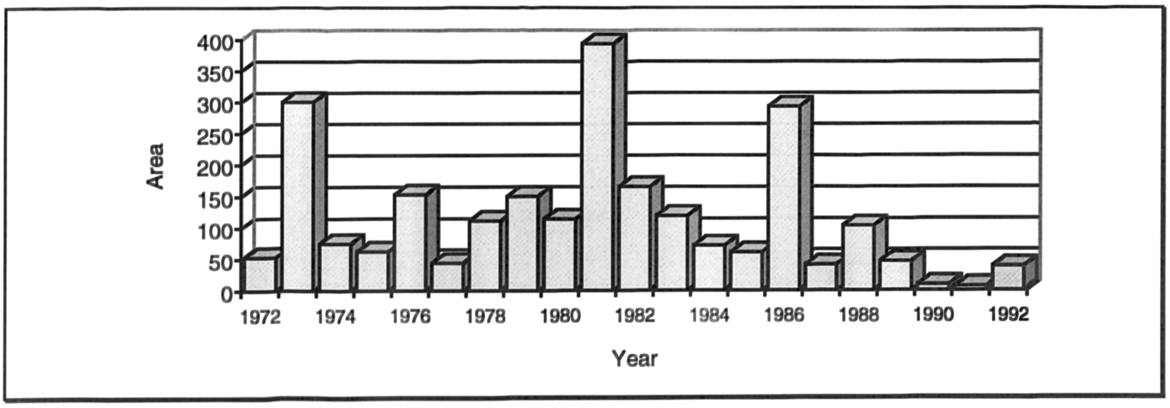


Figure 8: Mean area of excavation trenches (m^2), 1972–1992

4. Methodology

> With savage pictures fill their gaps
>
> And o'er unhabitable downs
>
> Place elephants for want of towns
>
> Jonathan Swift's indictment of 17th century cartographers (from Tufte 1983; 106)

Introduction

The methodological background to any project is vital to an understanding of the ways in which goals outlined within its research design were approached and achieved (Medyckyj–Scott & Hearnshaw 1993, Ives & Crawley 1994, Marble 1994). In tackling specific research questions, the underlying methodological framework influences questions that may be asked, the way in which they can be approached and, possibly, the types of answers which may ultimately be attained. This chapter looks at the data themselves and at the design decisions made during the structuring of both database engine and GIS interface.

In light of the production of the urban manual for the Monuments Protection Programme (Darvill 1992) and the Joint Data Standard (English Heritage & RCHME 1993a, 1993b) during this research, some of the differences between the approach adopted here and that recommended for adoption nationally shall also be explored.

Project Area

The modern extent of the administrative unit encompassing York is larger than the area which might, conceivably, have been viewed as 'urban' at any point in the past (Figure 9). Indeed, as evidence from an increasing number of excavations in the city is showing, areas at the urban core in one period may well become marginalised in subsequent centuries, making it difficult to define an area of study which adequately encompasses all aspects of urban York in all periods whilst minimising the inclusion of non–urban areas falling outwith the scope of this research.

It was seen as important to include identifiably settled areas for all known periods of settlement within the city, and also to maximise exploitation of existing resources such as the *York Development & Archaeology Study* database (Ove Arup 1991) and the archives of York Archaeological Trust. Given the richness of these resources, the lack of a formal Sites and Monuments Record (SMR) for the city did not prove to be a problem.

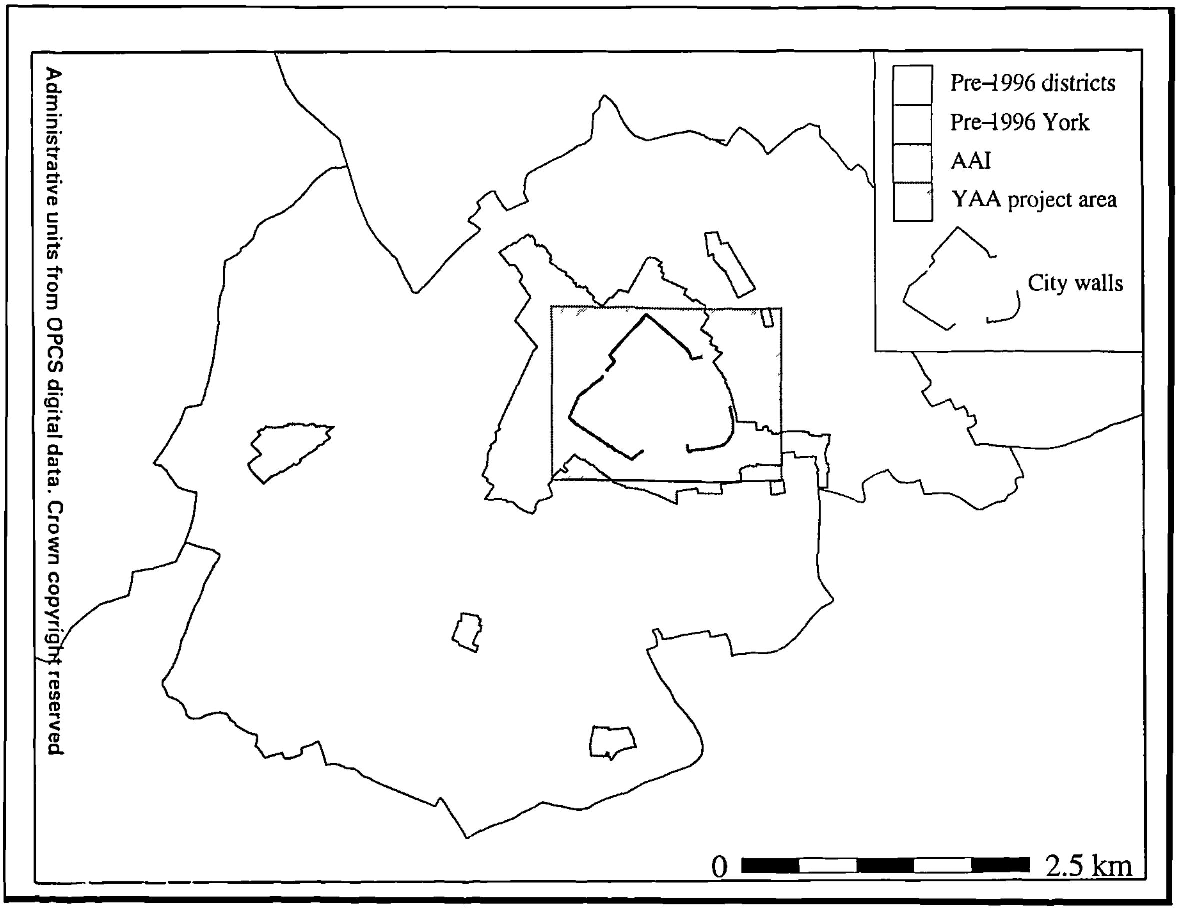


Figure 9: Pre-1996 administrative units in relation to the study area

The *York Development & Archaeology Study* defined a square area of interest focused on the city centre, from NGR 459500 451000 to 461500 453000 (Ove Arup 1991; 2, Figure 10), but data (16 of the 1084 records) were collected outside this area and many of the maps within the report actually use extents of varying size, making comparison difficult. The York Archaeological Assessment study area was defined by transforming the bulk of the data stored in the database to fit neatly the 500m squares available digitally from Ordnance Survey. The resulting 2km × 1.5km study area encompasses the Roman fortress and *colonia*; the Anglian *wic* and possible royal and ecclesiastic centres (Ordnance Survey 1988*a*); the Anglo-Scandinavian city, and the medieval walled city; as well as one of the densest concentrations of Listed Buildings (Ordnance Survey 1988*b*) and high quality archaeological deposits in the country. As Figure 9 shows, the area under study lies wholly within the modern district of York (and thus the remit of the City Council's Principal Archaeologist) and includes much of the Area of Archaeological Importance, as defined by Act of Parliament (HM Government 1979).

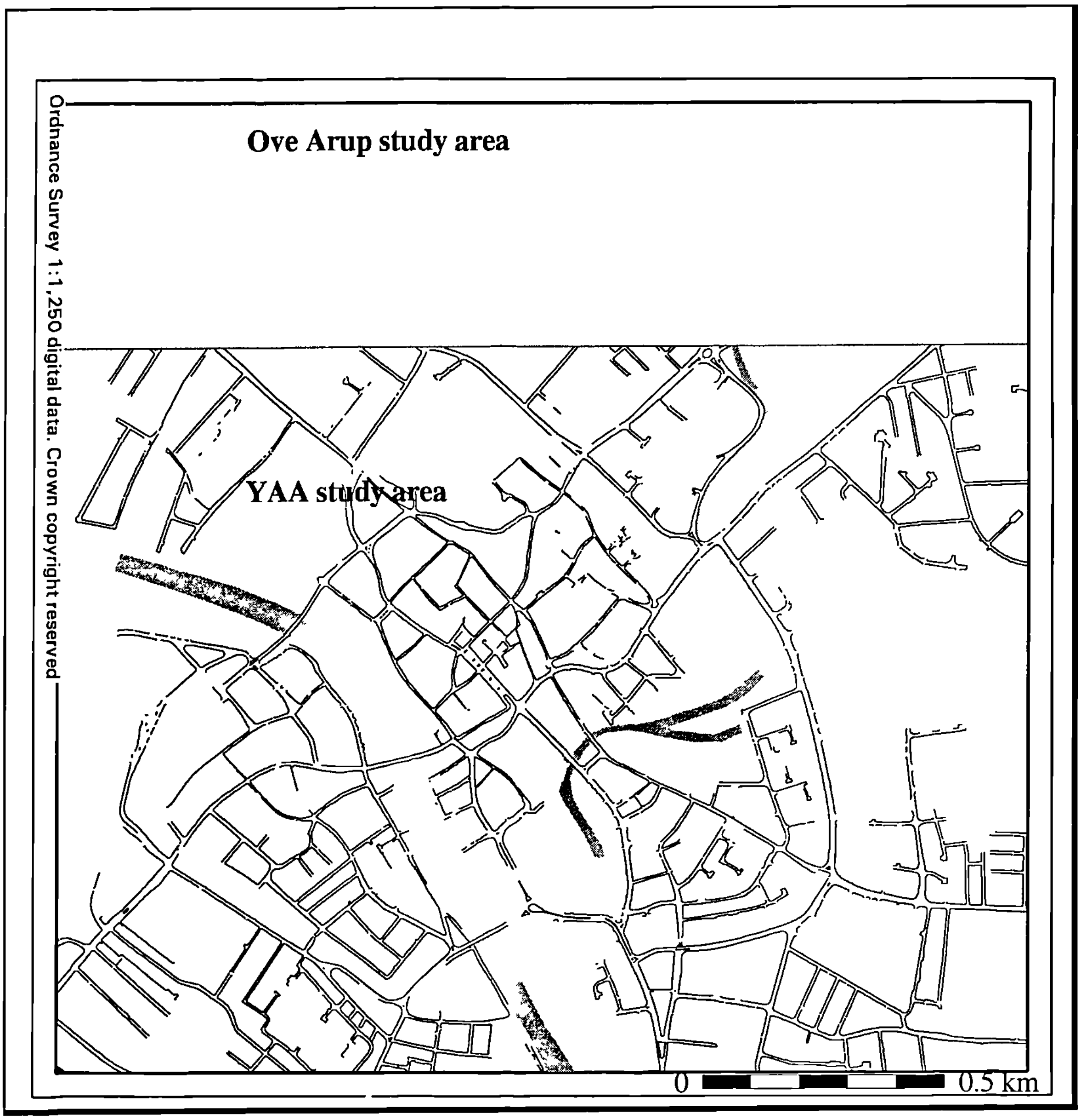


Figure 10: Relationship between Ove Arup and YAA project areas

Data

> The collation of data... has long been an important part of the activities of organised societies
> (Burrough 1986; 1)

Archaeological

Information pertaining to archaeological interventions within York has been gathered from a number of sources, although a large and only partly quantified pool of additional material remains to be drawn from by any future work (Ove Arup 1991; Appendix A) as it was felt that the effort to be expended in approaching these less structured archives was inappropriate for the limited quantity of deposit–related data likely to be contained therein. The aim of the data collection exercise was *not* to gather all available data on the archaeology of York, but rather to compile as complete a coverage as possible — with minimum expenditure of time and effort — of data pertaining to the location, thickness and nature of deposits. Whilst many of the antiquarian authors (Drake 1736, Wellbeloved 1842, Raine 1893, Benson 1911) provide rich descriptions of findings from early this century and before, the lack of a detailed spatial component makes these records of only comparative value within a primarily quantitative database such as that envisaged for this project. Experiments with a small sample data set showed the impossibility of recording sufficient of the flavour of these antiquarian records digitally, and it was felt that the best way of approaching such sources was simply to record their existence within the more quantitative computer records.

In exploring archaeological deposits, there are a large number of issues that may be addressed and a host of research objectives which may be explored (Carver 1993). In most cases, the actual course of research is constrained by a number of factors including time, expertise (Hearnshaw 1993), resources (Eason 1993) and — most important of all — the data themselves (Burrough 1994*a*). Whilst it is possible to ask questions and receive answers irrespective of the available data, such an approach is irresponsible and grossly misleading to those studying the results of such analyses at a distance from the data and methodology themselves. They, after all, often have no recourse to the original data and therefore cannot know how reliable any interpretations are. It is surely the responsibility of those gathering and using information to manipulate it responsibly, and to avoid analyses for which the data are unsuitable (Burrough 1994*b*).

In the case of the York Archaeological Assessment, the direction taken by research was often dictated (within bounds laid down by the research design) by the suitability of the available data for analysis and this has necessarily had an impact upon the analyses undertaken and reported later in this thesis.

The two main sources of archaeological data were the database compiled as part of the *York Development & Archaeology Study* (Ove Arup 1991; Appendix A) and that assembled from their own archive by York Archaeological Trust during 1993. In order to update, corroborate and clarify aspects of both databases, use was made of the bibliographic citations included with each entry, but — except in instances were an existing record appeared to refer to more than one event and therefore required splitting — new records were not added to the combined database.

As has been recognised before, archaeological data are often of varying quality and, with a database spanning interventions from antiquarian observation of a Roman cemetery in 1681 (`Component # 849`) right through to modern excavations underway 311 years later at the end of 1992, it is often difficult to reduce the entries to a common form which respects the paucity of early records whilst still allowing the detailed modern data to be used to good effect. As the project made use of data already in digital form — and therefore already filtered and interpreted by others to a large degree — many of the issues of data provenance and selection were sadly unapproachable (Goodchild *et al*

Field Name	Information stored
Record Number	Record reference number, unique within database
Period	Historical period code. One of: Post–medieval Medieval Anglo–Scandinavian Anglian Roman Prehistoric Natural (pre–settlement)
Easting	Five figure Easting for Ordnance Survey grid reference (missing leading value to define 100km map square)
Northing	Five figure Northing for Ordnance Survey grid reference (missing leading value to define 100km map square)
Accuracy	Accuracy (in metres) of grid reference
Height	Upper surface of deposit, in metres above Ordnance Datum
Thickness	Thickness of deposit, in metres
Nature of contact	Excavation, borehole, auger, construction *etc*
Deposit quality	Stratified or Disturbed deposit
Residuality	Residual deposit; Yes or No
Anaerobic	Anaerobic deposit; Yes or No
Description	Descriptive text about deposit
Comments	Any relevant information, *sometimes* including site name, number or address
Reference	Bibliographic citations

Table 1: Database structure for the Ove Arup archaeology database

1994), and much of my use of the data is necessarily based upon the premise that those creating the two databases were as careful in their recording criteria as I would hope to have been. The design of a unified structure to hold data from the two input sources was constrained by the information available, and the discussion of database design (below) should be read with this in mind.

The database utilised by the Ove Arup study was commissioned from York University's Department of Archaeology, and is discussed in detail as Appendix A of the Ove Arup report (1991). As discussed therein, the main sources utilised whilst compiling the database were the archives of York Archaeological Trust and the five volume survey of York compiled by the Royal Commission on the Historical Monuments of England (RCHME 1962, 1972*a*, 1972*b*, 1974, 1981) from their own work and existing archives or newspaper reports. The primary aim of the Ove Arup database was to compile a collection of point data for use in constructing terrain models for York at different periods in its past.

To this end, the data were entered into a *dBASE III+* database corresponding to the structure shown in Table 1. In the course of constructing this database, 1084 records were entered.

The York Archaeological Trust database enhancement was commissioned by York City Council and was intended to fill gaps in the existing Ove Arup archaeology database using elements of the York Archaeological Trust archive. This database used the same structure as the earlier project, but added several fields to the structure for the newly input records (Table 2). Once complete, the database enhancement had added 992 records to the database, bringing the total to 2076. Of these, 1,972 lie within the geographical region under study in this project.

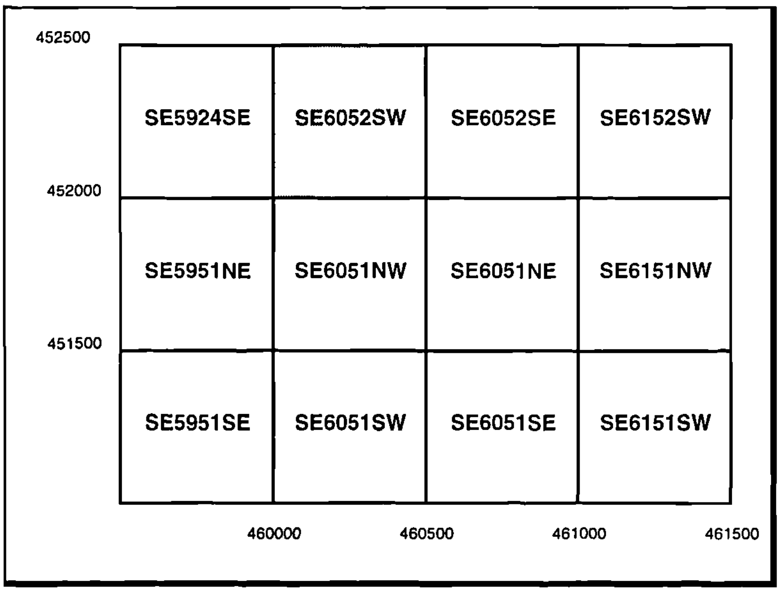
Interpretation	An interpretation of the deposits encountered
Site code	York Archaeological Trust site code for the excavation (*yyyy.ssss*)
Site name	Name & address by which excavation is commonly known

Table 2: Additions to database structure as part of YAT database enhancement

During the course of Ove Arup's evaluation of York (Ove Arup 1991), a second database was compiled to complement that recording the archaeology. This geology database was constructed by Ove Arup from a series of borehole logs for the city, and consists of 247 records. Sources consulted in compiling the geology database (Ove Arup 1991; A/14) included York City Council, the British Geological Survey, Ove Arup archives, the Yorkshire Museum, Yorkshire Water and the National Rivers Authority. Only a fraction of the 247 records lie within the current study area, but given the coarseness of many of the data involved, those records outside the area of interest were used in preliminary analysis in an effort to increase the value of the geological model.

Field Name	Information stored
Reference	Number of borehole log
Topography	Modern ground surface, in metres above OD
Fill	Thickness of deposit, from 'Natural' to modern
Insitu	Height of top of 'Natural', in metres above OD
Boulder	Height of top of boulder clay deposits, in metres above OD
Bouldertkn	Thickness of boulder clay deposits
Sandstone	Height of top of sandstone, in metres above OD
Awater	Height of main groundwater level (top of water table) in metres above OD
Bwater	Height of perched groundwater, where known, in metres above OD
Natgrid	Ordnance Survey national grid reference (Easting & Northing)
Number	Unique reference number for entry within database

Table 3: Database structure for the Ove Arup geology database (after Ove Arup 1991; Appendix A)



SE5924SE	SE6052SW	SE6052SE	SE6152SW
SE5951NE	SE6051NW	SE6051NE	SE6151NW
SE5951SE	SE6051SW	SE6051SE	SE6151SW

Figure 11: Ordnance Survey digital map squares and the case study area

Cartographic

A variety of sources for cartographic data were utilised throughout this research, although all maps — whatever their source — used Ordnance Survey crown copyright data as a basis for recording new information. Metadata on all maps used within this thesis are contained in **Appendix C**, allowing a detailed provenance to be established for any image or map–originated analysis.

The main source of map data for display was the Ordnance Survey 1:1,250 digital map series. Twelve of these 500m tiles were purchased by York University and York Archaeological Trust, and provided a complete coverage for the project area (Figure 11).

The data were provided in *AutoCAD* .DXF format — a well known format suitable for transfer between a variety of software and hardware platforms. Early work with the data from the case study area showed that the Ordnance Survey maps were digitally poor and that a significant amount of time would be required to clean them sufficiently for use in GIS–based analysis.

Line and polygon data used in a primarily vector based system such as *Arc/Info* must form sets of closed polygons before the software may assign the all–important topology which allows manipulation of the stored lines as *shapes* rather than merely as collections of lines (Burrough 1986). This ability to handle shapes, or polygons, is an important aspect of GIS work, and allows everything from simple commands colouring in buildings to more complex queries such as buffer analysis, where buffer zones are computed around the outer edges of shapes.

For topology to be defined in the first place, the stored sets of lines must form closed polygons which the software can identify. Common problems preventing this process include lines which overlap each

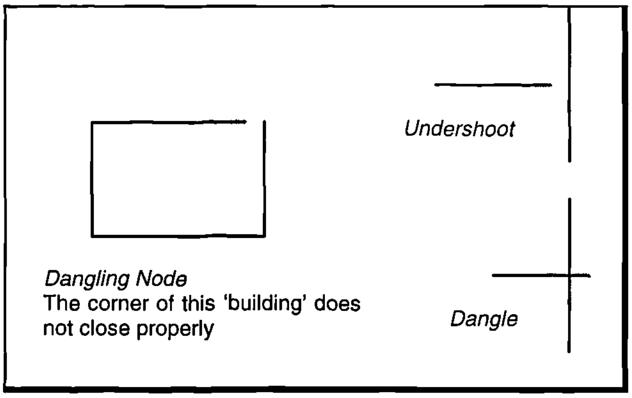


Figure 12: Some common digital map errors

other slightly — an overshoot — or those where the ends of two lines fail to meet — an undershoot (Figure 12).

The Ordnance Survey data available to the project had not been through the rigorous cleaning procedures applied to the current *LandLine* products and, as such, the data were digitally filthy. Early experiments showed that the case study area consisted of no closed polygons at all prior to cleaning, and 1,804 after several weeks of intensive work. With a further eleven sheets of similar data to clean — and with issues to resolve in linking them — it was felt that a more effective means needed to be found of providing digital basemapping. Originally, the intention had been to create a digitally clean basemap, where all polygons were correctly closed and where modern landuse and Listed Building status were recorded for every building polygon falling within the project boundary. Following detailed evaluation of the project goals, it was felt that this level of complexity in the basemap was unnecessary to the primary goals of the project, and that the real value of the basemap lay simply in allowing users to relate substrate to modern city. For this task, intensively cleaned maps were seen to be unnecessary and a compromise was arrived at by simply cleaning the case study area and only resolving serious (or visible) flaws in the remaining eleven map sheets.

In cleaning the case study area, additions were made to the Polygon Attribute Table (PAT) associated with the map coverage concerned (Table 4) in order to allow basic address and administrative information to be recorded. This PAT normally holds information relating to coverage topology and defined both the size and shape of individual polygons as well as the all–important relationships between neighbours.

Item Name	Information stored
Area	Area of polygon (automatically stored in PAT)
Perimeter	Perimeter of polygon (automatically stored in PAT)
Pilot_Study#	Internal numbering of database (automatically stored in PAT)
Pilot_Study-ID	Internal link between database entries and polygons (automatically stored in PAT)
Streetno	Numeric element of any address. Normally a house number
Street	Street on which the property lies
Landuse	Land use coding as defined in Hillier Parker (1988)
List	Listed Building grade

Table 4: Polygon Attribute Table (PAT) for coverage Pilot_Study

As detailed in **Appendix C**, a number of GIS coverages were created from the basemap, including those depicting the major streets, certain defined 'landmarks', the river system, the case study area, and the complete city basemap itself.

Topographic

In a project examining the build–up of deposits over the past 2,000 years, access to detailed topographic data was seen as essential (Turner 1989). Topography for the pre–modern landscape was provided by the elevation and deposit thickness data contained within the database, but information on modern features proved more difficult to obtain.

During the pilot phase of research, a search was undertaken in order to locate viable sources of elevation data for the city, without much success.

Utility Companies

Approaches to the utility companies (British Gas, Northern Electric, British Telecom, Yorkshire Water and York Waterworks) were generally rebuffed, either because data of sufficient quality for the project were not held by the company concerned, or because such data were considered to be commercially sensitive, and therefore unavailable in the public domain. It became apparent that the majority of utility companies operating in the York area do not find detailed elevation data for their plant to be important; in most cases it proved sufficient to record a position relative to major features on an Ordnance Survey 1:1,250 map, and store an approximate depth below modern street level at which the relevant plant may be located. This, of course, fails to consider the problems caused by raising and lowering street levels, but the precision afforded would appear sufficient for most utility needs.

National Rivers Authority

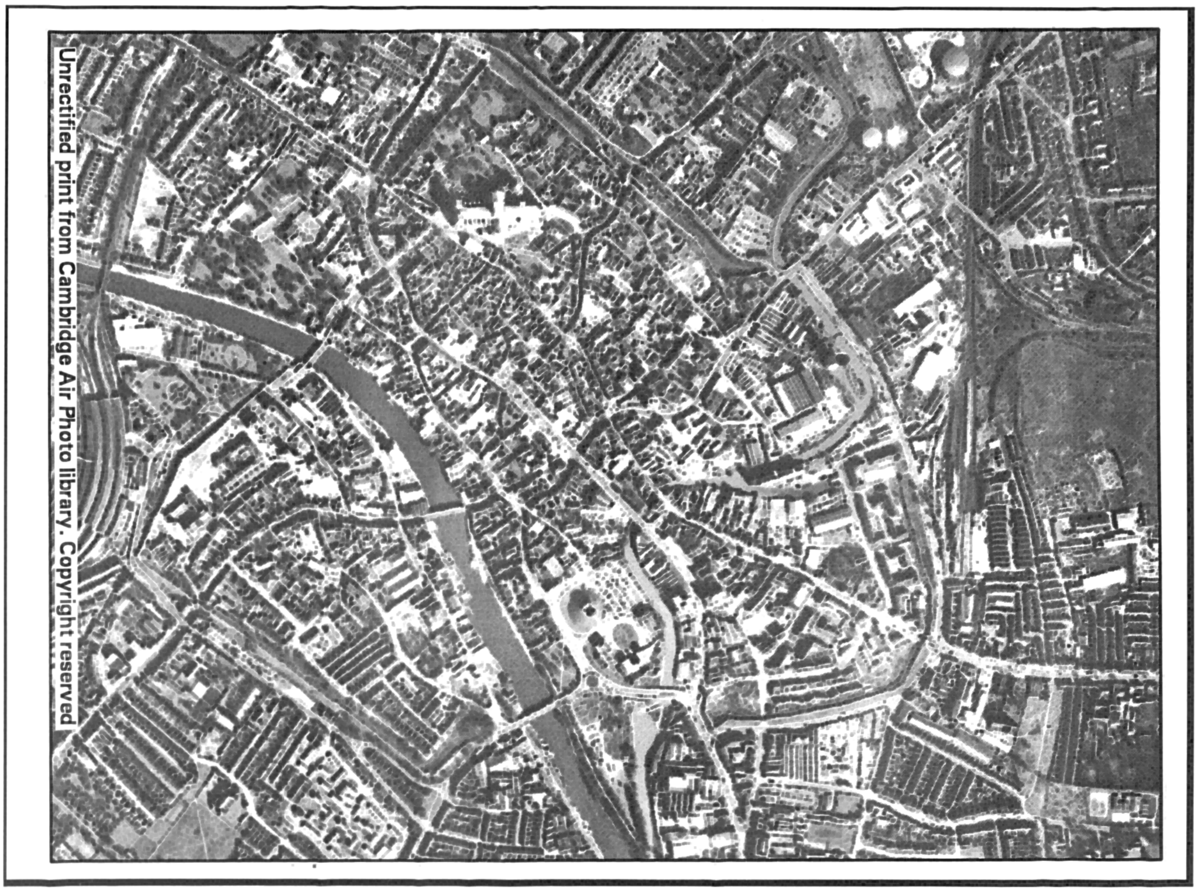
The National Rivers Authority (NRA) — amalgamated within the new Environment Agency (EA) as of 1 April 1996 — have been involved for some time in both monitoring hydrology in the region and implementing procedures to control excess river levels in urban and other high risk areas.

In York, extensive flood alleviation programmes have been undertaken on all levels from the provision of watertight gates to riverside properties through to the construction of a flood barrier on the river Foss capable of preventing floodwaters from the Ouse reaching the vulnerable city centre by backing up the Foss. In the course of these projects, the NRA have gathered a large quantity of data on elevations close to the river, and store this data on site plans and maps at their regional headquarters in Leeds. The contents of their archive were made available to this project and 78 points were gathered to enhance the waterfront element of the elevation model. Transects across the river have also been gathered by the NRA, but none appear to have been undertaken in the city centre and the closest — just north of the city at Clifton Ings — describes an area of the river very different to that just downstream in the urban core.

Remote Sensing solutions

Increasing attention is being paid to the ways in which remote sensing techniques may be applied to the acquisition of topographic data (Petrie 1994, Raper & McCarthy 1994). In this context, remote sensing describes a wider suite of techniques (*eg* McLaren & Kennie 1989) than normally associated with the term in archaeological circles (A. Clark 1990), covering such diverse data capture methods as ground–based survey and satellite reconnaissance. In the USA and areas of the world currently lacking detailed topographic coverage, air– and space–borne mapping have become commonplace as a cheap method by which relatively accurate elevation models may be constructed (Wood 1994).

Derivation of elevation data from airborne photography is becoming increasingly common in European countries, and the technique is used by the Ordnance Survey as part of their ongoing enhancement of the existing national map base (Finch *et al* 1994). In order to derive elevation, stereo aerial photographs are required, from which elevation may be derived by studying the 'warping' of known control points away from their expected position on a horizontal plane such as that assumed in a traditional paper map. For landscape applications, elevation models of reasonable precision (*c* ±10m) may be routinely constructed at relatively low cost. Given the stipulation for York that any elevation model generated from these photographs must have a precision no less than ±0.5m, costs for deriving the model rose prohibitively to in excess of £8,000 (price from Spring 1993) for an area of central York 2km by 1.5km — a cost the project could not bear. Despite this, aerial photographs proved useful in illustrating aspects of the townscape to those not familiar with details of the city (Figure 13).



Unrectified print from Cambridge Air Photo library. Copyright reserved

Figure 13: Computer–rectified aerial photograph of the Project area

The second main remote sensing technique of possible value was spaceborne imaging (Aybet & Walpole 1994). This technique was in many ways simpler than aerial photography as data already existed in digital form, suitable for computer processing. Data for much of the globe has already been gathered, and this is available from a number of suppliers, either free or for purchase (US Congress 1992). However, given the resolution of current publicly available satellite data — no better than 5m from the French SPOT and rather worse than 10m from the American LANDSAT — it was soon discovered that, as with aerial photography, the technique was unable to provide a model of sufficient resolution. Recent experiments with advanced radar on the American Space Shuttle (Freeman 1995) have produced impressive results, both in terms of locating buried features in areas such as the deserts of Iraq, and in constructing detailed elevation models of urban areas such as California's San Fernando valley, and it may be that the technique will prove of great value in the future; especially if NASA's current policy of distributing the data freely remains in force.

Global Positioning Systems

Over the past decade, the United States' military has been involved in a programme to provide a global network of satellites that can allow troops on the ground (or at sea or in the air) to know where they are, even without the aid of maps or obvious landmarks. This NAVSTAR Global Positioning System (GPS) is now fully operational and reputedly allows military personnel precision of around

±5m, even whilst on the move. The technology is available to civilian users, but the signal coming from the orbiting satellites is distorted by military 'Selective Availability', allowing locational precision of around ±15m in *x* and *y*, with far less precision in *z*. Using civilian receivers in their differential mode allows increased accuracy in location, and some modern receivers are capable of sub–centimetre precision.

The technology is basic in principle. Each of the 24 satellites in orbit is fitted with an atomic clock which constantly transmits both the time and a unique identifier differentiating that satellite from any other. A receiver on the ground detects this code arriving from a number of satellites and is able to calculate how far away each satellite is, based upon the delay between the time being transmitted in space and received on the ground. As the receiver is aware of where each satellite *should* be, and has just calculated how far away from *it* they are, simple triangulation is undertaken to derive a position for the receiver. Obviously, three satellites are required for this to be effective, and precision (and time taken to derive a fix) increases with the number of satellites used.

In the more accurate differential mode, two receivers are used on the ground. One (such as that within the Department of Surveying at the University of Newcastle) is placed in a fixed and known location, while the other moves about as normal, gathering data. Both receivers detect signals from the satellites, and both calculate where this data suggests that they should be located. As the position of the fixed base station is known, it is possible to constantly adjust for the variable error in the signal from orbit by calculating the difference between the true location and that suggested by the satellites. With a laser or radio link between receivers, this differential may be transmitted in real time to the roving receiver, providing an instant — and accurate — location. Without the radio link, this information from the fixed receiver is simply stored digitally, and positions from the roving receiver are then post–processed using special software capable of adjusting for the distortion.

GPS initially appeared to be an excellent technique for gathering detailed data within the city centre, especially as one GPS company — Leica — provided a powerful base station on loan, allowing mobile receivers to be used throughout the city in differential mode. The cityscape visible throughout York, replete with narrow streets and tall buildings, proved too much for the system however, as in many cases only 1–2 satellites could be detected at any time, rendering the technique useless. Even on occasions where multiple satellites were detected, the time required to achieve an accurate fix (around 4 minutes on average) made GPS far slower than a more traditional Total Station survey, where points can be gathered at rates approaching one every 15–20 seconds.

Ordnance Survey

Ordnance Survey produce a number of terrain–oriented products, mainly for use in landscape mapping applications. The University of York owns elevation model data for most of Yorkshire and this was examined with respect to elevation model construction within the study area. The Ordnance Survey data available derive from 1:50,000 Landranger paper maps, and consist of a matrix of elevation values, with a cell width of 50m. This grid may be interpolated to create a number of terrain views, but the distance of 50m between data points and the possible vertical error (RMS ±5m) makes the dataset impractical for use in the construction of an elevation model of an area so lacking in topographic variation as York. The data were used, however, to assist definition of the city centre elevation model towards its extremities, in an attempt to minimise the danger of edge effects.

York City Council

Given its role in maintaining the fabric of the city, York City Council are closely involved in a variety of projects that include the collection of elevation data, such as the widespread pedestrianisation schemes carried out in recent years. It would appear, however, that these data, although collected, are not stored after completion of a project (Oxley *pers comm*). The major source of data provided by the City is held by them for Yorkshire Water — who had denied holding relevant data when approached directly — and consists of some 1,412 manhole cover locations.

This information was not available in digital format, and it was necessary to relate paper records to annotated map sheets in order to construct the file of height values and subsequent elevation model.

Hardware & Software

Over the three years that this project ran, available hardware and software evolved to a remarkable extent, with many of the problems inherent in the earliest implementations being resolved through a rolling scheme of upgrades to equipment and tools.

Hardware

Due to the nature of communications links between the Archaeology Department and the main computing resources more than a mile away on the main University site, the preferable solution of holding and manipulating all data in a single environment proved impractical, and compromises needed to be reached between ease of analysis, ease of access, speed and storage.

The three major platforms utilised throughout the project were DOS and Windows based PCs, UNIX workstations, and UNIX compute servers. Local data capture and manipulation was undertaken on PCs within the Department of Archaeology, before transfer to the UNIX system. The central UNIX compute servers *tower* and *ebor* were used for the bulk of GIS–based analysis, with most non–printed graphical analysis being undertaken on centrally provided Silicon Graphics Indigo workstations. Occasional jobs requiring extensive computation were run on a private Silicon Graphics Indy, *peters*, with the permission of the University GIS Advisor. Everyday access to the various UNIX systems was by means of text–only terminals, occasionally constraining the flexibility of approach to data visualization as it was necessary to laboriously print results in order to view them. Visualization improved in the final months of writing up, due to desktop access to a Hewlett Packard UNIX workstation at the University of Newcastle. This machine allowed easy graphical interaction with all project data, either remotely on University of York machines, or mounted locally on the workstation.

Software

In a project such as this, no one software tool is sufficient for the range of tasks to be undertaken. This situation is exacerbated by the need to store and manipulate data on a variety of platforms, and by the need to use software available within the University rather than the best tool for each job.

On PCs, the main uses for software were in the areas of DBMS and CAD, as data arriving from different sources had to be cleaned to conform to project specifications and, in several cases, computerised from scratch.

Database work used Borland's *Paradox* software in all incarnations from 4.0 – 4.5 (DOS) and 4.0 – 5.0 (Windows). *Paradox* was used to clean data from disparate sources in order to allow merging into a unified database structure. In the closing stages of the project, Microsoft *Access* replaced *Paradox* as the project database due to the difference in database software provided at York and Newcastle. No problems were encountered in transferring data between the two.

In cleaning cartographic data for incorporation in the GIS, *AutoCAD* was used for the bulk of the process. *AutoCAD* versions 11 and 12 (DOS) were used for most of the project, with version 13 (Windows) utilised briefly for limited CAD tasks late in the project. *AutoCAD* provided cartographic output in standard formats for input to *Arc/Info*. During the coding of the YAT–provided excavation outlines, *ArcCAD* was used in addition to *AutoCAD* to add basic topological and attribute information to each trench. This process negated the need for difficult editing at a later stage within *Arc/Info*, but was later found to have been responsible for some corruption of the database associated with York Archaeological Trust site outlines.

On the UNIX machines, *Arc/Info* was the main program in use, in all versions from 5.1 – 7.0.4 (beta). This GIS software formed the core of the project and all links between software packages were focused to enabling easy importation into *Arc/Info*. The database element of the package — *Info* — was of limited functionality, and much of the non–cartographic analysis of database records was more easily undertaken using *Paradox/Access* on a PC.

Database Design

> An information search–and–retrieval system is most effective if it is viewed as a team consisting of the machine and the user
> (P–K Halvorsen, Xerox PARC. Cited in Clarkson 1992)

In a project of this nature, the data are of crucial importance to the success or otherwise in achieving aims laid down in the research design. In order to effectively query and manipulate data of such disparate provenance it is necessary to store information in a flexible and accessible manner. As such, the creation of a suitable database design is, in many ways, as important to the project as the data themselves and for this reason the database design was considered early in the life of the project (Medyckyj–Scott & Hearnshaw 1993).

At inception, this project had been intended to interact with a landscape–based study already underway within the Department of Archaeology. This York Environs Project (Chartrand, Richards & Vyner 1993) was examining data from Local Authority Sites & Monuments Records in the York hinterland, and was dealing with primarily point data in the form of findspots and site centroids. The work involved in structuring a single database design in order to cope with point data on the landscape scale as well as YAA's point, line, and polygon data on the urban scale is discussed elsewhere (Chartrand & Miller 1994), while the detailed issues of database design for the YAA itself are addressed below.

Requirements

In designing the structure for data storage, a number of external issues were considered. Although in many cases not a formal part of the project, it was felt that enabling easy interface between the project database and external systems was a valuable step towards providing a methodology that may have wider implications than this thesis alone, and might go some way towards breaking the prevalence within archaeology for proprietary database systems incapable of exchanging information with their neighbours.

As such, data were maintained in a form that would always be compatible with the *York Development & Archaeology Study* database (Ove Arup 1991) as used by York City Council, and the Yorkshire Museum site referencing system (*yyyy.ssss*) as used by York Archaeological Trust was established as the primary link between files. Although missing from Ove Arup's archaeology and geology databases, the adoption of this key field was endorsed by York City Council's Principal Archaeologist, the main user of the existing database, and a potential beneficiary of any database produced by this research.

The .dbf file format as used by *dBASE III+* was adopted as the standard for file transfer and for the storage of archive copies of the database. Although ageing, this format was felt to allow maximum flexibility of import and export between a wide range of systems, including *Paradox* and *Info* as used by the project.

The primary requirement in defining the database structure was that it should enable flexible querying — by site code or any other field — across the database in such a way that stored data could relate to either points or (one or more) polygons within the coverage base.

The final requirements constraining the design were that it should be modular (and therefore relational rather than flat file in structure) for maximum flexibility, and that it should be easily expandable through the addition of further modules as required.

Solution

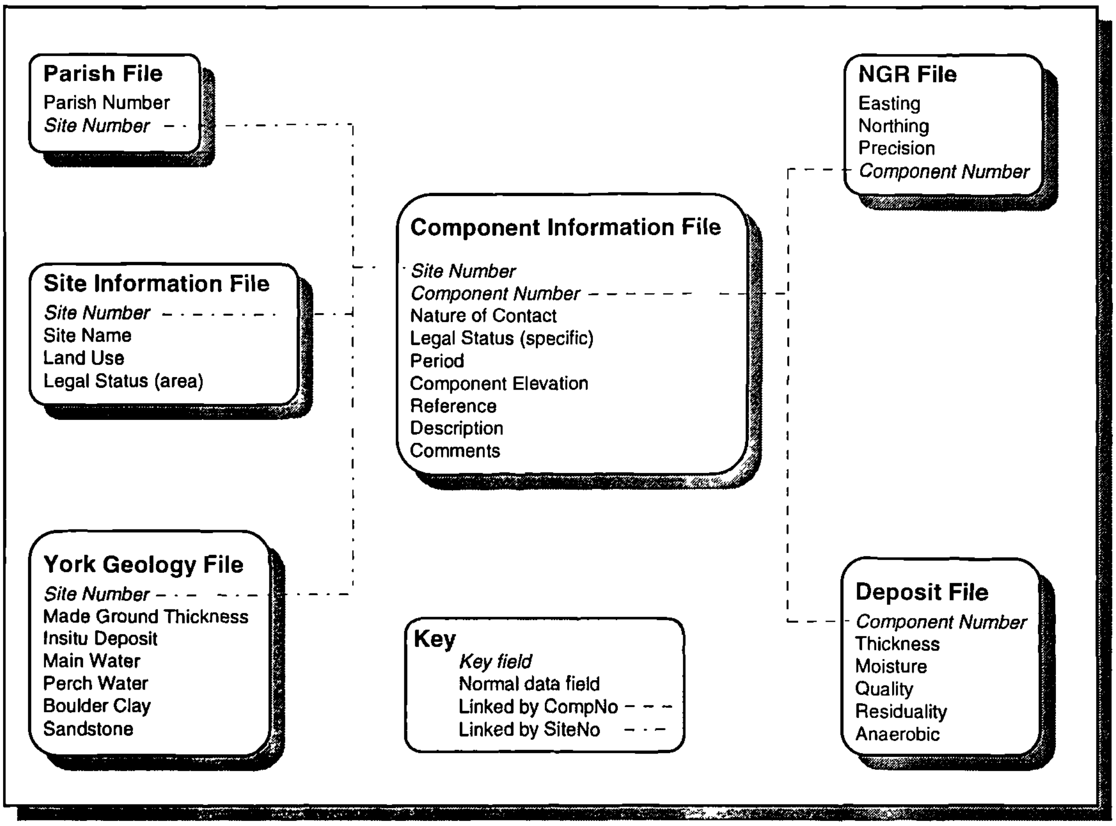


Figure 14: YAA database design model

The model solution adopted is depicted in Figure 14. As may be seen, the approach is modular in nature, relies upon one of two fields for all internal relationships and may be expanded into any number of further modules so long as one of the key fields is always present.

Relational database structures

Historically, archaeological databases have been designed to closely resemble the traditional card index from which many of them evolved (Aberg & Leech 1992). This 'flat file' data structure meant that individual records within a single database file were used to store all relevant information pertaining to a single event or location. In a Sites & Monuments type of solution, individual records often pointed to a find spot or site stored within the SMR, but in some cases it was necessary to store more information about a site or location than a single record allows (Harris & Lock 1992). Using the *York Development & Archaeology Study* as an example, each of the 1,084 entries within the file refers to a single event — a use of any one point in space at a given moment in the past. In this case, however, there are often multiple entries in the database for one particular location, providing information on that point at different periods in the past, or multiple spatially distinct entries for a single point in time. In databases where large volumes of data need to be entered, this unnecessary duplication of data rapidly makes manipulation unwieldy as databases begin to grow exponentially to the volume of *new* data actually being input.

By adopting a relational rather than flat file structure, it becomes possible to remove much of the duplication by holding repeated values in a separate file, and simply referring to that file, rather than repeating its contents time after time.

As a simple example, assume a database as follows:

Field Name	Information stored
Site Name	Common name for excavation site
Site Code	Numeric identifier for site
Town	Town in which site was discovered
County	County in which site was discovered
Country	Country in which site was discovered

Table 5: A simple flat file database

In a flat file database structure, each record within the database holds data for all five of the fields defined in Table 5. However, it is clear that (in most cases) all sites within any given town *automatically* lie within the same county and country as each other, and this information is therefore being duplicated unnecessarily. By moving to a relational structure in which the town name forms the key field, it becomes possible to prevent duplication of the extra fields, as shown in Figure 15.

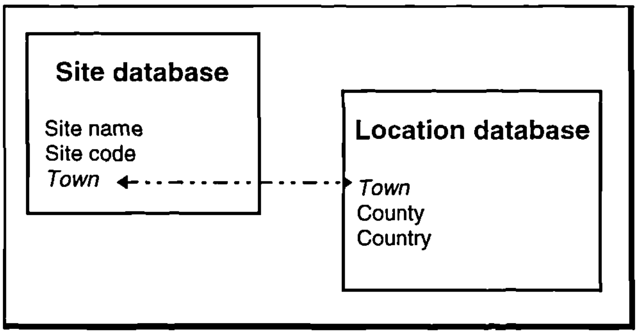


Figure 15: A simple relational database

In this case, the database is constructed of two files, which are stored and updated independently of each other, but queried together in such a way as to create the impression of a single, seamless, database to the user. Whereas in a flat file database it would be necessary to store the county and country information for every site within a given town — York, for example — in a relational structure as shown in Figure 15, it is only necessary to store the county and country information once for any town and a link is made within the software so that any site recorded in the site database as being in York will automatically be linked to the entry for York in the location database, and thus will be shown to be in North Yorkshire and the UK.

This simple, single tier, example demonstrates the effectiveness of a relational structure and makes clear the potentially huge savings in data input and storage overheads to be made by adopting such a structure, especially in a large database where more than a single tier of relationships are implemented. A second benefit is that of the potential for expansion. As the database already relies upon key fields or hooks (**town** in the example above), it is a simple matter to add information from further files without needing to restructure the database. In the example shown in Figure 15 a further file relating to archaeological units available for work could easily be added using the **town** field as a link between their details and the towns in which they are prepared to work.

Database field definitions

In attempting to provide comparability within and between the data files in use by the YAA and those from various Sites & Monuments Records required by the York Environs Project (Chartrand, Richards & Vyner 1993), it was necessary to alter the coding used in certain of the existing data structures, and to add new fields in some cases. This recoding was undertaken in the light of considerations for the ways in which the flat file data structures might be modularised to create the desired relational data model. In all cases, recoding was only undertaken in situations where data loss would not occur, and in many of the examples (such as **Period**, discussed on page 79, below) the recoding allowed scope for increased definition in the database descriptions.

The fields eventually defined were as follows:

Site Number: This is one of the two key fields utilised within the database, and forms the links between four of the six modules. Links relying upon **Site Number** can be seen in Figure 14 and are depicted by a dot–dash line style. The site number takes the form of a nine character numeric code of the form *yyyy.ssss*, where *yyyy* denotes the year of excavation for a site and *ssss* is a unique identifier pointing to one site within any given year, *yyyy*. This coding scheme is used by the Yorkshire Museum and York Archaeological Trust, allowing all YAT sites to use the same reference as utilised internally within their existing database systems. Pre–YAT sites are recorded using the same numbering scheme, with sites where the year of recovery is unknown coded 1000.*ssss*. In cases where sites run for several years, they would normally be numbered thus; 1976.7, 1977.7,... 1981.7, but within the database all such sites are simply numbered by their first year of excavation. Therefore, although the Coppergate excavation ran from 1976 until 1981, all references to the site within the database are to 1976.7 regardless of the actual year in which a deposit was uncovered. Coding embedded within the Polygon Attribute Table for the YAT site outline coverages provides information on the duration of an excavation for cases in which this is important.

Parish Number: Within the pre–1996 county of North Yorkshire, all modern parishes have been coded in order to allow storing of information by parish within the county council and local authorities. In order to maintain compatibility with the YEP, parish coding was used within the YAA database structure. As York is considered to be one parish within this county–wide coding scheme, all entries are automatically coded as parish 7,000.

Site Name: The full name and address of the site. For York Archaeological Trust excavations, this is a standardised form of the names stored in the YAT list of sites and excavations (YAT 1993*a*), and for non–YAT sites the name is derived as informatively as possible from whichever source identified the site.

Land Use: Local Authorities use a schema known as the Use Classes Order to classify all land as falling into one of several categories, as outlined in Table 6. Within the current implementation of the database, only land use within the case study area has been classified (Table 4), and even here only those land uses apparent from large scale Ordnance Survey mapping have been entered. It is postulated that a link may exist between modern land use on a site and the level of potential threat to buried deposits beneath that site. This premise remains untested.

Use Class	Description
A1	Shops
A2	Financial and professional services
A3	Food & Drink
B1	Business (offices not covered by **A2**, R&D, light industry)
B2	General industry
B3–7	Special industrial groups
B8	Storage and distribution
C1	Hotels and hostels
C2	Residential institutions (hospitals, residential schools)
C3	Dwelling houses
D1	Non–residential institutions (including churches)
D2	Assembly and leisure
Sui Generis	Other

Table 6: Planning Authority Use Classes (after Hillier Parker 1988)

Legal Status (area): A field denoting whether or not any site lies within the Area of Archaeological Importance (HM Government 1979). Within the city, any site lying outwith the statutory Area of Archaeological Importance automatically lies within the city council's Area of Archaeological Significance (York City Council 1992*b*).

Made Ground thickness: Mean deposit thickness, measured from top of natural up to the modern ground surface. Measured in metres. This field exists unaltered within Ove Arup's geology database as **Fill**.

Insitu deposit: Mean height of natural ground surface in metres above Ordnance Datum. This field exists unaltered within Ove Arup's geology database as **Insitu**.

Main water: Mean height of the water table (at the time the borehole was sunk) in metres above Ordnance Datum. This field exists unaltered within Ove Arup's geology database as **Awater**.

Perch water: $\bar{x}$ height of perched water (where known) above Ordnance Datum. In some areas of York, lenses of water — known as perch water — exist some way above the water table, and can have significant impact upon the potential for waterlogged preservation on archaeological sites. The presence or absence of perched water may also have implications for locating areas of anhydrous soils. This field exists unaltered within Ove Arup's geology database as **Bwater**.

Boulder Clay: $\bar{x}$ top of boulder clay deposits above Ordnance Datum. This field exists unaltered within Ove Arup's geology database as **Boulder**.

Sandstone: $\bar{x}$ top of sandstone deposits above Ordnance Datum. This field exists unaltered within Ove Arup's geology database as **Sandstone**.

Component Number: This field is used to identify individual components within a 'site' (see discussion of the component approach on page 74, above). Depending upon the level of recording in any excavation, these components may record areas of a site, contexts, or even individual artefacts. Along with **Site Number**, this forms the basis for linking database modules together. This field exists as **Record Number** within Ove Arup's archaeology database where it is used simply as a unique identifier for each entry. The field exists as **Number** within Ove Arup's geology database. In order to create space for the subsequent recording undertaken within the YAT database enhancement programme, all values of this field within the geology database have been incremented by 1,000 so that the numbering sequence runs from 2,501 – 2,747 instead of 1,501 – 1,747. Database enhancement programme records are slotted into this numbering sequence starting at 1,500.

Nature of Contact: This field defines the primary means by which information on a particular component was gathered. The free–form nature of coding this field within the Ove Arup archaeology database (where it was field **Nature of Contact**) has been replaced by a list of acceptable terminology. Recoding of the database was necessary to apply these keywords.

Aerial photography
Borehole
Construction
Documentary Source
Earthwork
Excavation
Extant Structure
Find (stray)
Find (unprovenanced)
Geophysical
Watching Brief
Other

Legal Status (specific): Related to **Legal Status (area)**, this field records the presence of any specific archaeological protection for a component:

Grade I Listed Building	I
Grade II* Listed Building	IIs
Grade II Listed Building	II
Grade III Listed Building	III
Scheduled Ancient Monument	SAM

Period: An important element of any archaeological application is dating, and this field is used in order to provide dates for each component within the database. Given the variability in our ability to provide a consistent level of precision in dating, a flexible coding scheme has been adopted in which it is possible to provide merely a period; a century; or even to code to the precision of a single year (Table 7). This field existed as **Period** within Ove Arup's archaeology database, but was constrained to recording only the main periods of occupation.

Component Elevation: $\bar{x}$ height above Ordnance Datum for the component, recorded in metres. This field exists unaltered within the Ove Arup archaeology database as **Elevation**.

Reference: Any relevant bibliographic citations to the component. This basic level of metadata should allow users access to the original sources from which the database was compiled. This field exists within the Ove Arup archaeology database as **Reference**.

Description: This field provides basic descriptive information on the deposit character and preservation, and exists within the Ove Arup archaeology database as **Description**.

Comments: Any relevant information on the intervention not provided in other fields. Within the Ove Arup archaeology database, this field occasionally provided information on site code (reproduced here as **Site Number**) and address (reproduced as **Site Name**) as well as other useful details.

Prehistoric (pre AD 0)	100.0
Palaeolithic (> 10,000 BC)	110.0
Early Palaeolithic	111.0
Middle Palaeolithic	112.0
Upper Palaeolithic	113.0
Mesolithic (10,000 – 3,500 BC)	120.0
Early Mesolithic	121.0
Late Mesolithic	122.0
Neolithic (3,500 – 2,000 BC)	130.0
Early Neolithic	131.0
Middle Neolithic	132.0
Late Neolithic	133.0
Bronze Age (2,000 – 600 BC)	140.0
Early Bronze Age	141.0
Middle Bronze Age	142.0
Late Bronze Age	143.0
Iron Age (600 BC – AD 0)	150.0
Early Iron Age	151.0
Middle Iron Age	152.0
Late Iron Age	153.0
Roman (AD 0 – AD 400)	200.0
1st century	201.0
2nd century	202.0
3rd century	203.0
4th century	204.0
Anglian (*c.* AD 400 – AD 800)	300.0
5th century	305.0
6th century	306.0
7th century	307.0
8th century	308.0
Anglo–Scandinavian (*c* AD 800 – AD 1066)	400.0
9th century	409.0
10th century	410.0
11th century	411.0
Medieval (AD 1066 – AD 1600)	500.0
11th century	511.0
12th century	512.0
13th century	513.0
14th century	514.0
15th century	515.0
16th century	516.0
Post–Medieval (AD 1600 – present)	600.0
17th century	617.0
18th century	618.0
19th century	619.0
20th century	620.0

Where an exact year is known, this may be recorded after the decimal point as follows; the year AD 1314 could be coded as 500.1314 or, preferably, 514.1314.

Table 7: Period classification as used by the YAA (after Chartrand & Miller 1994)

Easting: First element of the standard Ordnance Survey grid reference. This field must include six digits before the decimal point, so that locational integrity is maintained. Where the ten metre and metre (fifth and sixth digits respectively) are not known, this part of the reference is simply padded with '0's to form the six figure reference. This field exists within the Ove Arup archaeology database as **Easting** and in the geology database as the first element of **Natgrid**, but a leading '4' has been added to all references to denote the 100km map square in which the references are located. In many archaeological reports, the old fashioned letter coding system is still used, but it is necessary to translate this into part of the grid reference for computer–based applications. In the case of York, the city lies in square SE, which translates into a '4' being added to both **Easting** and **Northing**.

Northing: Second element of the standard Ordnance Survey grid reference. This exists within the Ove Arup archaeology database as **Northing**, and in the geology database as the second element of **Natgrid**. As with the **Easting** the grid reference locates the centroid of any large feature described, rather than any other point.

Precision: This field is used to describe the locational precision present within the grid reference expressed by **Easting** and **Northing**. **Precision** exists in the Ove Arup archaeology database as **Accuracy**, but whereas the **Accuracy** field describes an error in metres (± x metres), **Precision** uses a nominal scale in order to define an error range.

Sub–metre precision	0
Reference precise to within 1m	1
Reference precise to within 10m	2
Reference precise to within 100m	3
Precision uncertain	9

Thickness: $\bar{x}$ thickness of component deposit, expressed in metres. This field exists as **Thickness** within the Ove Arup archaeology database.

Moisture: A measure of wetness in a deposit, with deposits coded either 'wet' or 'dry'. This field exists as **Moisture** within the Ove Arup archaeology database.

Quality: A basic measure of deposit quality, related to the degree of post–depositional disturbance. Deposits are coded as either 'disturbed' or 'undisturbed', as in the Ove Arup report's archaeology database.

Residuality: Basic logical field, recoding whether a deposit is considered to be residual or not. This field exists as **Residuality** within the Ove Arup archaeology database.

Anaerobic: Basic logical field, recoding whether a deposit is considered to be anaerobic or not. This field exists as **Anaerobic** within the Ove Arup archaeology database.

National Initiatives

The methodology outlined in this chapter addresses aspects of the management and storage of archaeological data also approached in a number of national policy and standards documents produced by the statutory bodies for England; English Heritage and the Royal Commission on the Historical Monuments of England (RCHME). The very different approach of the Royal Commission on the Ancient & Historical Monuments of Scotland (RCAHMS) is also highlighted briefly due to its implementation of GIS.

The approach adopted within these policy documents differs somewhat from the *polis*–based strategy employed within this research, and the reasons for the variance are worthy of exploration in order to better understand the different requirements of each initiative. In order to best understand the differences between the YAA and national approaches, it is worth first describing these briefly. The main documents referred to below were consulted in draft form only, and the final published versions may vary somewhat from those discussed herein.

The most important documents relating to the creation and maintenance of research–driven databases for urban centres are the *Urban Archaeological Database* (English Heritage & RCHME 1993*a*, 1993*b*) and the Monument Protection Programme's manual on urban areas (Darvill 1992). *Managing the Urban Archaeological Resource* (English Heritage 1992) defines the constraints within which the more specific reports operate. Also of relevance in this discussion are the *York Development & Archaeology Study* (Ove Arup 1991) itself — which in many ways created the model from which the later documents evolved — and PPG16 (DoE 1990). Cirencester's contribution (Darvill & Gerrard 1994) to the urban archaeological assessments called for in *MUAR* (English Heritage 1992; 9) is useful as an example of a very different approach to that adopted in York (Ove Arup 1991) in response to the same brief, and also begins to adopt many of the suggestions to be found within the MPP's urban manual.

Managing the Urban Archaeological Resource

> The urban archaeological resource requires active management
> (English Heritage 1992)

Managing the Urban Archaeological Resource (English Heritage 1992) was prepared as a specifically urbanocentric response to the policies enshrined in documents such as PPG16 (DoE 1990), and defines the broad strategies proposed by English Heritage for quantifying and managing the urban archaeological resource. In itself, this document carries little weight, but it is of great importance in providing background for a more detailed examination of both the urban volume of the Monuments Protection Programme (Darvill 1992) and the proposed standards for urban databases (English Heritage 1993*a*, 1993*b*).

The document emphasises the importance of *managing* urban archaeology and repeatedly implies that an urban area is at least subconsciously perceived as an entity (or *polis* — see **Chapter 2**) by the authors, created from an amalgam of contacts with the archaeological resource. Given the explicit move away from this view within the MPP, this unconscious recognition of the *polis* is interesting, and conforms more closely to the approach adopted by the YAA than with the other national policy documents.

In discussing the relationship between above– and below–ground archaeology, *MUAR*'s

> The cellars and foundations of historic buildings extend down onto, and form part of, below–ground archaeological deposits — the surviving fabric of historic buildings is *simply an upward extension of those deposits*
> (English Heritage 1992; 4 emphasis added)

reinforces the concept of an urban 'whole' at odds with the excessive categorisation evidenced within the draft manuals of the MPP. This statement, studied along with

> listing of historic buildings... introduces... a partial presumption that the ground beneath and immediately around the building is likely to be preserved from development
> (English Heritage 1992; 7)

suggests a refreshing and coherent perceptual model of the urban area as a discriminable entity consisting of a number of components, where extant structures and buried deposits are of equal weight, and part of a continuum extending seamlessly above and below ground, as well as stretching out through horizontal space. In many discussions of archaeology, urban and otherwise, standing structures are often isolated from remains currently buried beneath the ground. This artificial distinction, although to some extent perpetuated within this thesis — a study of *deposits* — makes consideration of any whole difficult, if not impossible. The insistence upon classification of 'monuments' within both the MPP and urban database volumes reinforces this dichotomy, and is directly opposed to the modular approach espoused by YAA, where an urban area consists of components which may equally refer to deposits and standing structures.

The Monuments Protection Programme

The English Monuments Protection Programme (MPP) was established in 1986 in an attempt to categorise the archaeological resource, both as a research tool and in order to assess the representivity of the national Scheduling process (Darvill *et al* 1987). Its principal objectives are defined as:

> to review and evaluate existing information about sites of archaeological and historical interest so that those of national importance can be identified;
>
> to make recommendations to the Secretary of State that those monuments identified as being of national importance should be protected by law, or that some appropriate alternative action should be taken;
>
> to collate information on the condition of those monuments so that the resource requirements for future preservation, and the priorities for action, can be assessed.
> (Darvill *et al* 1987; 393)

Documentation for the MPP is extensive and based upon four main manuals (Darvill 1992). Part I introduces the programme, and discusses the main evaluation procedures. Part II describes the evaluation of single monuments, whether urban or rural, part III explores cultural landscapes, and part IV details the evaluation of urban areas. Release 02 (July 1992) of this fourth manual (Darvill 1992) is examined here in order to evaluate the national recommendations for mapping, evaluating and managing the urban resource.

The urban manual of the MPP is extremely detailed, running to some 412 pages in two volumes. As well as discussion of evaluation procedures, the pages include lists of component and monument types, as well as detail on a number of urban forms and a series of case studies outlining the MPP's application to several urban areas.

The MPP adopts a similar approach to urban entities as that discussed below for the UAD — namely, an insistence upon the definition of sets of 'monuments' rather than a true consideration of the urban space as proposed in **Chapter 2**;

> ...each urban area is conceived as one or more superimposed sets of associated, spatially related, and physically interconnected archaeological monuments and intervening deposits which because of their juxtaposition, proximity to one another, and geographically restricted areal extent can be conceived and studied as a single unit.
>
> Thus... an urban area is effectively a mosaic of single monuments...
> (Darvill 1992; 16)

In using the term 'monument', both MPP and UAD draw upon the definition thereof proposed within the *Ancient Monuments & Archaeological Areas Act 1979* (HM Government 1979);

> (a) any building, structure or work, whether above or below the surface of the land, and any cave or excavation;
>
> (b) any site comprising the remains of any such building, structure or work or of any cave or excavation; and

> (c) any site comprising, or comprising the remains of, any vehicle, vessel, aircraft or other movable structure or part thereof which neither constitutes nor forms part of any work which is a monument within paragraph (a) above; and any machinery attached to a monument shall be regarded as part of the monument if it could not be detached without being dismantled.
> (HM Government 1979; Ch. 46, S61(7))

although most users of the term are more likely to intend a definition more closely aligned to that found in a dictionary of modern English;

> a notable building or site, esp. one preserved as public property
> (Collins English Dictionary 1992)

In early writings on the shape the MPP would take (Darvill *et al* 1987), the monument paradigm was applied closely to urban areas, with the suggestion that an urban area comprised

> spatially and stratigraphically associated single monuments, linked by deposits, of an essentially unclassifiable nature...
> (Darvill *et al* 1987; 401)

Following such a scheme, it is difficult to explore relationships — whether stratigraphic, physical, or conceptual — between elements of the urban whole and research is necessarily reduced to the examination of numerous discrete units rather than the entity epitomised by the idea of *polis* outlined in **Chapter 2**. It is undoubtedly easier for a national body such as English Heritage to legislate for tightly defined and identifiable units such as their 'monument', but this method of recording constrains both free-form research and an understanding of the essential continuity represented in the urban form.

Value

An important element of the MPP is the search for ways in which archaeological remains may be categorised and assigned a *value*, with the underlying danger that one monument may be judged as 'better' than another — totally unrelated — monument form. Value is discussed here in the context of MPP terminology only. A more generic discussion of archaeological value may be found in **Chapter 2**.

In assessing value, the urban MPP examines three areas in order to assess the worth of any monument (Darvill 1992; 43–44);

Use Value: archaeologically rich urban areas have a value in terms of the ways in which their past may be utilised in the present. This use may be academic, as in the study of changing societies, or the vestiges of ancient urban forms; or it may be public, with the perceived worth of living in a place with history — people *like* living surrounded by old buildings and a sense of place.

> The sense of history implicit in many urban areas, the presence of place, is currently used heavily for commercial and aesthetic purposes. New shopping centres in historic towns, holidays, guided tours, tourism, leisure activities and so on take the very spirit of what is essentially the archaeological resource as their raw materials.
> (Darvill 1992; 43)

Option value: a historic town, similarly to any other resource, is not simply of value in the present. It is likely that uses will develop in the future which cannot be conceived now. A resource as diverse as the urban form has many potential uses which must be allowed for.

Existence value: archaeologically rich urban areas such as York have value to the present simply because they exist. Given the current search for roots and a sense of belonging (Hewison 1987), surviving manifestations of a past are sought and valued by most elements of society, whether or not they profess a strong interest in the past as represented through the academic world of archaeology as delivered to them in museums.

Evaluation

In evaluating the urban resource, three main stages are undertaken within the MPP, ranging from characterisation through discrimination to appraisal (Darvill 1992; 45–69).

Characterisation: involves studying the occurrence of the resource both nationally and locally, in order to identify its main components and record it in a standard form. At a national level, this characterisation involves such tasks as evaluating the rarity, diversity and survival of different monument types.

Discrimination: involves examining the extant resource within a single urban area, both in terms of the constituent individual monuments and in terms of the underlying linking deposits. In this way, it is hoped to evaluate the archaeological interests to be fulfilled by examination of any one monument, and to identify those areas of the urban space most worthy of further study. Criteria examined during the discriminatory stage include basic deposit survival, as well as assessment of potential and value, and evaluation of the sources providing data pertaining to the area under study (Darvill 1992; 57–61).

Appraisal: relates to an evaluation of the procedures best suited to managing either whole urban forms or specific monuments of value within the urban space. A complete management appraisal should result in guidelines or policy statements for the management of the area in question, with respect to the earlier stages of MPP evaluation and any relevant local or national legislation and policy.

Urban Archaeology Databases

In order to fulfil the data collection objectives of *Managing the Urban Archaeological Resource* and to facilitate detailed nationwide data collection in a similar manner to the rural Sites and Monuments Records, English Heritage and the Royal Commission on the Historical Monuments of England embarked upon providing a standard data structure for recording the information from urban assessment projects.

The data structure is intended to allow data exchange between the new databases and existing local and national data repositories such as the SMRs and the National Monuments Record (NMR) and as such closely reflects the existing wider data standard (RCHME & ACAO 1993) for all new databases.

The philosophy underlying this data structure depends upon the recording of 'events' and the subsequent definition of one or more 'events' as 'monuments' (English Heritage & RCHME 1993; 3). In this context an event is defined as any observation of archaeology, and a monument is a

> single period structure or complex having a specific function, purpose or symbolic meaning
> (English Heritage & RCHME 1993; 3–4)

Within this two–tier data model, there is no mention of the desirability for storing such data within a relational database, and the implication is that a flat file database may be used. It is likely that a flat file structure of this nature would rapidly become unwieldy, with either a large investment required to input quantities of duplicate data or else the need for time consuming and error prone manual cross referencing within the system.

Whilst initially intended for traditional methods relying upon paper maps and a computerised database, the data structure is suggested as being suitable for transfer to GIS at some point in the future (*eg* English Heritage & RCHME 1993; 3). It is likely, however, that any database designed from the outset as primarily paper based will *not* transfer easily to a truly functional GIS due to the differences in data structure, conceptualisation and representation involved in such a move. The authors of the urban database standard appear to have greatly misunderstood what GIS are, identifying them more as some Holy Grail which, once attained, will solve all of the problems inherent in their current applications. It is unlikely that any of the authors had much personal experience of GIS, given the vague manner in which the tool is discussed, and the appearance that references to the potential of a GIS–driven system have simply been added to an existing — and finalised — document intended for a primarily antiquated recording system. A great opportunity to guide the evolution of computer–based urban management systems has been sadly missed in this report.

The basic form of an Urban Archaeological Database (UAD) is described as consisting of:

> an urban area base map
>
> event records
>
> an event overlay depicting events
>
> monument records
>
> a monument overlay depicting monuments
> (English Heritage & RCHME 1993; 3)

Event and monument records provide a comprehensive description of archaeological contacts, with the event database holding 97 fields (English Heritage RCHME 1993; 8–10) and the monument database 80 fields (English Heritage & RCHME 1993; 22–24). In practice, most of the data in the two files are duplicated with both files potentially holding information on such details as location, landuse, nature of contact, *etc.* In order to avoid much of the needless duplication of data such a system implies, the report suggests that

> Monument and event records will be cross–referenced, so that most information will be held at the level of the event record and will not be repeated in the monument record.
> (English Heritage & RCHME 1993; 25)

Without the implementation of a relational database structure such as that adopted for the YAA, such a course greatly increases the possibility of data elements becoming inaccessible, and makes the manipulation of the data sets slow, labour intensive and error prone. It seems strange that, given an insistence upon the 'event' / 'monument' dichotomy, the report authors have not at least *recommended* the use of relational database software.

Throughout the document it is recommended that the existing thesaurus of archaeological terms (English Heritage & RCHME 1992) is used in order to standardise terminology between projects. In describing deposits, however, the thesaurus provides few suitable terms and it becomes difficult to provide the level of detail required without either using less than suitable descriptors or else creating new — and local — terms for the deposits encountered.

Further difficulties are added to the definition of the archaeological events with the recommendation (English Heritage & RCHME 1993; 19) that terminology from the Monuments Protection Programme should be used, but *without* the 'scoring' associated with these terms within the MPP. In everyday use, it is likely that those using and maintaining a UAD would also be involved in the implementation of MPP–driven surveys of archaeological survival and value. By suggesting that both projects should use the same terms, but that these terms should only describe relative worth in one of the two is likely to cause confusion and misunderstanding. This recommendation brings the danger of interpretative value judgements entering into a primarily *data* based archive, and will inevitably lead to the threat of developers — and possibly planners — judging only those sites described in the most glowing of MPP terminology as worthy of preservation or excavation, despite the fact that terminology within the UAD is supposedly without associations of value or quality.

The Scottish approach

Scotland currently lacks equivalents to both the Urban Archaeological Databases (UAD) initiative and the Monuments Protection Programme (MPP), although PPG 16 (DoE 1990) has direct parallels in National Planning Policy Guideline 5 (Scottish Office 1994*a*) and its related Planning Advice Note (Scottish Office 1994*b*).

The different legislative framework, along with practical considerations of significantly less expenditure on national heritage than in England (Miller *pers comm*) and notably different histories of urbanism (Moody 1992) and urban archaeology (Ottaway 1992), make Scotland a very different environment to England as far as relevant national archaeological initiatives are concerned. Nevertheless, it is worth briefly touching upon the pioneering work of the Royal Commission on the Ancient & Historical Monuments of Scotland (RCAHMS) with GIS, as their efforts far exceed those of similar organisations in England, Wales and Northern Ireland and admirably demonstrate what *might* be accomplished by agencies south of the border.

Begun as a pilot for parts of Fife Region and the city of Edinburgh as long ago as 1992 (Murray 1992, 1995, 1997), RCAHMS now has a significant commitment to GIS, both as an interface to the National Monuments Record for staff and public, and as a foundation of the Commission's survey programme.

The Commission fulfils a role both in disseminating existing information about the archaeological and architectural resource in Scotland, and in continuing the Survey of archaeology and architecture across the country. Information captured by Commission surveyors may be overlaid on Ordnance Survey mapping, aerial photography and other survey sources during the evaluation process, and then accessioned directly to the National Monuments Record for long–term storage and potential re–use.

National Monuments Record staff continue to explore means by which data held within the record may be more effectively exchanged with other heritage agencies within Scotland, including local authority archaeology services such as those in the West of Scotland (Flower *pers comm*) and Historic Scotland, which has recently begun to evaluate use of the RCAHMS *Genamap* system for itself (Murray *pers comm*).

Whilst the issues facing implementation of such a system elsewhere in the United Kingdom are undoubtedly diverse and complex, the innovative example set in Scotland is one from which other heritage agencies can learn, and represents a marked contrast to the less enlightened and notably GIS–

free products of English agencies working at the same time (*e.g.* Darvill 1992, English Heritage & RCHME 1993).

Setting the standard — problems and some preliminary solutions

Initiatives such as those for England outlined above may be considered as part of a wider requirement for a degree of standardisation within the profession. This standardisation is intended to facilitate comparison of archaeological features and transfer of these feature data between one person or system and another and, as such, is potentially required at all points from the manner in which a 'context' is described on an excavation site to the definition of systems for local authority Sites & Monuments Records.

The usefulness of standardisation is not in any doubt, as the more 'standard' an archaeological resource, the more useful it theoretically becomes to other users and the more compatible it becomes with other resources collected by the same — and other — organisations over time. The degree to which standardisation should be carried is, however, open to debate, as over–prescriptive application of standards and terminologies may equally be interpreted as stifling innovation or creative thought and suppressing local differences under a false impression of a nationally uniform vision of 'archaeology'. The role of standards is surely to aid understanding, rather than to smother diversity, and a fine line must therefore be walked between one and the other.

> The nice thing about standards is that there are so many to choose from.
> (Anon. quote, oft–cited on the Internet)

Archaeology has seen the development of many standards and guidelines over recent years (*c.f.* Miller & Wise 1997), although few have been adopted widely, greatly reducing their value as *standards*. In the past, the problem of slow adoption of standards has primarily been felt by regional and national organisations such as Sites & Monuments Records or National Monuments Records, responsible for accepting data from a wide geographical area. With changes in archaeological practice, however, the problems are now being felt even at the local level (Oxley *pers comm*).

As increasing numbers of archaeological contractors begin to work in close proximity to each other (**Chapter 1**), the importance of widely adopted standards grows, and the potential for losing important information grows ever more real. Prior to the advent of competitive tendering for work in a city such as York, for example, it was merely necessary for the contracting unit, York Archaeological Trust, to develop and document internal procedures. A knowledge of these procedures would then allow a researcher access to the entire archive of York Archaeological Trust and, by extension, access to most of the knowledge gathered about the city of York since the early 1970s.

With the possibility of any archaeological contractor tendering for — and getting — jobs in the city, the issues become more complex, as each contractor potentially uses their own internal procedures. At best, the researcher is now required to gain knowledge of multiple documentation and archiving schemes while, at worst, integration projects such as those attempted by Ove Arup (1991) or in this thesis become significantly more difficult due to inconsistencies and conflicts between the various cataloguing schema.

If the disintegration of the model whereby archaeological centres of expertise (such as York Archaeological Trust) work predominantly in the area they know (York) is to continue, allied with a growth in projects which attempt to draw upon data from diverse sources, then steps must be taken to ensure that the former does not impinge significantly upon the latter.

For such an environment to prove successful, discipline–wide adoption of standards becomes increasingly pressing. These standards need not be monolithic and prescriptive, as a standard suited to the detail of describing single contexts on an urban excavation in London is perhaps not fully applicable to a Neolithic landscape in the Yorkshire Dales. Rather, these standards need to provide a flexible framework within which more detailed local implementations may be constructed, safe in the knowledge that they remain largely interoperable with similar implementations elsewhere in the country.

The work of organisations such as the Archaeology Data Service (ADS 1997) and the Royal Commission on the Historical Monuments of England's (RCHME) recently formed Data Standards Unit (Quine *pers comm*) offers an important pointer to these widely adoptable, flexible, standards frameworks, and their efforts are as relevant to the archaeology of towns as to the rural environment.

As well as flexibility and widespread usability, a further cornerstone of the current re–assessment of standards requirements within archaeology is that of terminology guidance, through recommended use of thesauri such as RCHME's *Thesaurus of Monument Types* (RCHME & English Heritage 1995). Thesauri offer a degree of control over the manner in which terms are used in the description of archaeological features, such that recommended terminology may be declared, along with lists of widely used synonyms and, potentially, antonyms. With thesaurus creation, too, flexibility remains important, and catalogues such as that being developed by the ADS do not *require* the use of a specific thesaurus; rather, a number of alternative thesauri are *recommended* for specific uses (RCHME *et al* 1995 for monuments, MDA forthcoming for artefacts, *etc.*) and users are asked to define the thesaurus they have used when entering terms. With knowledge of the thesaurus used in each case, the meaning of terms becomes more apparent. A period coded as 'Roman', for example, allows the reader to make certain assumptions (although see **Chapter 2**). Those assumptions may change, however, were the reader to become aware that the period label had been selected from a thesaurus offering only 'Prehistoric', 'Roman', 'Medieval', 'Post–Medieval' and 'Modern'. The assumptions made would be different again if the term had been selected from a thesaurus offering 'Roman', 'Sub–Roman', 'Post–Roman', *etc.* As can be seen, a term which is apparently the same carries very different connotations when seen in the context from which it is drawn; one scheme is fairly crude, whilst the other offers a far greater degree of apparent precision. One is not, of course, necessarily always better than the other.

The data available to this research had already been standardised to a large degree during the construction of the Ove Arup (1991) project database, and represented the aggregation of an extremely diverse set of recording and archival practices within York Archaeological Trust and elsewhere. The data were further refined during design of the project database, with the addition of controlled terminology lists for such fields as **Nature of Contact** (above). The lack of standardisation such as that proposed for the future by ADS and RCHME, for example, potentially prevented those compiling the Ove Arup database from extracting the maximum information from these archives for minimum effort, but represents an amalgam of the confused practices of the past few decades, rather than any failing on the part of those constructing the archives or compiling the Ove Arup database.

Current developments with standardisation and the use of 'metadata' to adequately document resources, however, offer potentially exciting opportunities for the manner in which data might now be collected, and the ways in which such collection might feed into future enhancements to a project such as this. These developments are explored further in **Chapter 6**.

GIS implementation

What are GIS?

> A system for capturing, storing, checking, integrating, manipulating, analysing
> and displaying data which are spatially referenced to the Earth.
> (AGI 1995)

Definitions of GIS are as numerous as the software packages around the world claiming to *be* GIS, and it is difficult for the researcher to select one definition capable of encompassing even the limited subset of GIS functions an individual might use. To define the entire scope of GIS functionality in such a way is near impossible, and this task is further complicated by the overlaps between GIS and other related areas of computer science such as ViSC, CAD, and DBMS.

A brief history

From the early development of systems such as CGIS in Canada in the 1960's (Tomlinson 1990), the power and diversity of GIS systems has greatly increased. Early distinctions between raster and vector (Burrough 1986) have blurred with the increasing power of systems such as *Arc/Info* which offer flexible means of integrating both cell–based raster and line–based vector data in a near–seamless fashion.

Fundamental to all true GIS is the interface of textual and cartographic data at a variety of scales. While it is not necessary for GIS analysis to result in the production of a map (tables and charts are equally valid outputs), the ability to link large databases to locational factors by means of a common spatial component lies at the heart of the GIS concept.

As much of the writing on the subject shows (Burrough 1986, Peuquet & Marble 1990, Fotheringham & Rogerson 1994, Hearnshaw & Unwin 1994) GIS is more than merely the linking of CAD with DBMS (Cowen 1990), but is equally not a panacea to solve all spatial problems. In many cases, simple CAD or DBMS systems may be more appropriate to a problem than GIS, and at the other extreme, a high powered ViSC system such as *AVS* or *Explorer* will outperform the current visualization capabilities of most GIS.

GIS is a toolchest of spatial techniques. Like any other tool, it is suited to some tasks more than to others. The current challenge is to refrain from applying the GIS hammer to every spatial nut, and to better evaluate the needs of individual projects in order to select the best available tool.

For this particular project, the tool selected is the GIS, *Arc/Info*.

The *Arc/Info* GIS

The *Arc/Info* GIS is produced by the American Environmental Systems Research Institute, Inc. (ESRI) and is the best selling GIS worldwide (ESRI publicity material 1994). Although prohibitively expensive to purchase normally, *Arc/Info* is available to UK universities at a greatly reduced price through the efforts of the Combined Higher Education Software Team (CHEST).

As a system, *Arc/Info* successfully combines the two elements of computer–based map representation with effective management tools for both its traditional vector mapping and the alternative raster representation. A variety of tools allow raster and vector map layers to be translated routinely between the two formats, permitting great flexibility in the ways that data may be stored and analysed.

Unlike traditional software packages such as word processors and databases, *Arc/Info* consists of a series of modules, each containing related spatial management and analysis tools. The user selects from these tools in order to build the required applications. The main modules of relevance to this research were:

ArcPlot: the basic mapping module. This allows analysis and presentation of maps.

TIN: 3D surface analysis module, incorporated within ArcPlot

Grid: raster analysis module, allowing image processing and complex manipulation of raster mapping

Tables: a limited relational database tool, used to manage the spatial databases

As with most GIS, the real world is represented within *Arc/Info* as a series of map layers, each describing one feature class or logical feature grouping. The basic unit of two dimensional mapping by which this is achieved in *Arc/Info* is the coverage. Coverages consist of a map file containing the actual points, lines and polygons for a particular map layer and an associated attribute table, in which topological data are stored. These attribute tables may also be used to store database information about elements of a coverage. Alternatively, this information may be stored in a separate database file which links to the coverage by means of a logical relationship known as a relate.

With polygon coverages, the polygon attribute table (PAT) automatically stores data on perimeters and areas of all shapes within the coverage, as well as a unique identifier (Table 4). Point (PAT) and Arc (AAT) attribute tables store similar information relevant to the feature type they record.

Working with the database

Although designed with both *Paradox* and *Info* in mind, the database structure (page 74) was formulated at a distance from the programs themselves. In this manner it was hoped that a database might be designed that managed the data exactly as required and, where necessary, pushed the DBMS software towards the limits of its functionality, rather than forcing the data to fit software–imposed limitations as is so often the case.

The resulting suite of database modules within *Arc/Info* closely resembles the model database structure discussed above (Figure 14) and would appear to provide the level of functionality required with a minimum of complexity.

A two–tier system

The database of archaeological contacts consists of two groups of files; non–YAT and YAT excavations. YAT excavations stored in the database are directly linked to the coverages of site outlines (`yat70`, `yat80`, and `yat90`) and, as polygons, may not be directly associated with those pre–YAT sites which lack trench topological data and are stored as points. As a result, site data are stored in two identical sets of files which the user may query together or independently.

Module Name	**Polygon data (`yatxx`)**	**Point data (`ove_db`)**
Parish file	parish_tr.dat	parish_pt.dat
Site information file	sif_tr.dat	sif_pt.dat
York geology file	geol_tr.dat	geol_pt.dat
Component Information file	cif_tr.dat	cif_pt.dat
NGR file	ngr_tr.dat	ngr_pt.dat
Deposit file	deposit_tr.dat	deposit_pt.dat

Table 8: Relationship between data storage model (Figure 14) and actual data files

Arc/Info handles querying of modular data structures such as this using the 'relate' feature which allows users to establish links between two or more files containing a common field in the data structure. The relationships are stored in a single file which is accessed whenever modules of the database are queried. As shown in Figure 14, the YAA database structure depends upon one of two key fields for all internal linking; the **Component Number** and the **Site Number**. Within the database itself, these fields are known as `compno` and `siteno`, respectively. Table 9 shows the links established between data files by the project relate file, `sites`.

Database module	Internal file name	Relate ID	Key field
Parish file	parish_tr.dat	parish_tr//	siteno
	parish_pt.dat	parish_pt//	siteno
Site Information file	sif_tr.dat	sif_tr//	siteno
	sif_pt.dat	sif_pt//	siteno
York Geology file	geol_tr.dat	geol_tr//	siteno
	geol_pt.dat	geol_pt//	siteno
Component Information file	cif_tr.dat	cif_tr//	siteno
	cif_pt.dat	cif_pt//	compno
NGR file	ngr_tr.dat	ngr_tr//	compno
	ngr_pt.dat	ngr_pt//	compno
Deposit file	deposit_tr.dat	deposit_tr//	compno
	deposit_pt.dat	deposit_pt//	compno

Table 9: Relationships defined between data modules (Figure 14) by relate file, `sites`

In order to undertake a search through the database, the user simply enters a query that identifies the location of the desired data, and the actual value to be searched for.

For example, the query;

```
resel $DIGS/yat70 poly cif_tr//period >= 400 AND cif_tr//period < 500
```

instructs *Arc/Info* to locate any site outlines from the 1970's (contained within coverage `yat70`, which may be found in the logical directory, `$DIGS`) containing features identified as being Viking in date (period code `400`, as defined in Table 7). As Figure 14 shows, period information is stored in the field **Period** within the Component Information File. Reference to Table 9 shows that the relate identifier for this module is `cif_tr`, thus `cif_tr//period` directly locates the data field within the correct module.

The corresponding query to locate non-YAT sites stored in the point coverage is;

```
resel $DIGS/ove_db point cif_pt//period >= 400 AND cif_pt//period < 500
```

Similar queries may be constructed to access any element of the database, and relate items may be compounded in order to locate data in less accessible modules (Figure 16).

Working with maps

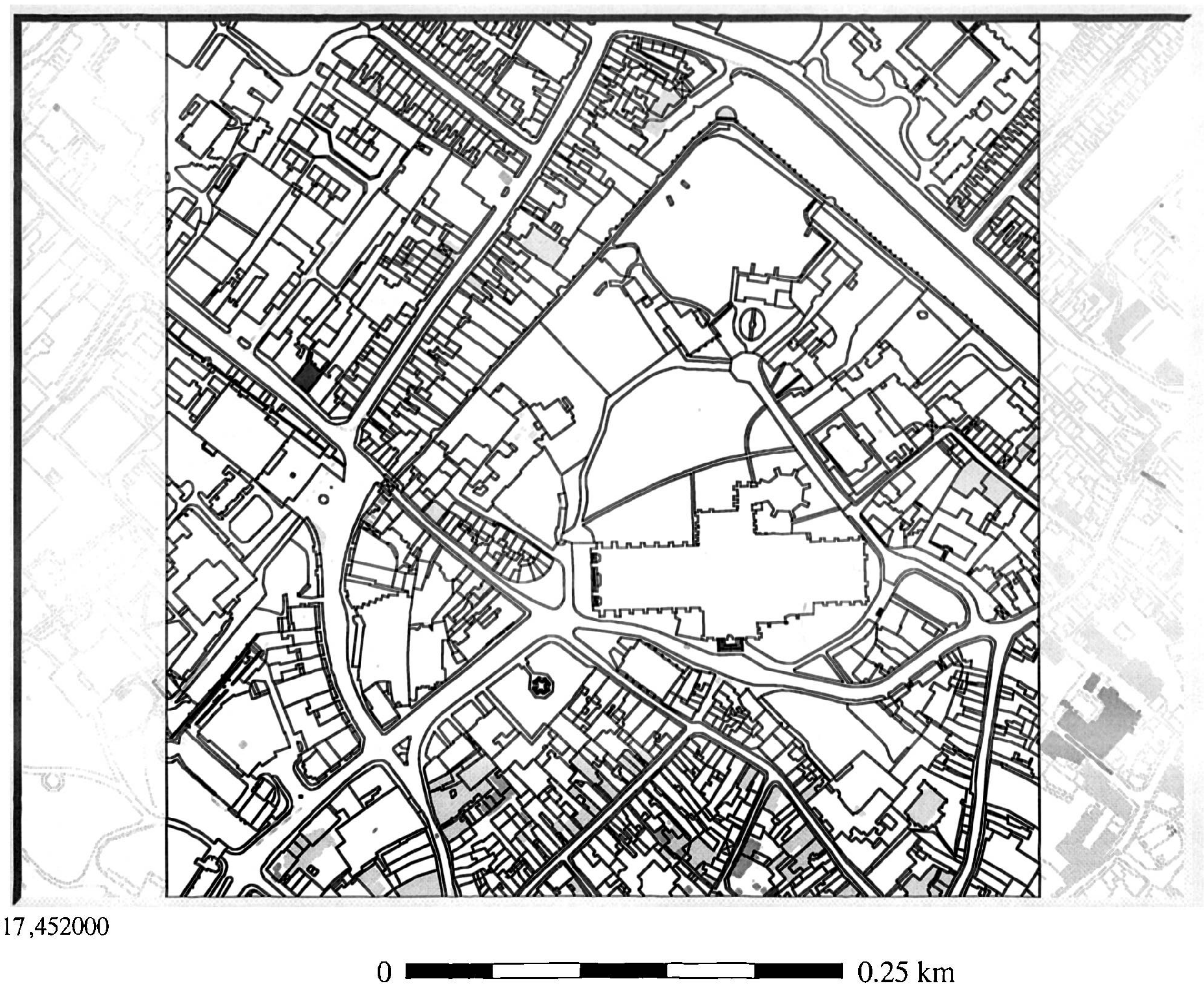
For a project such as this, cartographic data exist in many forms, and interrelationships between map–based and database information must be designed and manipulated in such a way as to enable maximum flexibility in the display composites that may be analysed and viewed. The problems associated with cartographic data collection are discussed above (page 66) and a full list of core map coverages is presented in **Appendix C**. In working with the system, it was discovered that certain elements of information were more useful if attached directly to the relevant polygon attribute table (PAT), rather than being stored in a separate database in the same manner as the bulk of data.

In the majority of cases, this extra information takes the form of a key field which may be used to provide logical associations between the PAT itself and the related elements of the database. Both `yatXX` and `ove_db`, for example, contain the field **siteno**, which enables them to attach to the remaining data files.

In the case study coverage, `case_study`, experimental information on land use, listed building grade and address were stored (see Table 4), and the start and end years for YAT excavations were attached to the PAT for `yatXX`.

YAA

Figure 16: An example of database selection;
sites with a Roman deposit thicker than 0.75m



- ░ non –Roman sites
- ▒ Roman sites
- ▓ Roman deposits > 0.75m thick

A P Miller 1996

Ordnance Survey 1:1,250 digital map data Crown Copyright reserved

The Visualization Engine

Making GIS work for *you*

In a system as complex as *Arc/Info*, it is neither easily possible nor really desirable for the software developers to provide a level of interface provision commensurate with that of a simpler product such as a wordprocessor or spreadsheet. With GIS applications, the user base is extremely diverse (Green & Rix 1994) and user requirements vary far more than in more task–oriented products, meaning that an in–depth interface would often interfere with users' ability to freely interact with both data and software in order to undertake relevant analyses in a manner suitable to both data and user requirements.

Whilst a wordprocessor is a unified package which exists solely to produce textual documents, a GIS may more usefully be considered as a toolkit consisting of a large number of tools — more than 1,000 commands not being unusual (Medyckyj–Scott & Hearnshaw 1993; xvii) — which the user may gather together in any fashion they see fit in order to achieve results. This freedom and flexibility is one of the major disadvantages in using a high–end GIS as novice users are often overwhelmed by the morass of options facing them in undertaking even the most apparently simple task (Gould 1993). It is, however, also the greatest strength of a system such as *Arc/Info* as the user is able, with sufficient input of effort, to tailor systems that perform tasks specifically as required, rather than being forced to change working practices to fit the software's capabilities.

Access to all of *Arc/Info*'s flexibility is provided by two means; the Arc Macro Language (AML) and the newer *ArcTools* (ESRI 1993*a*, 1993*b*). AML is a powerful scripting language that may be used to control all aspects of GIS analysis within *Arc/Info* through a series of user–created AML scripts and, with the added functionality of *ArcTools*, the language can be used to construct complex menu interfaces to any aspect of the GIS itself or locally written tools such as the pilot `Dig_It` borehole simulation system discussed in **Chapter 5**.

In approaching the issues of interaction with the GIS and data presentation, effort was expended in working towards a standard feel for all project output. The model around which AML scripts were written, and which directed considerations of style, was known as the Visualization Engine, or VE. This VE consists of a series of implicit assumptions about data presentation, and a suite of linked — modular — AML scripts designed for all tasks from the production of a basic north arrow or scale bar to more complex analytical undertakings, and managed by the Visualization Engine Control Program (VECP).

As with the design of the database (page 74), a modular approach was adopted in order to reduce duplication to a minimum and to provide the fullest degree of flexibility in the manner analysis and display could be undertaken. In any display, the user accesses a number of existing scripts to build components for the presentation such as the north arrow, scale bar and background (`north_arrow`, `scale_bar` and `plot_creator` in **Appendix D**), on to which the specific analyses may then be plotted using further scripts.

Many of these scripts are of generic value, and have been used extensively by other projects such as the York Environs Project (Chartrand forthcoming), whilst others have been developed jointly with others (in the case of `surface_base`, Clayton Crawford at ESRI–Redlands in California) and incorporated into applications around the world. In all cases, however, the primary design drive has been towards application within the VE and utility to external users has been merely secondary. The requirement within the VE rule set that all scripts be extensively documented (below) has meant that other users are easily able to adapt scripts to their own uses but here again, the *raison d'être* was rather to aid adaptation of scripts internally to the project; it is not easy to remember the exact purpose of every line of code if a script requires updating some time after its original creation.

In search of style

In the preface to their book (1993), David Medyckyj–Scott and Hilary Hearnshaw suggest that the almost meteoric rise of GIS acceptance worldwide has been largely responsible for the apparent lack of serious consideration for issues long understood in the related fields of graphic design (Tufte 1983, 1990) and HCI (Gould 1993, Monk *et al* 1993). They suggest that system developers and end users are concerned primarily with increasing the power and diversity of their systems, and have been unable or unwilling to devote time to the less 'important' aspects of GIS design. Many GIS applications — while undoubtedly technologically and analytically advanced — fail to adequately impart their true message due to sloppy design and presentation, and an apparent failure on the part of the designer or user to consider the needs and abilities of the viewer.

To develop a valid presentation style for the YAA, it is important to consider the value of coherence between individual images as well as the issues of design within any one figure. Wherever possible, an illustration should follow a clear and standard format in order that a viewer need spend the minimum time locating and interpreting background information, and may quickly concentrate upon deciphering the message conveyed by the image. Following on from earlier, non–GIS, works (Itten 1961, Foley & Van Dam 1982, Tufte 1983, 1990, Travis 1991), an increasing volume of work concentrates upon or contains guidance on the issues involved in effective interface design and data dissemination (Ellis 1993, Medyckyj–Scott & Hearnshaw 1993, Hearnshaw & Unwin 1994, Lock & Stancic 1995).

As detailed elsewhere (Miller 1995*c*), one of the most frequently ignored considerations in developing display techniques is the use and abuse of colour and shading in order to enhance the clarity of a message.

Careful use of hue can add greatly to an image (Travis 1991), whilst a careless selection confuses, misleads, or overloads with surprising ease. In the *UNIMAP* terrain modelling package, for example, the default colour table displays low elevations as blue and in areas such as York where the lowest elevations correspond roughly to river valleys, viewers automatically — and wrongly — assume a direct correspondence between the colour blue and water.

Terrain Modelling

Archaeologists and other spatially aware disciplines are becoming increasingly aware (Raper 1989*a*, Kvamme 1990, Hearnshaw & Unwin 1994) that the data we model do not exist on a two dimensional plane, but in a three dimensional world where the extremes of topography have a significant effect upon the use of space both now and in the past.

Cartographers have, for many years, attempted to depict the underlying topography on their maps using techniques such as the hachure or contour to depict slope, gradient and altitude (Monmonier 1991, McCleary *et al* 1993, Phillips 1996). With the decreasing cost of computer hardware and software, the power of the Digital Elevation Model, or DEM, has become available to a huge number of researchers and, given adequate data, it has become possible to construct pseudo–three dimensional topographic models on the computer screen, as well as the more traditional isoline maps.

In exploring the deposits beneath York, an ability to accurately and clearly map the varying topography was seen as vitally important for both analytical and presentation purposes.

Detailed results of the terrain modelling programme and its archaeological implications shall be discussed elsewhere in a more archaeological context, but some archaeological interpretation will necessarily be found in this chapter where it helps to explain decisions made during the modelling process. Terrain models under analysis here are those for the modern surface of York and the underlying Roman surface as these two are the most complete.

The Modern topography

Construction of an accurate model of the modern surface was seen as of great importance to the success of all stages of the terrain modelling process. The work undertaken as part of the Ove Arup study (1991) constructed period surfaces by building points upwards from the natural pre–Roman topography. This natural topography was constructed from less than a thousand data points, almost entirely gathered from borehole investigations around the city.

During the data collection phase for the terrain model (discussed from page 61, above), all available sources of terrain data were approached, and a number of active data collection methods were investigated.

Interpolation

It is impossible to accurately capture values at *all* points across an irregular and chaotically varying surface such as a physical landscape. Accepting that recording values at every location is impossible, it becomes necessary to evolve a means by which values at any unrecorded point of interest may be calculated with respect to neighbouring known points. This process is known as interpolation (Burrough 1986; 147). Interpolation techniques vary greatly in accuracy and complexity but due to the manner in which surfaces are interpolated it is effectively impossible to identify a 'best' method of interpolation for all types of data — the fourier series, for example, is useful for interpolating across regular or periodically varying surfaces such as wind–blown sand dunes, but is incapable of effectively rendering more chaotic surfaces (Burrough 1986; 164). Even such a simplistic classification as 'Use fourier series for regular surfaces but not for irregular ones' is not guaranteed to generate the best representation of a surface, and it is necessary to tailor the interpolation technique to each case individually in order to accommodate the differing methods of data collection. In considering an interpolation technique to transform a series of surveyed *x*, *y*, and *z* values into a surface, the horizontal distribution of the points themselves has a bearing, as tightly clustered groups of points will result in a different representation of a surface to that produced from a more regularly spaced sampling strategy. Where feasible, it is important to consider the surface in question *before* data collection commences so that a data capture strategy may be formulated to most effectively acquire information that will fit the real surface to one of the available interpolation techniques. In the case of the current research, data were gathered from existing sources and it was impossible to exert any influence upon data capture policy.

Once data have been collected for the area of interest, the most suitable interpolation technique should be selected for describing the surface itself.

At a simple level, the Thiessen polygon or Voronoi tessellation is a form of interpolation, albeit only in two dimensions (Burrough 1986; 148). Although of no use for describing three dimensional surfaces, the simplicity of the Thiessen technique is often valuable as a means of reducing the complexity of large multi–dimensional data sets during initial analysis and checking. The interpolation method is based upon the polygon boundaries themselves and relies upon the assumption that the best source of information about any unknown point within a polygon is the known point at the polygon centroid. The only criterion used in calculating the distribution of polygons across a region is the known data points themselves, and the size of the polygons therefore becomes a crude indicator as to the potential accuracy of a terrain model at any point; the smaller a polygon, the more accurate a value obtained for any unknown point within it.

Unlike most interpolation techniques, Thiessen polygons are dependent upon discrete units. These units — the polygons — represent areas of uniform value throughout, such that if modelled in three dimensions a terraced effect would be seen (Burrough 1986; plate 8). The majority of interpolation techniques are based, as Burrough argues (1986), upon a premise of continuous change to which a smooth mathematical surface may be fitted, and they can be divided into two types; the global and local techniques.

Global Interpolation Techniques

In using global techniques, the interpolation model is constructed with reference to all available data points across a surface, and local anomalies may therefore be only poorly represented in the final output. Trend surface analysis and models based upon the fourier series are examples of global interpolation.

These techniques are best suited to gradual long–range variations in data, which may be described by a relatively simple mathematical technique known as a polynomial regression. The data points are analysed and an equation is defined that adequately describes the surface as a whole, without necessarily respecting the actual locations of the original data in the resultant surface. The main advantage with a technique such as trend surface analysis is that it is *superficially* easy to understand, with simple surfaces being described in terms of relatively simplistic mathematics. The technique is also useful as it does not place great demands upon available computer power in generating the final surface. Problems often occur where large variations in z need to be mapped, especially when these variations are localised. As the technique is applying a best fit curve to all available data, a small number of points with values greatly above or below the norm may easily distort the whole image.

It is important to remember that, because of the techniques used, a trend surface will *rarely* pass through the surveyed points themselves. In any accurate analysis of surface characteristics, this renders the technique almost useless, except for initial data visualization.

Local Interpolation Techniques

Local interpolation techniques such as splines or moving averages (Burrough 1986) differ from the global techniques in that, as the name implies, interpolation is undertaken locally rather than across the surface as a whole. With global techniques, an analysis of the trend across a whole surface is used to calculate values at any unknown point, whereas the local technique looks to those known points surrounding the unknown to interpolate a value.

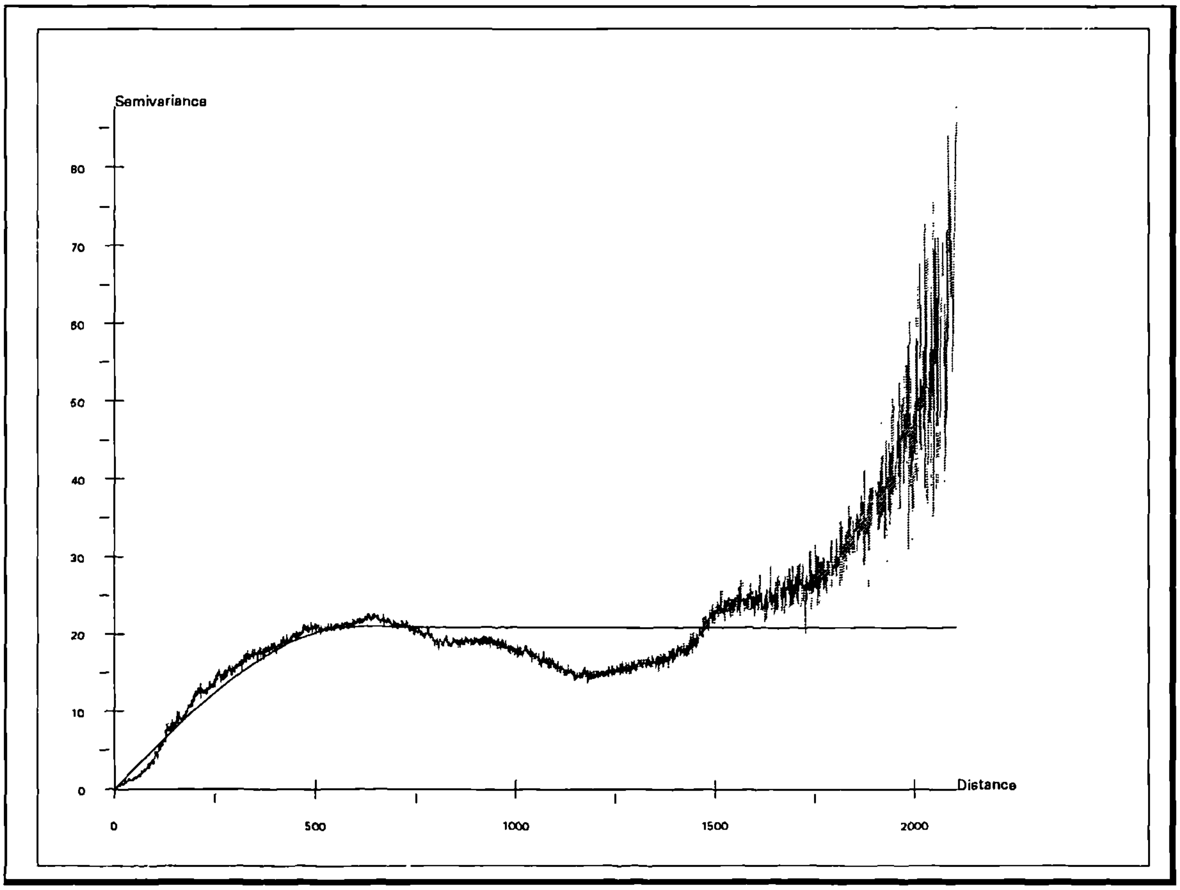
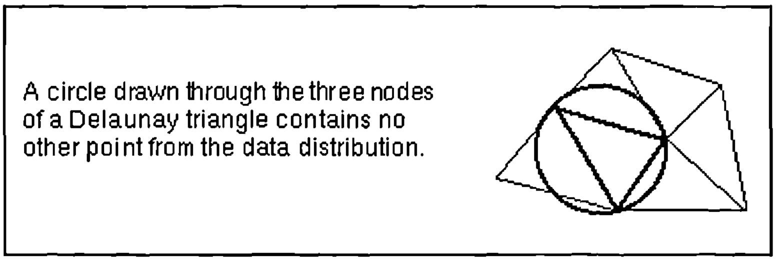


Figure 17: A semivariogram, as produced by the Kriging procedure

Kriging is one of the most powerful of the local interpolation techniques, and was developed by Krige and Matheron (Matheron 1971, Burrough 1986; 155) for use primarily in the mining industry. The kriging technique provides a best linear unbiased estimate (BLUE) at any given point across a surface by recognising that real world variables are too irregular for classic mathematical curve fitting techniques and accepting that a more stochastic approach is required. Kriging assumes that variation in any variable (in the case of a terrain model, *z*) may be expressed as the sum of three major components; a structural component (a constant average or constant trend); a random spatially correlated component and; a random error (Burrough 1986).

As an exact interpolator, kriging ensures that known values for a surface will be respected in a way that some of the global techniques fail to do. Due to the complexity of the mathematics employed, kriging techniques are very compute–intensive, making everyday use of kriging unlikely. It is also possible to produce widely varying representations of the same initial data set, as the process relies fundamentally upon the selection of a suitable mathematical model for the computation. In theory, the model to be used should be selected by producing a series of variograms comparing the real data to a mathematical curve computed by each model. The model which best fits the measured distribution should then be used in the kriging procedure. As can be seen from Figure 17, however, even the best of the available models produced a poor match between observed and modelled data. The smooth line on the graph shows the modelled curve, while the more erratic plot depicts the distribution of surveyed points.

The greatest benefit of this technique is that it becomes possible to produce error maps for the terrain models. As kriging relies upon the fitting of actual data points to a semivariogram, the distribution of interpolated points about that variogram may be computed and displayed as a new surface. This surface then provides a useful indicator as to the likely precision of a terrain model at any given point, as those areas with high variance may be assumed to offer a less accurate depiction of the real surface.



A circle drawn through the three nodes of a Delaunay triangle contains no other point from the data distribution.

Figure 18: TIN construction and the Delaunay criterion (ESRI 1995)

The basic form of interpolation used within *Arc/Info*'s TIN module is the triangulated irregular network, or TIN. The data structure for a TIN consists of a series of surveyed points with *x*, *y* and *z* values, and a series of edges joining the points to form triangles in a continuous multi–faceted surface. Importantly, the triangles must all satisfy the Delaunay criterion that a circle drawn through all three points of a triangle will contain no other point; *ie* the points are connected to their *nearest* neighbours to form the triangles (Figure 18).

Building the modern surface

Various forms of interpolation have been used in the solution of specific problems throughout this thesis, and an understanding of the techniques available — and their limitations — is important, but the basic format employed in construction of the modern terrain model shows the practicalities of many of the techniques. This section examines the construction of the modern elevation model, and demonstrates the effect upon the model of adding each subsequent data set to the whole. Kriging techniques are used throughout to identify areas of high error probability.

The modern elevation model consists of 2,378 data points (Figure 19) derived from the following sources:

- 283 spot heights derived from Ordnance Survey 1:1,250 digital maps (Figure 20)
- 605 points extracted from YAT's database enhancement project and Ove Arup database (Figure 21)
- 78 points derived from National Rivers Authority annotations to Ordnance Survey 1:1,250 paper maps (Figure 22)
- 1,412 manhole cover heights derived from Yorkshire Water paper listings and associated Ordnance Survey 1:1,250 and 1:10,000 paper maps (Figure 23)

Due to the nature of the data (Figure 19), the distribution of points across the city is far from even, and some areas contain large concentrations of data whilst others are only sparsely mapped. In constructing the modern terrain model, it has been necessary to assume that all the data used are of equal — and high — accuracy. Thus, the kriged error maps used below include the implicit assumption that the data points themselves (shown in black) are of the highest accuracy, with decreasing precision shown by a decrease in saturation towards white. This implicit assumption of high data accuracy for the points themselves is perhaps not unreasonable; given that, whatever the actual agency providing individual points, the common frame of reference in all cases is the 1:1,250 scale map library of Ordnance Survey, it is reasonable to assume that accuracy *relative to the Ordnance Survey* is reasonably consistent — and within tolerances — across the whole area. Errors in Ordnance Survey data capture relative to the reality of the cityscape are known but irrelevant, as all data capture has been undertaken relative to the Ordnance Survey version of reality rather than the ground–truth version visible to the naked eye. Errors are therefore consistent between map sources and may be discounted within inter–map analyses.

Most software used to create elevation models from surveyed data creates the surface by interpolating between points using a variety of mathematical equations. These interpolation algorithms tend to describe smooth gradients between data points, which can cause problems where abrupt 'faults' disrupt the surface. These fault features may be vertical displacements of the surface, such as those occurring at cliff edges or in geological faulting, or artificial disruptions such as cellars or pits. A related problem is that posed by the definition of water features, which tend to be horizontal interruptions to the shape of any surface; most interpolation techniques will attempt to describe the underlying bathymetry rather than the visible surface of a hydrological feature.

The favoured solution to both of these deviations from the normal mapping of natural topography is known as the breakline; a technique by which areas of a map are defined as being of a uniform height around which other more ephemeral features are interpolated.

In the model of modern York, breaklines were used extensively to control major topographic features and create a surface more realistic than the default (Figure 24). The major breaklines present in the model were used to define the banks of the rivers Ouse and Foss, significantly altering the shape of the whole surface. The banks of the Ouse were defined as 5m above Ordnance Datum and the Foss behind Castle Mills lock was set at 7m. These flat areas prevent interpolation from taking place within the rivers themselves, but also have a significant effect upon the river banks. Figure 25 demonstrates the effect upon one transect across the river of applying breaklines. As can be seen, the banks change shape, and the river itself changes position slightly.

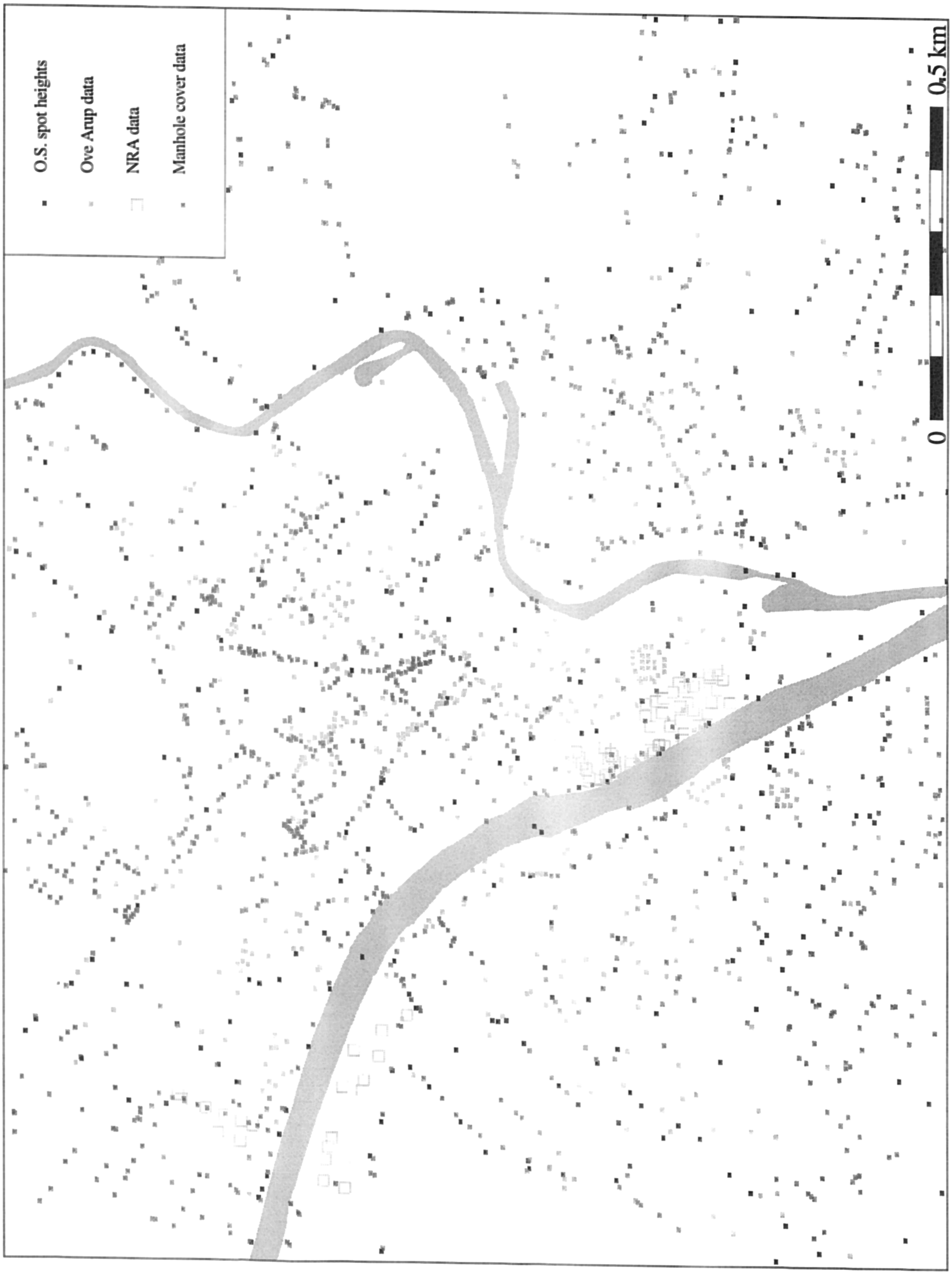


Figure 19: Data points comprising the modern elevation model

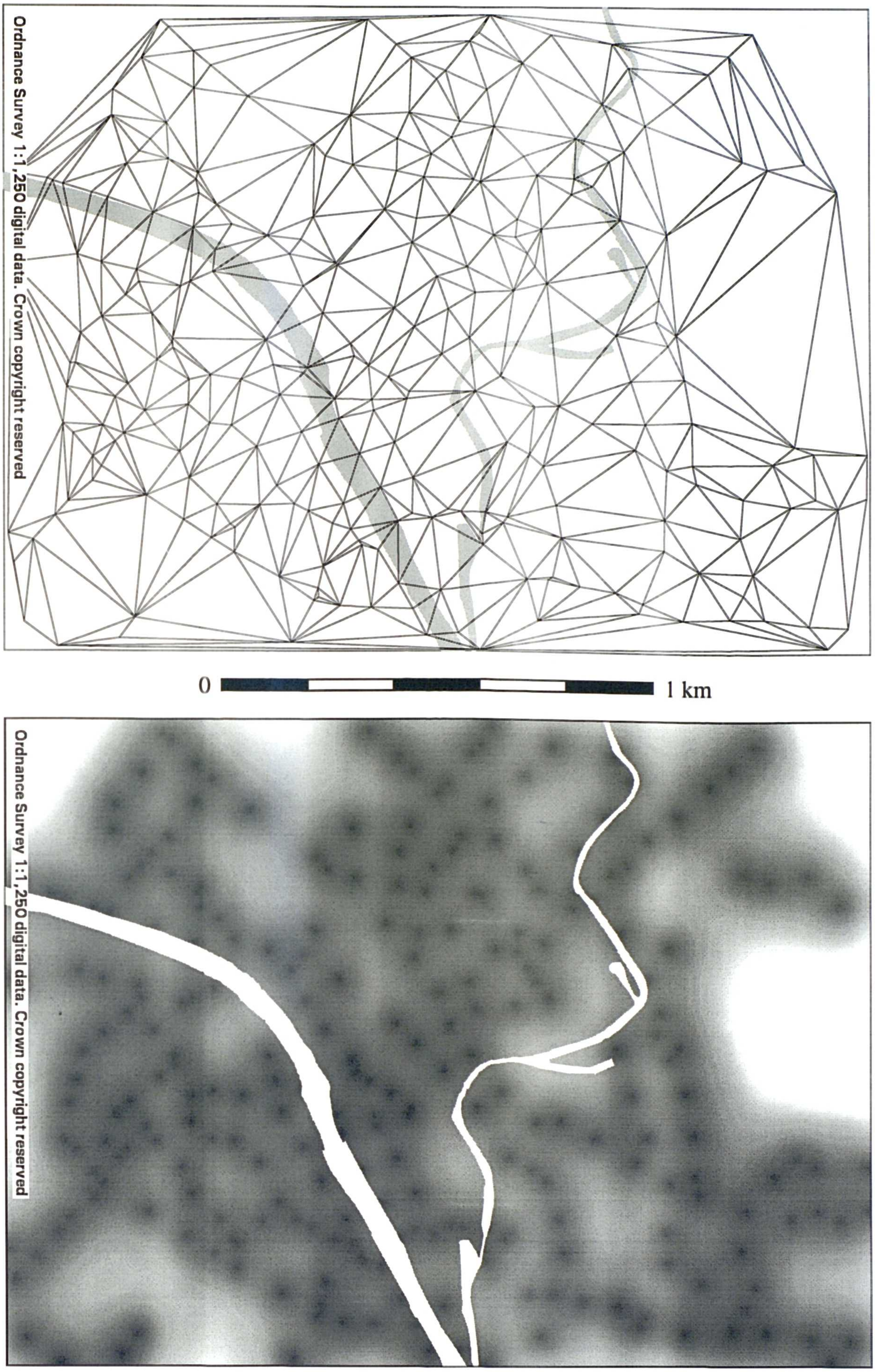


Figure 20: Modern TIN constructed from Ordnance Survey spot heights, plus Kriged error plot

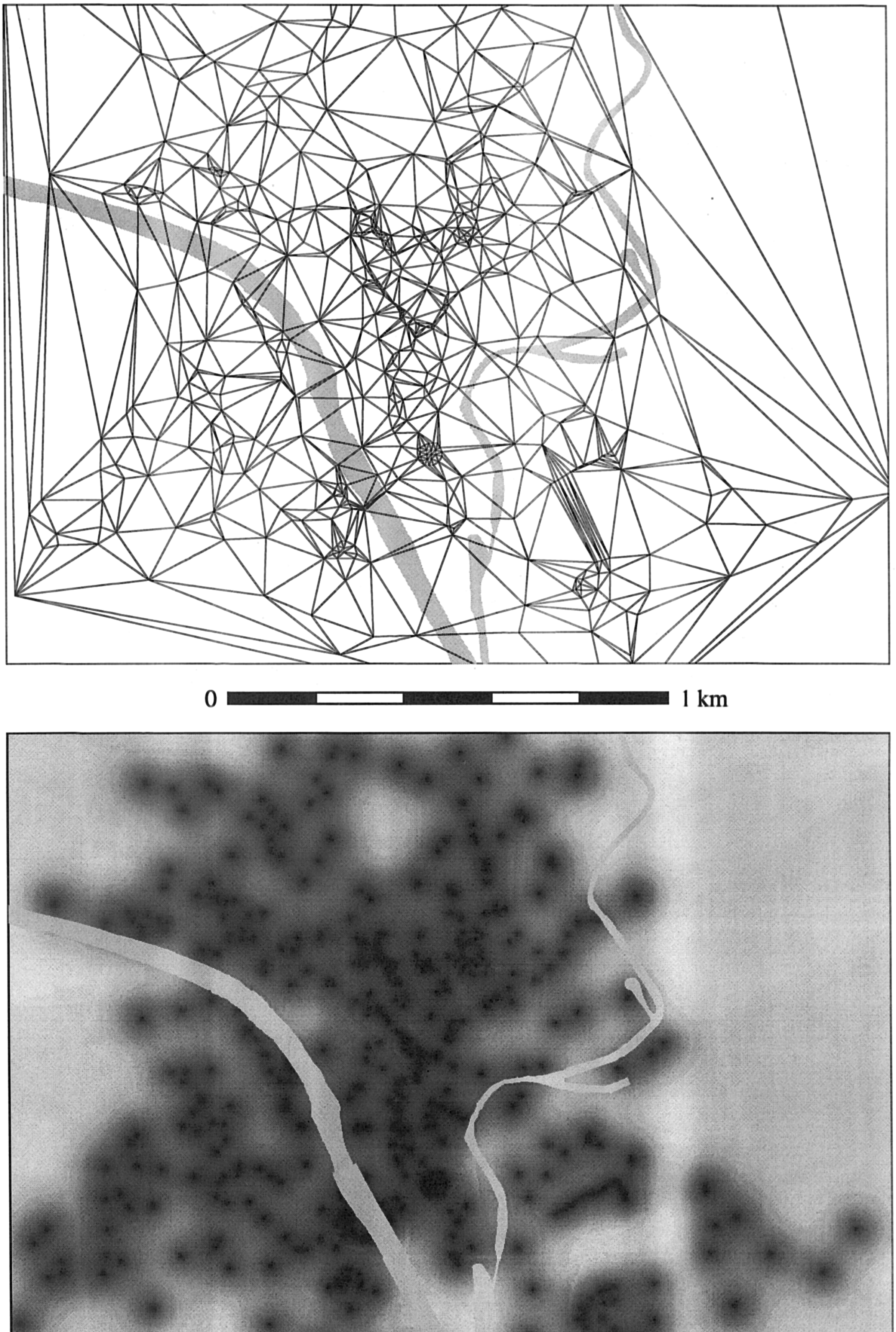
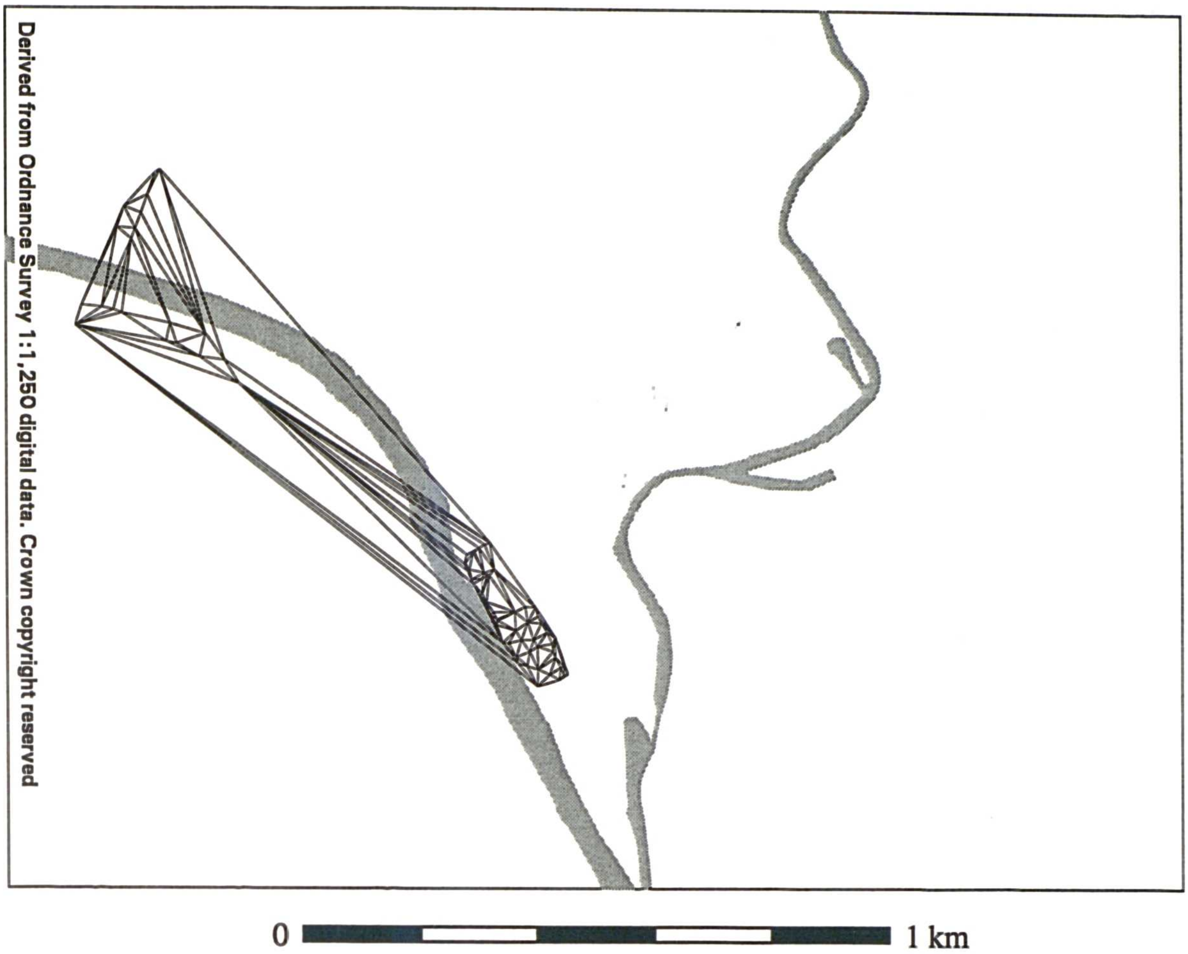
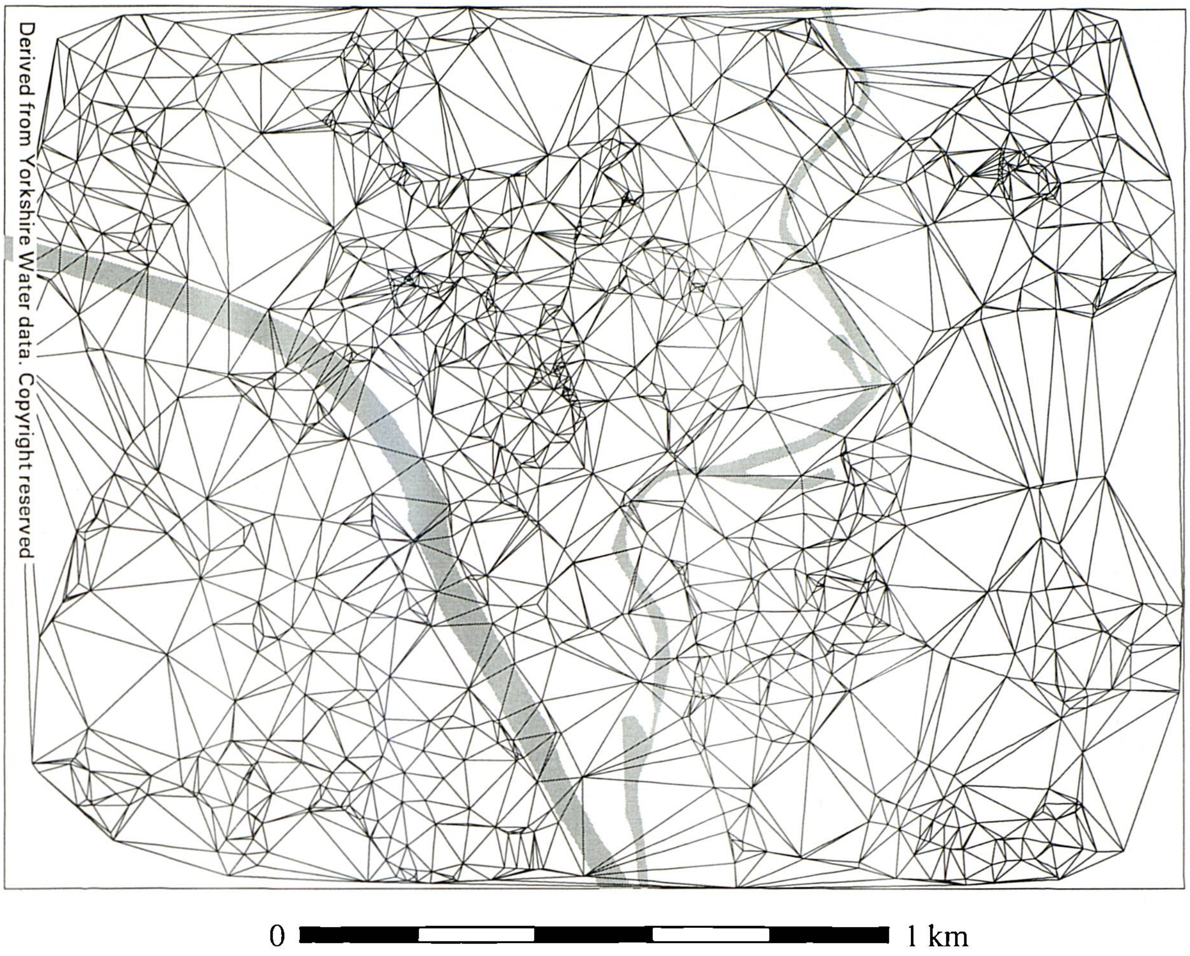


Figure 21: Modern TIN constructed from YAA project database, plus Kriged error plot



Points not sufficiently distributed for Kriging

Figure 22: Modern TIN constructed from NRA flood alleviation data, plus Kriged error plot



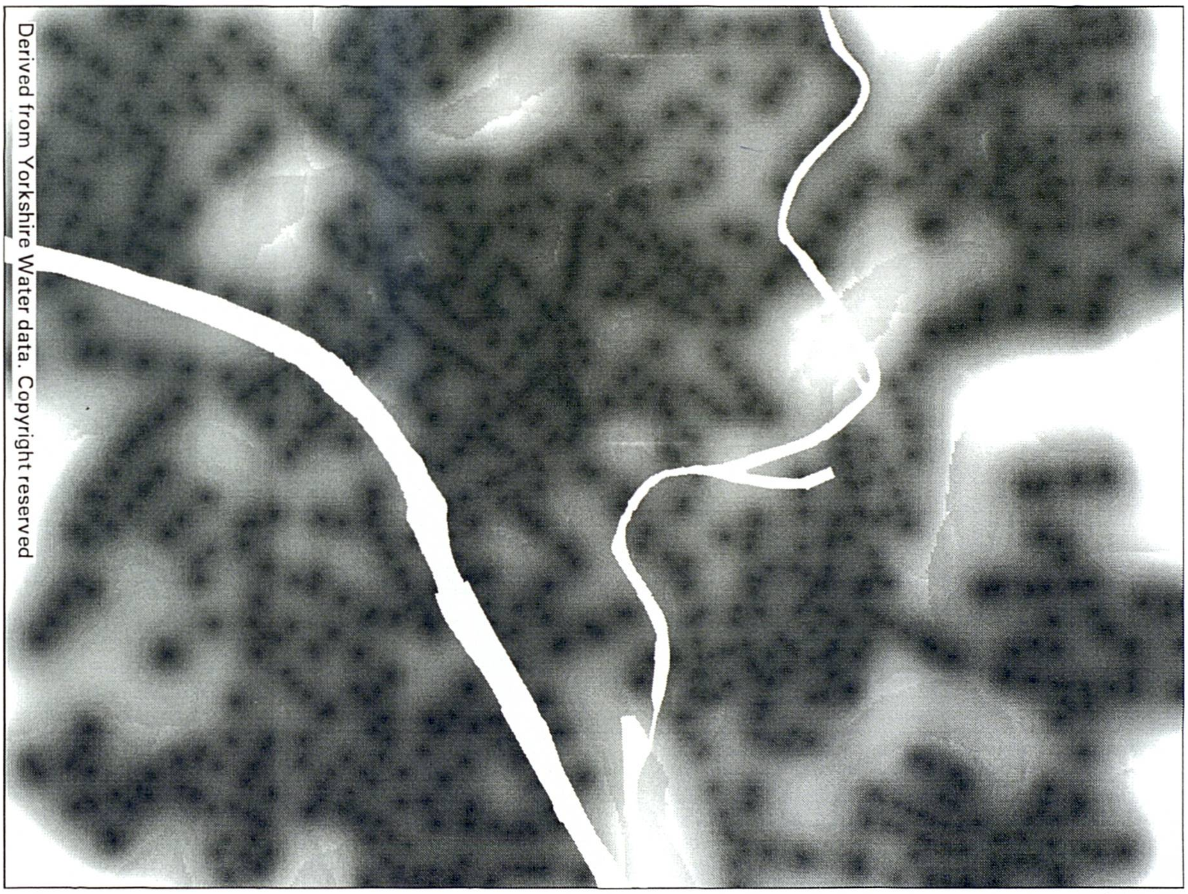


Figure 23: Modern TIN constructed from Yorkshire Water manhole cover heights, plus Kriged error plot

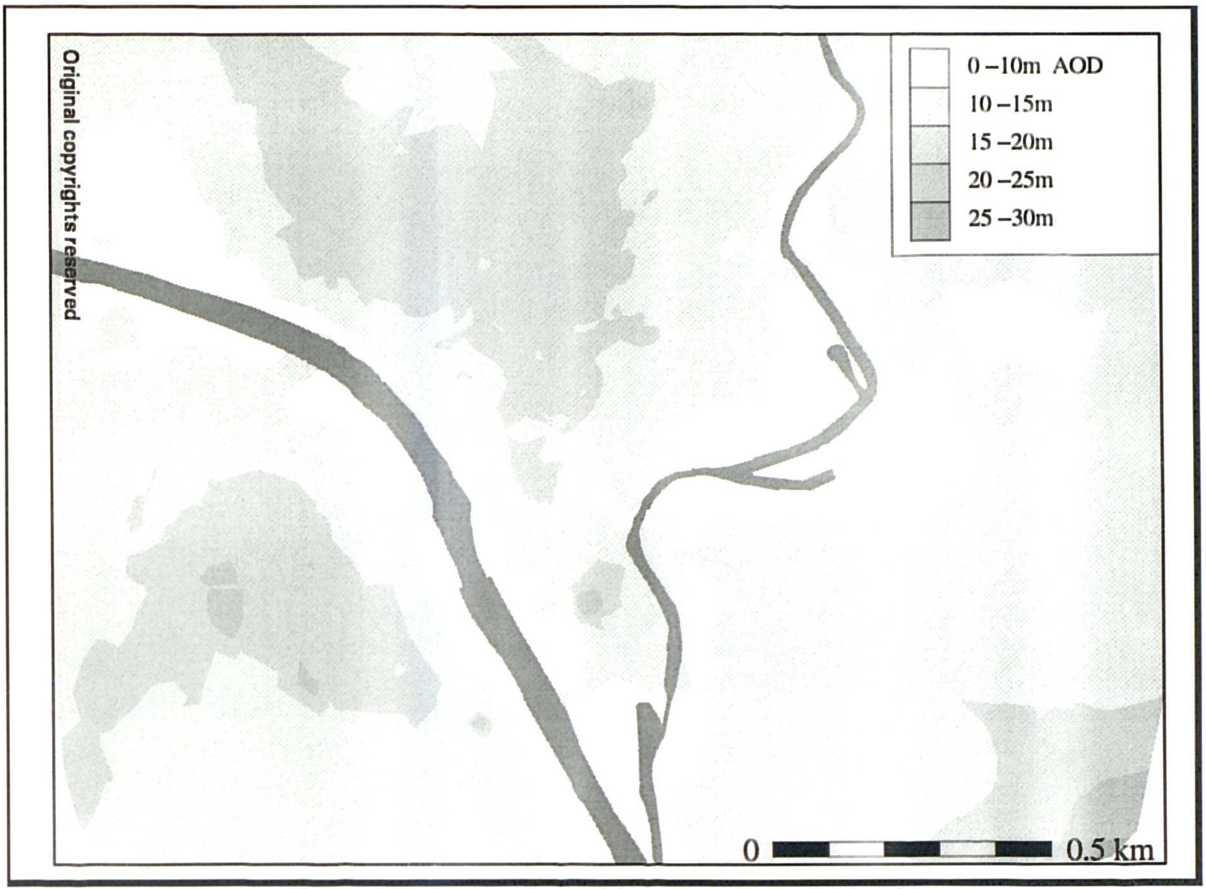


Figure 24: Modern elevation model constructed from all data points

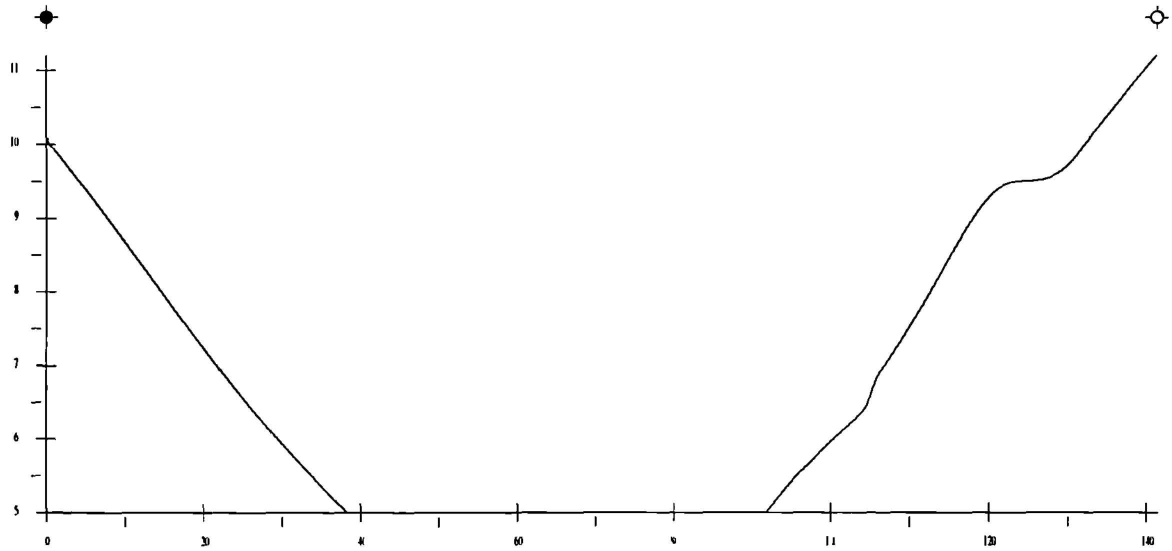
The other breakline within the model is that defining the edge of the project area. This barrier creates a neat edge to the surface and goes some way towards eliminating the ever–present edge effects.

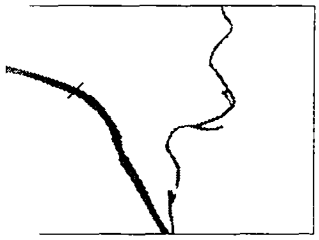
The completed modern surface, then, reflects the existing topography as exactly as possible, and may be used in detailed analyses of both the modern surface and the relationship between this and earlier strata (Figure 28). The major omission — and one that should be rectified in any further work — is the lack of data for the banks around the circuit of the medieval city walls. It unfortunately proved impossible to gather data of sufficient quality for the whole circuit of the defences given problems of time, access and resources.

The Roman topography

In constructing a model of York's topography early in the first millennium AD, the task was more complicated than that for the current surface discussed above. In the first instance, far fewer points were available, and it was impossible to draw upon the archives of utility companies to fill in the gaps in any surface.

Transect calculated without breaklines





Transect calculated with breaklines

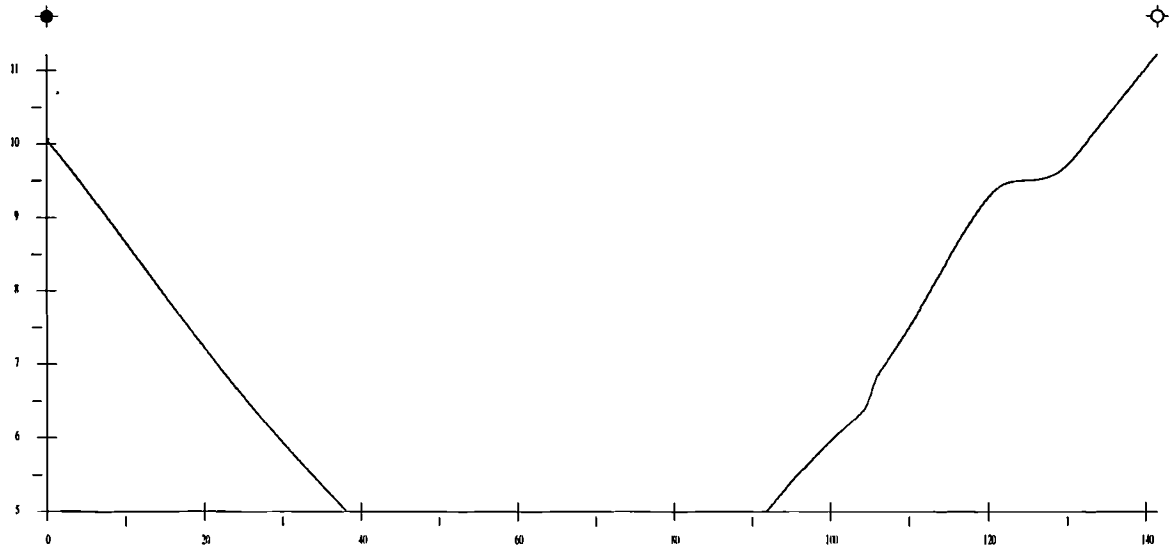


Figure 25: The effect of river breaklines upon the River Ouse

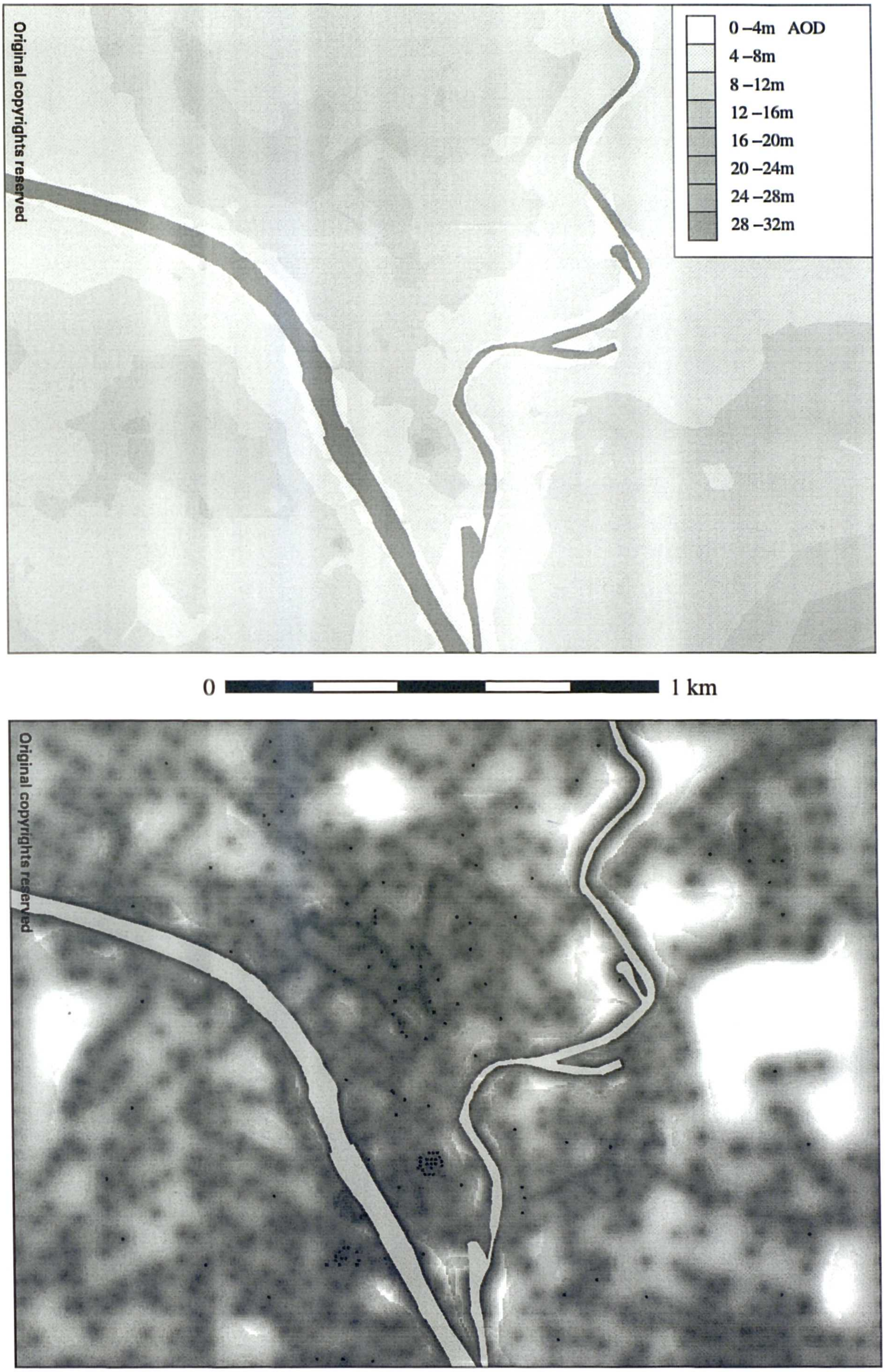


Figure 26: The modern elevation model including breaklines, plus Kriged error plot

Information for the Roman surface was derived primarily from archaeological contacts stored within the project database. 1,324 heights of identifiably Roman and immediately pre–Roman date were available. In all cases, Roman deposits were laid directly upon, or cut directly into, the pre–settlement 'Natural' strata as deposited by retreating ice sheets in the last Ice Age. It was therefore considered acceptable to use heights identified as being pre–Roman for those areas lacking Roman height information, as these features are likely to belong to the same underlying topography as that encountered by the Roman builders of *Eboracum*.

In constructing the modern terrain model, breaklines were important in defining the shape of the current river system (see page 105), as well as in controlling the model at its extents. The series of figures (Figure 24–26) charting the development of the modern surface clearly show the benefits of physically defining the river system rather than relying solely upon computer interpolations. Figure 25 is especially valuable for indicating the control exerted upon the river course itself by breaklines.

In the Roman period, however, one of the questions facing archaeologists is to define the extent of the rivers throughout that period, and there has been some debate both about the mean levels (Ordnance Survey 1988*a*) and about the extent of any flooding (Ramm 1971, **Chapter 5**). It was therefore impossible to define the positions of the rivers, and the GIS was instead used to *explore* possible river courses in the period. Given the visible differences between the modern surface with and without breaklines, the computed river courses discussed here should, of course, be treated with due caution and as computer generated *prediction* rather than computerised representation of *fact*.

In the map of Roman and Anglian York (Ordnance Survey 1988*a*), YAT attempted to depict the course of the Roman river system through the city centre. Their prediction resulted in an Ouse some 125m wide — more than twice the current width — and a similarly engorged 60m wide Foss meandering to the convergence, often flowing some distance from the current heavily canalised course. Excavations on the site of the new General Accident headquarters building on Wellington Row from 1987–91 (`siteno 1987.24`) showed the Ouse to lie further north than expected, with evidence of buildings uncovered inside the area tentatively identified on the Ordnance Survey map as underwater in the Roman period.

Later, in 1993, Ottaway remarks that

> excavations... suggest, however, that in the late first century its [the Ouse] level may have been, on average, some 3–4m (10–13') below its present summer average of *c*.5m (16') OD.
> (Ottaway 1993; 21)

This evidence has been used in order to test various river levels by constructing the Roman topography and then 'flooding' it to different levels in order to examine both the predicted river course and its interaction with known excavated deposits (**Chapter 5**). In order to aid visualization, and as an experiment in translating topographic data from the GIS, a model of the Roman topography was built by John Watt of York Archaeological Trust's Archaeological Resource Centre (ARC). As would be expected, the model is similar to the computer simulations, but there is an added level of realism in the simulation, as pouring water over a physical model seems in many ways more satisfying than viewing a computer simulation of the same. The ARC have expressed an interest in building further models for use in their interactive displays (Jones *pers comm*).

In line with Ottaway's suggestion (above), the majority of the computer simulations were based around river levels of 1–2m AOD. Based upon the available data, it is impossible to conclusively identify the course and level of the Roman hydrology, with the figures below merely marking the next stage on from the predictions published back in 1988 (Ordnance Survey 1988*a*). Further work on changing river levels is discussed as one of the case studies in **Chapter 5**.

Problems inherent in constructing intermediate surfaces

As in the Ove Arup study (1991), intermediate surfaces were constructed between those for the modern and Roman periods. These surfaces were based upon fewer points than the upper and lower boundaries to the strata and therefore form less reliable representations of the buried strata. Attempts to extract information from layers above and below each period surface proved unsuccessful, as a methodology could not be formulated in order to accurately decide when to add points from a second surface and to reliably decide *which* surface to extract the data from.

The major problem involved in constructing period surfaces for York was not related to the logistics of building the surfaces themselves, however, but was rather of a methodological nature in that it concerned the practice of building these surfaces *at all*.

As is apparent from the very existence of thick archaeological strata, deposits and artefacts are not restricted to narrow bands of deposition amenable to the easy classification of 'period layers' as is implied by surface maps such as those produced in this thesis. Rather, deposits are laid down through time throughout the thickness of an archaeologically definable stratum with the potential for artefacts and important contexts to occur at any point in the three dimensional matrix forming the excavated strata. These essential units of the archaeologically recoverable past will therefore often rest above or below the single slice defined for each period within a standard deposit map, with the likelihood of a given deposit resting *upon* the computer–generated surface being remote. The period surfaces themselves should therefore be viewed more as boundaries to deposition of a specific period rather than as the ground surfaces upon which all activities of a given era occurred.

Despite the gross simplification of reality involved in generating these individual period surfaces, it remains possible to visualise the ways in which the topography has varied from one period to the next, both by examining differences between one surface and the next and by generating sections through the deposits (Figure 27) in order to examine build–up along a specified transect.

The result of this figure should be examined with reference to the earlier kriged error maps for each period, and it should be remembered that the most complete surfaces are those at the top and bottom of the section. The apparent thickness of the modern deposits, for example, may be more a result of poor definition to the medieval and Anglo–Scandinavian surfaces than a reflection of reality.

Possibly more useful in many ways than the surfaces themselves is the opportunity to use the data constructing the surfaces in different ways. This includes the generation of sections as discussed above, but also encompasses the creation of maps depicting deposit thickness (Figure 28). A map such as this very clearly enables the user to perceive areas of greater and lesser deposition, as well as regions of the city where the deposits are likely to have been removed altogether.

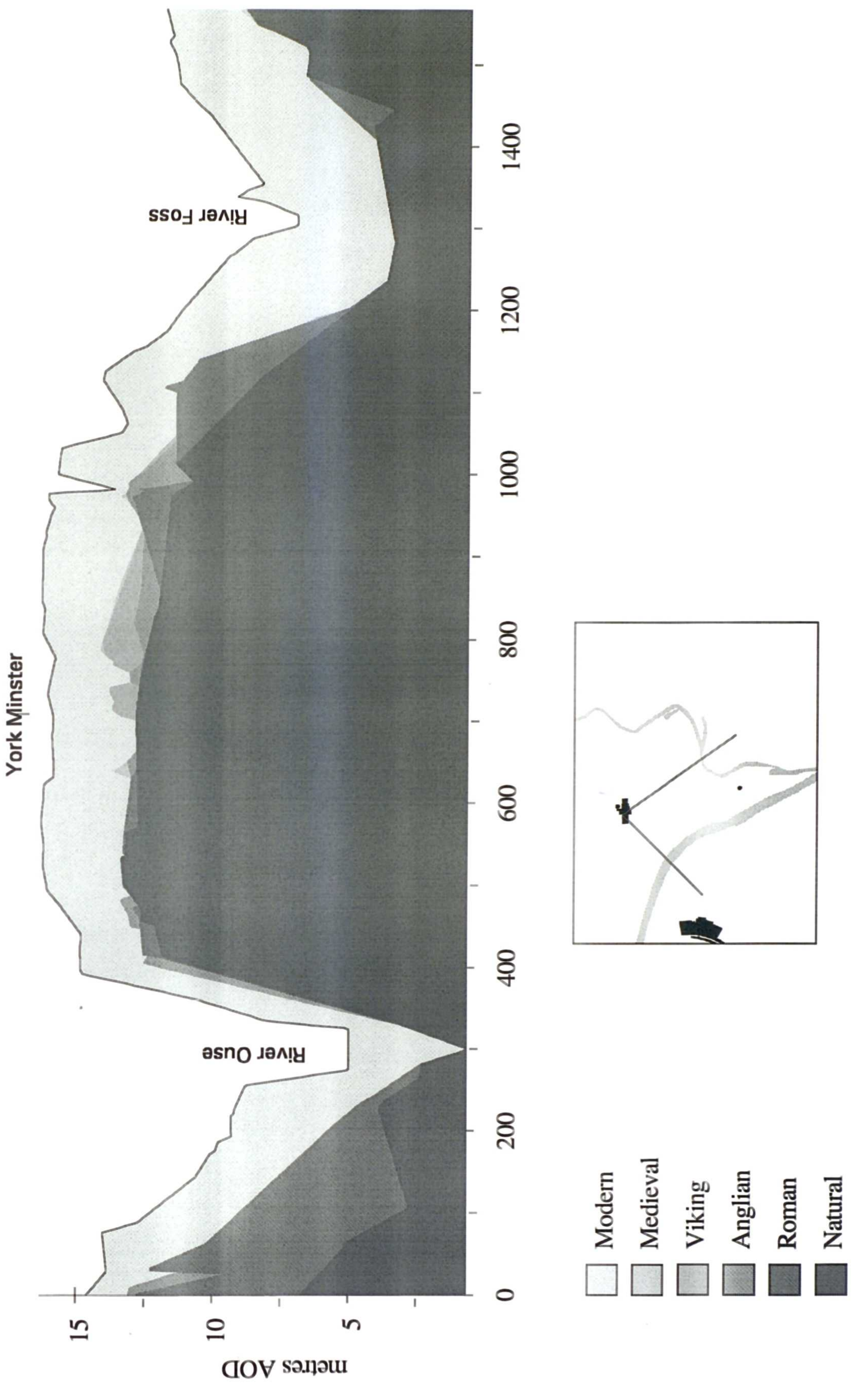


Figure 27: Cross - section through York's deposits

Figure 28: Deposit buildup in York

5. *Case Studies*

Introduction

Having created a Geographic Information System (GIS) following the methodology outlined in **Chapter 4**, a series of case studies was formulated to test the efficacy of the selected structure and to demonstrate the archaeological potential for such a system, even when confronted with the limitations of real archaeological data collected with less precision than might be expected on an urban excavation of the 1990s. The greatest power of a GIS lies in its everyday use and often in the ways in which previously possible tasks become more than merely possible and potentially even routine. Such power is difficult to demonstrate in a medium so static as the paper report, but the case studies below have been selected as hopefully representative of the archaeological applications to which such a system might be put.

During development of the system, techniques were first applied to a subset of the data in order to increase flexibility and to enable the relatively rapid modification of data to match evolving ideas and methods. The Case Study Area used throughout this development process is introduced below. Of the five case studies then presented, two still make extensive call upon this Case Study Area, with **Case Study 3** wholly based therein, and **Case Study 2** largely focused upon this map tile. The final study examines the way in which improvements in the GIS user interface might enable more widespread use of the technology — and, consequently, the data — within archaeology, and this discussion is re–examined throughout **Chapter 6**.

The Case Study Area

In a project of this scope, it is difficult to assess the validity and relevance of a proposed research design prior to application across an area considered in some way as representative of the whole. As problems and errors are encountered, research is delayed whilst solutions are developed and implemented. In an effort to minimise these difficulties, a subset of the total project area was designated for a pilot programme in which the proposed methodologies could be developed and tested.

In the latter stages of the project, the same area was used to investigate a series of archaeological case studies (**Case Study 2** and **Case Study 3**) which time did not permit being applied to the whole area of interest.

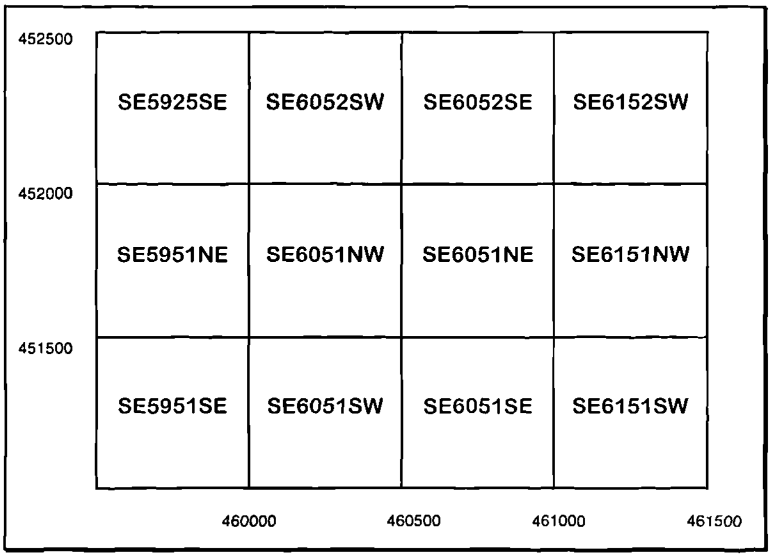


Figure 29: Ordnance Survey digital map squares and the case study area

Of twelve Ordnance Survey map squares within the project area, one (SE6052SW) was selected for the case studies (Figure 29). The chosen square is located in the northern area of the city and includes both intra– and extra–mural buildings. The area is relatively flat and lies approximately seven metres above the River Ouse — or *c* 15m above Ordnance Datum — on a low band of moraine traversing east–west across the Vale of York (Figure 1). It is likely that most of this area has been above possible river incursions over the past 2,000 years, making it an ideal site for early settlement in the area.

The case study area contains elements of most modern landuses present within the city as a whole, including ecclesiastic sites (*eg* York Minster, Holy Trinity Goodramgate), medium and high quality housing (High Newbiggin Street, Minster Court), education (Bootham School, The College of Ripon & York St John), commercial development (Stonegate, Back Swinegate), leisure services (the Theatre Royal or Public Library) and light industry (Bootham Row). Buildings range in age from the late Roman 'Anglian' Tower to the modern developments in the Swinegate area, and modern reuse of older buildings in this area is an ongoing concern for the Planning Authority.

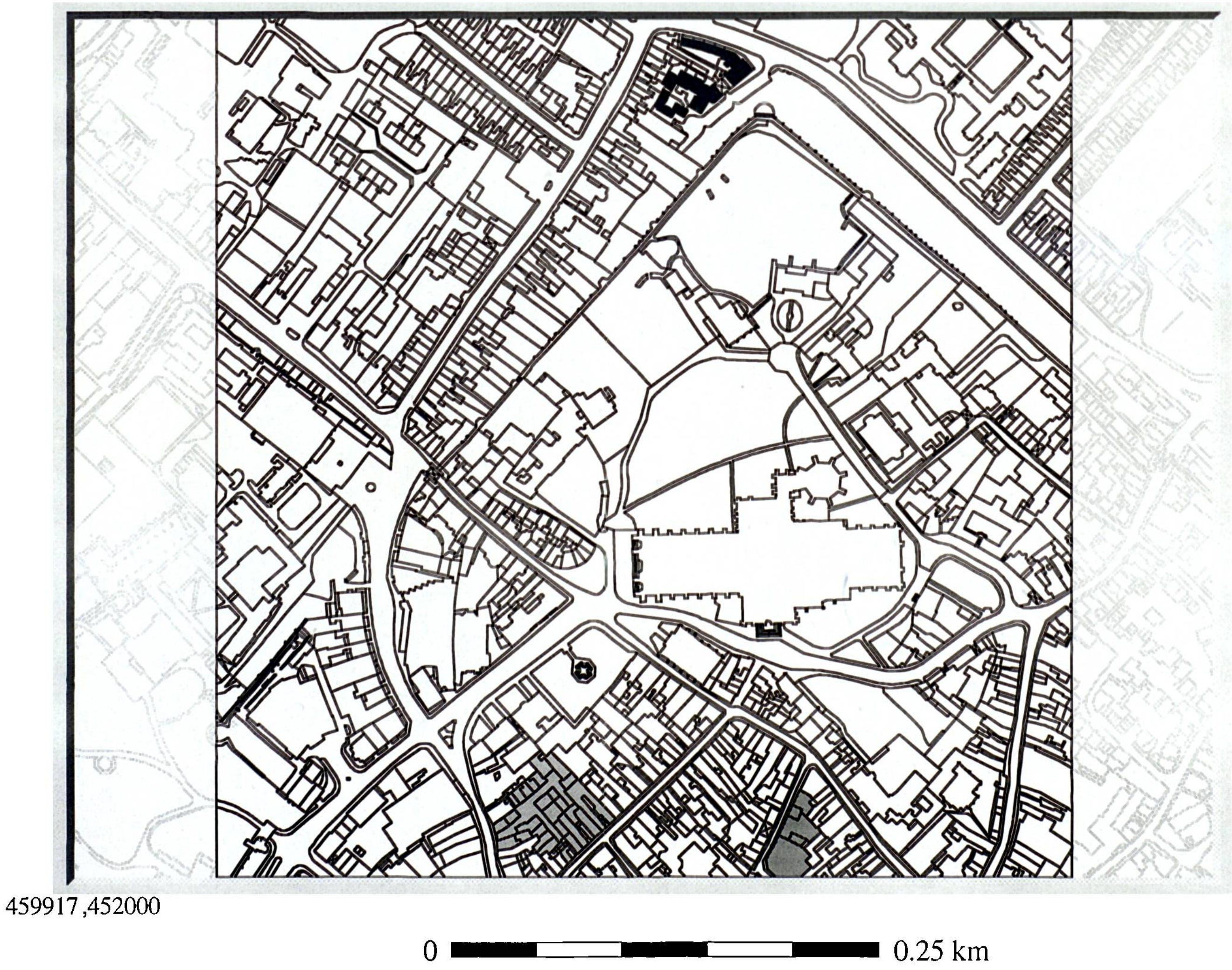
Table 4.2 of the Ove Arup report (1991; 22. See also Figure 4.1) identifies twenty zones into which York is compartmentalised. Two of these lie within the case study area; the Roman fortress (Zone 1) and the northern extramural zone (Zone 19). The information for these two zones may be summarised:

Zone	Description	*x* Depth	Anaerobic	Coherence	Periods	Quality
1	Roman fortress	3–5 metres	Roman deposits	High	All periods	Highest quality
19	Extramural (north)	*not known*	*not known*	Average	Roman–Medieval	*Insufficient data*

Table 10: Zonal summary of deposit characteristics (after Ove Arup 1991; 22 [table 4.2])

YAA

Figure 30: Modern development in the Pilot Study area



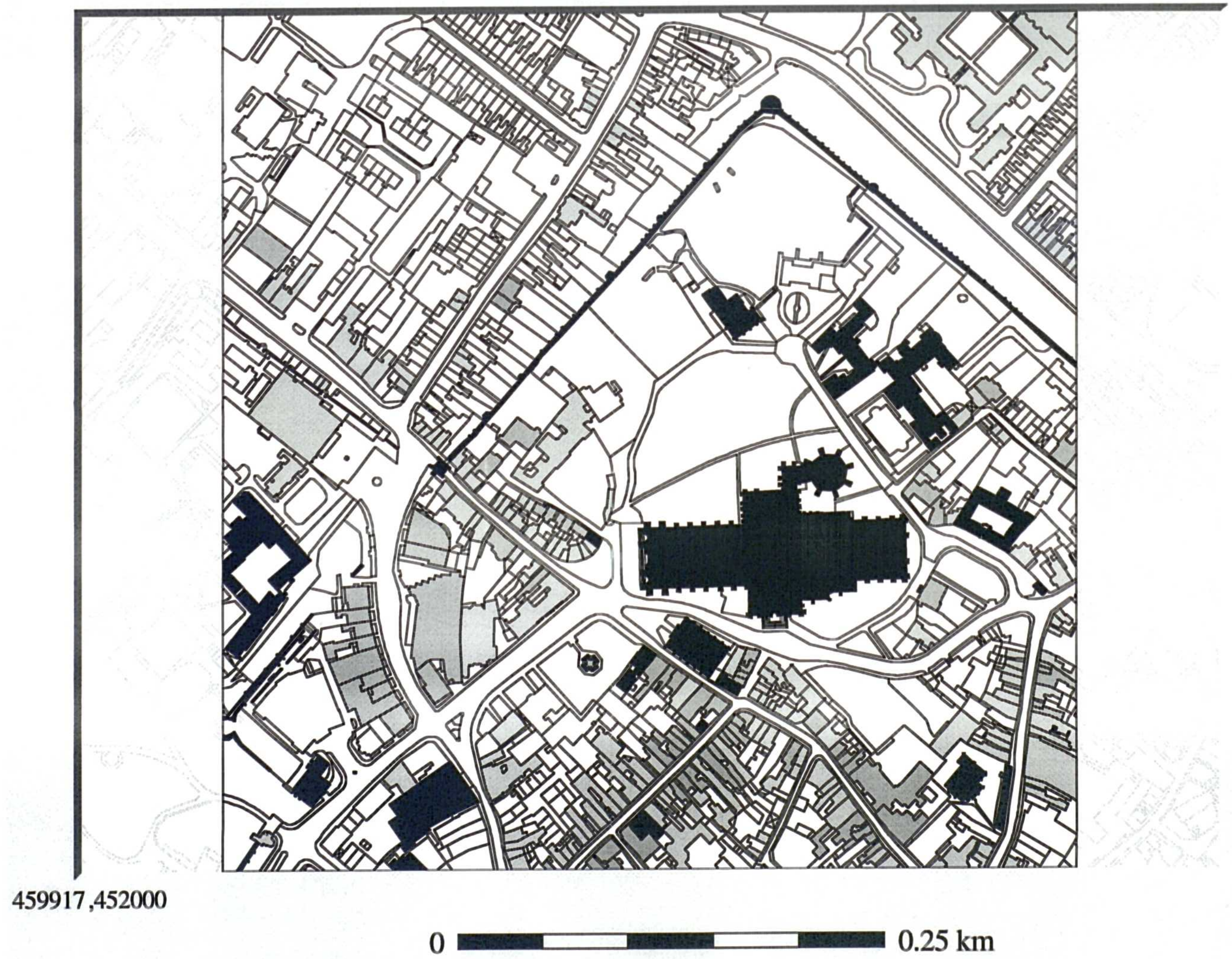
■ Moatside Court development
□ Stonegate Arcade development
▨ Swinegate development

A P Miller 1996

Ordnance Survey 1:1,250 digital map data

YAA

Figure 31: Listed Buildings in the Pilot Study area



A P Miller 1996

Ordnance Survey 1:1,250 digital map data Crown Copyright reserved

The area chosen for the case studies forms a useful microcosm of the modern city as a whole, with old and architecturally significant historic buildings and modern commercial or residential developments side by side within the 500m square around York Minster (Figure 30).

Modern development includes the recently completed Swinegate shopping precinct (NGR 4603 4520), the Stonegate Arcade (NGR 46017 45204) and housing on the corner of Lord Mayor's Walk and Gillygate (NGR 46025 45248). The development of the Swinegate area during the early nineties allowed for comprehensive excavation of the area on a large scale, providing detailed data for the Roman fortress and post–Roman settlements (Pearson 1990*a*, 1990*b*).

The area is well endowed with historic buildings with 303 (20.2%) of the 1,500 Listed Buildings recorded in York in 1983 (Figure 31) to be found here. Much of the square also lies within Scheduled Monuments or the Minster Yard Scheduled Area, and the whole square is within the Area of Archaeological Importance (HM Government 1979, Figure 9).

254 of the 2,076 archaeological contacts (12.23%) recorded in the project database lie within this square, providing valuable information about the state of the subsurface archaeology in the city centre. As shown in Table 10, these contacts indicate relatively shallow deposits that would appear to be in a good state of preservation.

Data Issues

The sources of data utilised during these case studies are discussed in detail in **Chapter 4**, where the great diversity of origination is illustrated. In undertaking the case studies, below, many deficiencies in the source data were encountered, both in general and — more often — in their application to questions such as those posed.

The selection of case studies offered here serve to illustrate the types of archaeological question suitable for exploration within a GIS environment. They also serve equally well to illustrate the difficulties encountered in re–using archaeological data for further research, rather than merely for the publication of an excavation. Although it *is* possible to derive answers from the analyses offered below, if research–driven questions such as those explored here are to be routinely posed in the future, the consistency and quanifiability of archaeological data need to improve. This issue is explored where necessary in each case study, and many of the general issues are re–examined in **Chapter 6**.

Specific problems were encountered with those data relating to the Anglian and Anglo–Scandinavian periods (although note the discussion of temporal issues in **Chapter 2**), primarily because these data were not available across the city, but rather in a number of isolated clusters such as the Coppergate/ Ousegate area. Case Studies 1 and 4 primarily address the Roman period, and thus do not need to use the poorer data of these two periods. Case Study 3 uses a totally different data set from the rest of the project, drawn directly from the archives of two excavations, and Case Study 5 addresses issues primarily related to interface rather than data; as such, data from the two periods in question are left in for the sake of completeness, but output from the system specifically warns users of the dangers of spurious data (Figure 74). The first half of Case Study 2 includes a subset of Anglian data for one area of the city where these are available, and Figures 39–41 also include Anglian and Anglo–Scandinavian data, partly for the sake of completeness and partly to illustrate their limitations (Table 11). The Anglian and Anglo–Scandinavian results from the process discussed towards the end of Case Study 2 were considered — because of the localised nature of the data — to be inadequate for presentation along similar lines to Figures 42–44, and were thus omitted.

Software Considerations

Details of the software utilised in developing this research are given in **Chapter 4** and summarised in **Appendix B**. The specific work of obtaining results for these case studies was all undertaken within the *Arc/Info* GIS, although initial data preparation for the project as a whole often took place in other applications, as discussed in **Chapter 4**.

Arc/Info was selected for this research both for the pragmatic reason that it was available — and supported — at the University of York whereas other GIS were not, and because the program offered great flexibility in the manner data were manipulated and presented. The case studies, below, make use of *Arc/Info*'s terrain modelling capabilities (*e.g.* Case Study 1), its arithmetic processing (Case Study 2), database querying (*e.g.* Case Study 3 and Case Study 4), raster/ vector integration (Case Study 4) and its interface customisation (Case Study 5), and together succeed in requiring more capabilities than offered by most other GIS when the project was initiated.

Selection of the Case Studies

The five case studies offered below were initially selected for a number of reasons, principally including;

- exploration of archaeological questions (Case Studies 1–4)

  a city as complex as York poses many questions of interest to the archaeological community, from the influence of the rivers upon the city through time (Case Study 1), to the changing use of the city towards — and after — the end of the Roman period (Case Study 2). Whilst not intending to definitively *answer* any of these questions — each a thesis in its own right, after all — the case studies demonstrate the manner in which available depositional data and technology might be applied to such questions in order to aid the process of archaeological discovery. Those selected were of especial interest to the author at the time of selection and, in several cases (Studies 2–4), address questions of interest to the sponsors of this research, York Archaeological Trust.

- data assessment (Case Studies 1–5)

between them, the five case studies draw upon much of the information available in the project database, including topographic details (Studies 1, 2, 4 and 5), level of water logging (1 and 4), *etc.* Information available from this database is outlined further in **Chapter 4.**

- GIS assessment (Case Studies 1–5)

  between them, the five case studies utilise many of the GIS functions offered by *Arc/Info*, including interface design (Case Study 5), topographic modelling (1–5), arithmetic raster processing (1–5, especially 4), and database querying (1–5).

- diversity of scale (Case Study 3, contrasted with 1–2 and 4–5)

  the case studies explore the use of available data and techniques at a variety of scales, from the intra–site analysis of Case Study 3 to the far wider questions of deposition across the study area in the second half of Case Study 2.

- diversity of approach (Case Studies 1–5)

  the five case studies offered are each very different, and serve to combine both different approaches to the archaeology and different uses of the available GIS tools, all within the limitations of the available data.

Case Study 1: The changing river regime

> The river can't be controlled, but it could certainly be managed
> (Colin Thorne, quoted in BBC 1994; 23)

> There is an interesting story about Einstein's son. The story goes that Einstein's son went to his father and said, 'Dad, I'm thinking about working on sediment movement in rivers, what do you think?' Einstein replied, 'Son, take my advice. Don't get mixed up in that stuff, it's too complicated.'
> (Gary Parker, quoted in BBC 1994; 23)

The Question: In search of the Roman river system

Over the centuries since Petilius Cerialis first established a base at York in AD 71 (**Chapter 3**), the two rivers have played an important part in the livelihood of the city, as resources to be exploited for food and power; as important highways for the transport of merchandise and people; and possibly as an ever–present threat to waterfront property.

Although the larger River Ouse is today held at an artificially high level by lock gates downstream at Naburn and the smaller Foss is heavily canalised, both rivers still have the capability to cause extensive damage in the very centre of the city and it has been argued (Ramm 1971) that the less tamed rivers of earlier centuries would have had the capability to cause similar disruption.

Disaster hypotheses such as Ramm's are now out of favour and scientific opinion is beginning to suggest that the relatively recent attempts to control rivers lead directly to more catastrophic and far less predictable flooding (BBC 1994), but it remains likely that changes in waterflow and river course would have had a direct effect upon the inhabitants of York; effects which may well be visible archaeologically whether they were catastrophic or not.

The Data

As discussed in **Chapter 4** (page 114), evidence from excavations points to a Roman river level some 3–4 metres lower than the present, but little firm evidence for a Roman waterfront has ever been discovered, despite attempts at sites such as the Stakis Hotel (`siteno 1987.24`) to locate a definitive shoreline. Suggestions of a wharf and crane on Hungate (`siteno 1951.2`) and further wharfs on Walmgate and Saint Denys' Road (Ordnance Survey 1988*a*) are treated with a degree of scepticism and further evidence is required before many are prepared to accept these discoveries.

In exploring these questions of hydrology, the project database of topographic data was utilised to construct a model of York's topography as it may have been in the Roman period (Figure 32). As discussed in **Chapter 4** (pp. 111–115), the database contained 1,324 elevations of identifiably Roman and immediately pre–Roman date, making this the most data–rich of the pre–Modern elevation models available to this project.

The Methodology

In attempting to define the Roman river system in the absence of such concrete evidence as a Roman shoreline, the best that can be attempted with the information available in the database is to explore the height to which a river *could* rise without inundating sites known to be occupied at the time, and then to judge a suitable level based upon the suggested river courses output by the computer. The work in **Chapter 4** applying breaklines to help define the course of the modern rivers (*eg* Figure 25) illustrates the relatively low resolution of riverine definition without the aid of controlling breaklines, but in the absence of such information for the Roman period little may be done to enhance model resolution.

Having created the elevation model itself, possible river levels were explored in a relatively simplistic manner by using the GIS to 'fill' the elevation model to a pre–determined height, thus creating the impression of water–filled river courses, and allowing visualisation both of likely river channels and of those areas within the model lacking sufficient data for effective analysis; namely, the course of the Foss, and the upstream (western) end of the River Ouse. The flood models in Figures 33 and 34 were computed in exactly the same fashion by simply altering the 'fill' height to which the GIS was calculating.

Riverine change has also been explored archaeologically in other areas, notably the Upper Tisza Project in north–east Hungary (Gillings 1995). Here, a 432 km^2 block of the Tisza flood–plain was studied to explore — and hopefully explain — changes in environment, settlement and land use over the last 10,000 years (Chapman & Laslovsky 1992). Given the different circumstances — large, rural area, with a detailed modern elevation model likely to be a usable representation of the prehistoric landscape and a surface area sufficiently large for the application of hydrographic modelling techniques as opposed to a very small, urban area, with significant deposition and, consequently, an incomplete model of the period's topography — the Upper Tisza Project adopted a quite different approach to riverine modelling to that applied in York.

Gillings argued (1995) that the severe and regular inundation of the Tisza prior to the construction of extensive levee systems in the nineteenth century would have had a significant effect upon settlement across the low–lying flood–plain, and he set about utilising GIS to explore the problem. Historical sources cited by Gillings suggested serious — yet predictable — flooding of the plain each year, compounded by more severe summer flooding approximately every seven years. These summer floods inundated as much as 30–50% of the available land surface, with much of the area remaining underwater for up to four months. Worse still were wildcard floods triggered by flooding of the Danube itself, causing the Tisza to back up from its confluence with the Danube and flood a third of the flood–plain for up to a year, and a further third during the flood season itself.

To explore the relationship between flood zone and surveyed prehistoric settlements, Gillings constructed an elevation model for the study area. In principle, this was much like those constructed for York, but was abstracted from *modern* 1:10,000 scale maps at elevation intervals of 0.5m, and computed on a regular 20m grid. In an area of great deposition such as central York, it would be meaningless to apply the modern topography to a study of prehistoric riverine activity, but for an area of fairly uniform deposition (some six metres or more of alluvial deposit in the lower lying areas of the flood plain) such as the Tisza flood–plain such generalisation is, perhaps, more permissible, especially as variations in minor micro–topography likely to greatly influence a model covering the relatively small 2 × 1.5 km York study area are likely to be less noticeable on the far larger Tisza model.

As well as utilising a detailed *modern* topographic model, Gillings applied hydrographic modelling techniques to his data in a more complex manner than the simple raising of water levels employed in York. These techniques seek to analyse direction and rate of water flow, as well as incorporating the effect of tributary streams upon the flood, and omitting 'pools' of water isolated from the river and flood zone by areas of high land from the final results.

Such advanced techniques were assessed, and felt to be wholly unsuitable for application to Roman York. The study area was found to be too small for the effects of flow direction and rate to have any useful impact upon the model, and the topography of the Foss area too poorly defined for effective analysis of tributary effects. Finally, it was seen as counter–productive to omit pools of water from the resulting output. Although the available terrain data suggested that they were isolated from the main river course, this was perceived as a fault of the *intervening* — poorly defined — terrain rather than anything else. They were interpreted as either parts of the river which — given more detailed topographic survey in the intervening areas — should be linked up to the main body of water or else as low–lying areas of marsh crossed by riparian streams, and lying on or just below the water table (Figure 70). Further data, derived either from excavation or borehole survey, is required in the western reaches of the Ouse and along the course of the Foss in order to better address these questions.

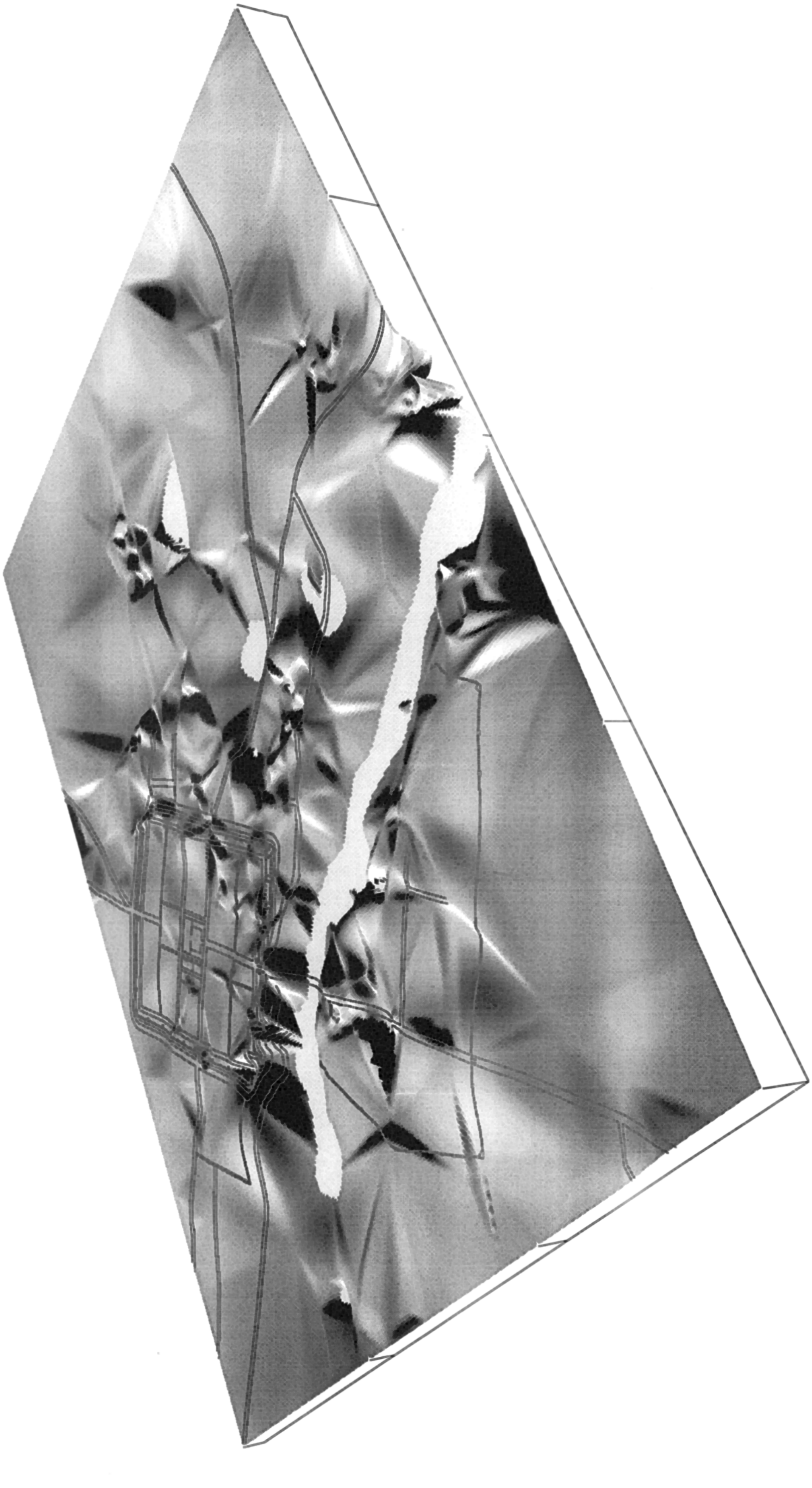
The Results

The figures below represent output from the GIS following exploratory modelling of the Roman terrain model in association with the locations of the Roman excavated evidence, with Figure 32 providing a view of how *Eboracum* may have looked based upon the best results of these analyses. This figure depicts a model of the Roman topography, based upon 1,324 elevations of Roman and immediately pre–Roman date. A computer prediction of the Roman river course has also been derived by 'flooding' the elevation model to 1.5m AOD, and the YAT–digitised outlines of the Roman fortress, *colonia* and assumed routes of the major roads have been draped over the topography. The scale intervals shown along the model's plinth are 500 metres apart.

The Ramm hypothesis

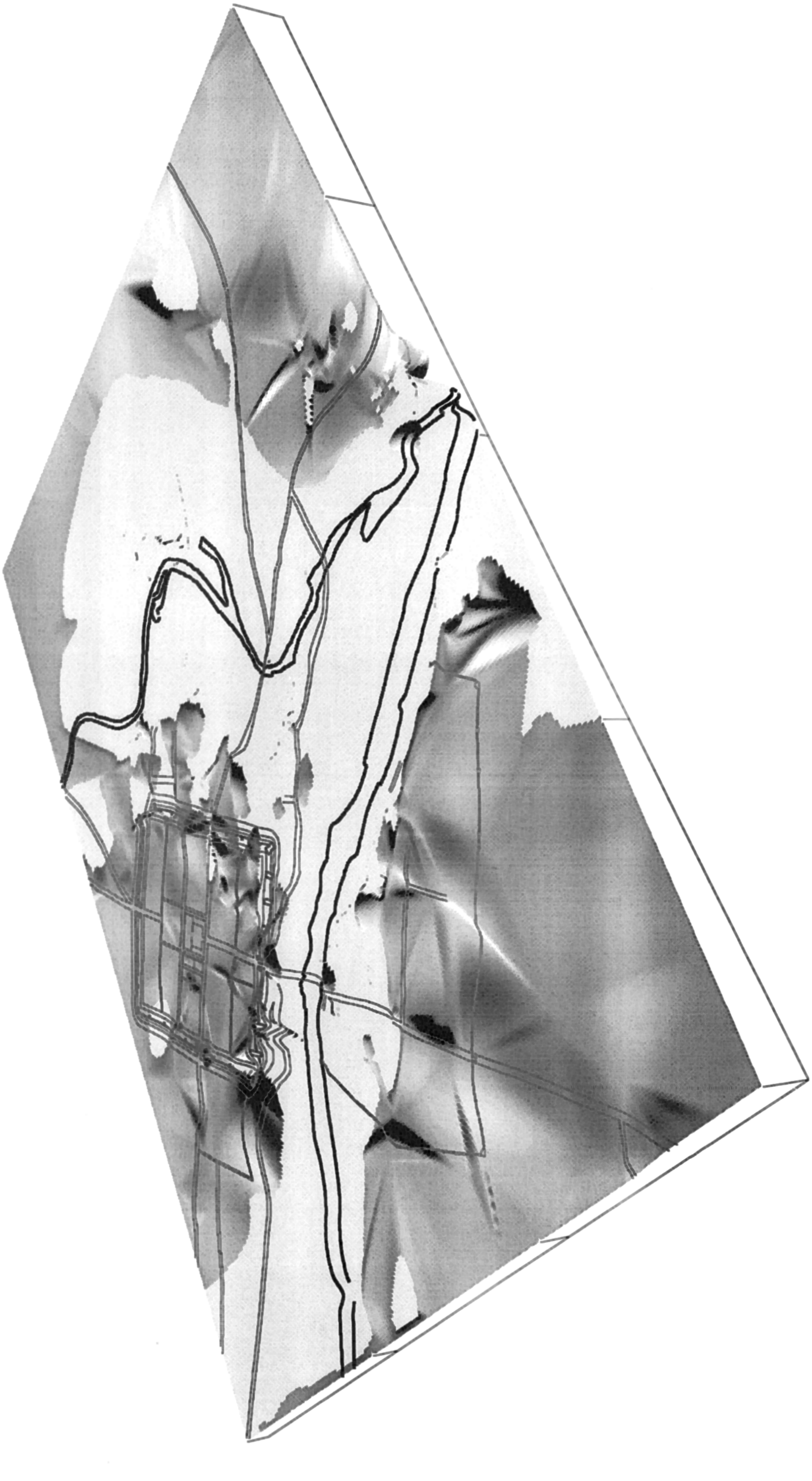
The best known of the theories relating to changing water levels and their impact upon the city is that proposed by Herman Ramm in 1971 in his paper, *The end of Roman York* (Ramm 1971). In this paper, Ramm assembles evidence from a number of sites across the city, and suggests that significant hydrological inundation in the late Roman period significantly — and perhaps terminally — affected the Roman presence within *Eboracum*. Ramm recognises the probability that there was occupational continuity of some form within the city from the Roman into post–Roman period with

> The possibility of continuous occupation and of more gradual change shifts the emphasis of the question raised by the title — not so much when or how did Roman York end but when or how did it cease to be Roman.
> (Ramm 1971; 179)



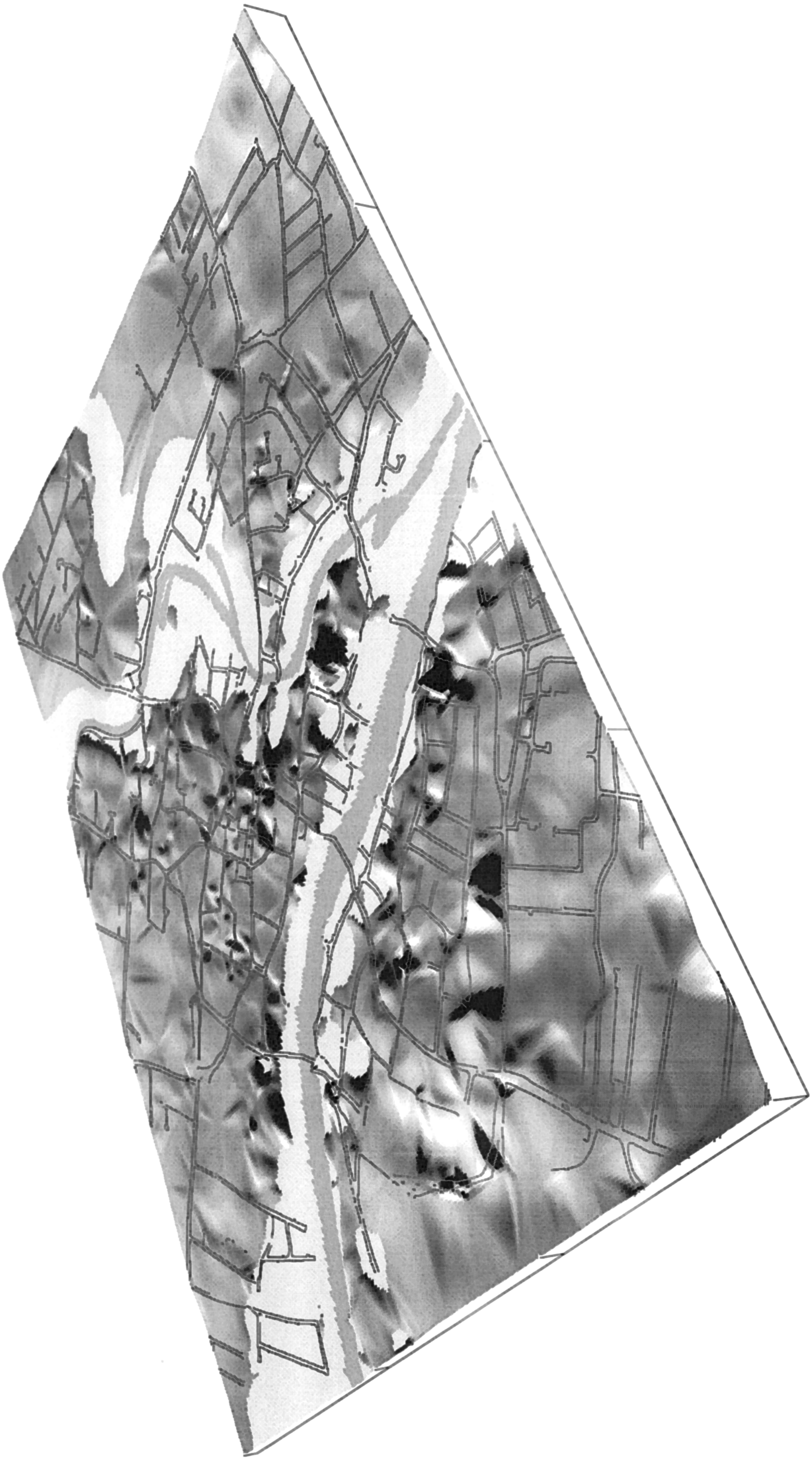
Modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown copyright reserved

Figure 32: Eboracum as it may have looked in the late Roman period



Modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown copyright reserved

Figure 33: The effects of flooding to 10.66m, as proposed by Ramm (1971)



Road network & modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown (c) reserved

Figure 34: Simulated effects of the floods of 1982 upon the modern elevation model

Road network & modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown copyright reserved

Figure 35: Possible river levels in the Roman period

Road network & modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown (c) reserved

Figure 36: Zone of potential flooding, plus excavated Roman sites

Ramm draws evidence from a number of sites around the city, and suggests that seasonal flooding up to 35' (10.66m) AOD was almost commonplace in the late Roman period. A computer model of the likely consequences of such flooding are shown in Figure 33, where the Roman topography has been used to illustrate the destruction wraught upon *canabae* and *colonia* by such a severe flood event. The lines of the modern river courses have been added to emphasise the severity of flooding.

Perhaps more important than the suggestion of flooding *per se* is the implication for collapse of centralised control where this flood–deposited material is not cleared away, and survives to be discovered archaeologically. Sadly, the evidence utilised by Ramm in framing his argument is now thought to be less conclusive than he implies, and few modern archaeologists accept that the alluvial warp and leg bones of a stork or heron discovered on High Ousegate in 1902 (`siteno 1902.1`), for example, (Ramm 1971; 196) *really* provide incontrovertible evidence of floodwaters reaching 10.66m AOD towards the end of the Roman period. To put Ramm's claims in context, it is worth comparing a rise of perhaps 9m (mean level 1–2m, flood level 10.66m) in the Roman period with the most severe modern flooding, where the river rose 5m from a summer mean 5m AOD to a Spring flood level of 10.12m in January 1982 (Peter Welsh, Environment Agency *pers comm*). Figure 34 shows the 2,378–point modern elevation model for York, with the current street network. The mean summer water level (5m AOD for the Ouse, 7m AOD for the Foss) is displayed, along with the predicted extent of flooding in 1982. The model is not an exact representation of the real flood event due to the restraining effect of walls and buildings upon flood water at the time. Flooding as depicted is a model of water movement across a hypothetical landscape devoid of buildings and is included merely to demonstrate the extreme nature of Ramm's hypothesis, rather than as an accurate representation of modern flooding. Although the technique *could* be used in modern flood assessment, information would need to be added to the model describing the location and elevation of walls and buildings and — most importantly, perhaps — the locations of *gaps* in those walls.

Issues Raised and Future Directions

Information available within the project database is not sufficiently detailed for 'flood' deposits to be represented, and evidence of flooding is not obviously forthcoming within the site archives of York Archaeological Trust. In the light of this, it is difficult to either locate the mean Roman river level or to identify evidence of seasonal flooding, whether minor or catastrophic.

Instead, the best that may be offered is a series of predicted river levels, all of which are lower than the lowest Roman deposits within the city (Figure 35). In itself, this forms a valid investigative result and the onus is now placed upon those undertaking fieldwork within the city — and especially at the interfaces between 'wet' and 'dry' proposed in these figures — to look carefully for evidence of river–borne material, as well as for evidence of the more apparent riverfront construction. Sites investigated in the area between waterfront and maximum possible flood extent (Figure 36) should also be carefully studied environmentally in the hope that river incursions may be identified or definitively shown *not* to be present. In this way, the extent of any flooding may be narrowed down and the Roman river regime perhaps better understood. Extensive work in the area around the Foss and its intersection with the Ouse is required, as model definition in this area is especially poor, and little is known about even the approximate course of the Foss, let alone the position of its banks.

The simulated river levels depicted in Figure 35 do not compare well with the proposed routes of Roman roads shown on the same figure. At one point, for example, two roads apparently join under water — even with the shallowest proposed course for the Foss — and roads appear to follow a less than direct course across the Foss area whilst still avoiding the narrower sections of the river.

Several acts of generalisation combine in order to create these apparently improbable results, and far more archaeological work is required in the area of the Foss basin in order to resolve these — and other — confusions.

The road network itself, for example, is based solely upon YAT conjecture in this area, with the closest excavated evidence being in the Coney Street area over 200m from where the road first encounters the Foss (Ordnance Survey 1988*a*) and aerial photographic evidence providing no information until well outside the built–up extent of modern York (Addyman 1984).

The definition of the river here is also suspect, with far less topographic detail for the Foss than for the better understood Ouse.

Medieval damming to create the King's Fishpool, followed by extensive post–Medieval canalisation has served to obscure evidence of the earlier river course, and this problem is compounded by relatively little modern excavation having been undertaken in the sectors of the city through which the Foss might once have flowed.

As such, the apparently discontinuous course of the Foss may well represent the extent of sufficiently detailed excavation, rather than any 'absence' of a definable river in the pre–Medieval period. However, a member of York's Environmental Archaeology Unit (now at the University of Bradford) has examined the elevation model and computed river course and has confirmed the suggestion that a series of small, shifting — and probably seasonal — riparian rivulets flowing through an expanse of marshy ground would be conceivable at this period (O'Connor *pers comm*). A programme of boreholes to provide environmental data may serve to resolve this question to some degree, as might limited archaeological intervention in the area.

Case Study 2: Differential deposit accumulation

Although it is clear that the greatest deposition within York is in the areas immediately adjacent to and between the rivers Ouse and Foss, external factors probably influenced the manner in which deposits built up elsewhere; and possibly even the actual rates of accumulation in the zones of greatest deposition.

Given a model of sufficient spatio–temporal resolution, it would no doubt be possible to identify relatively small or short–lived deposition foci and to comment upon artificial topographic changes across the city due to such events as waste disposal and levelling of ground prior to construction.

A model of the resolution available for York is unlikely to be capable of accurately identifying depositional variations on such a scale, but potential should exist for the identification of broader trends such as the impact of the legionary fortress walls upon intra– and extra–mural deposition in the immediate post–Roman period. It should also prove possible to identify a trend for deposition across the city, and to locate those approximate areas in which deposition significantly exceeds or falls short of expected volumes of material for a particular period.

Intra– and extra–mural deposition in the post–Roman period

Patterns of deposition through time are not uniform in spatial distribution or in quantity of build-up, and extant features of earlier landscapes are likely to have an effect upon later development, with major linear features possibly trapping deposits and dense areas of ruined structures constraining later attempts to develop.

In York, such a major feature is presented by the circuit wall of the Roman military fortress, and it is possible that the effects of the wall may remain visible within the archaeological record, with a noticeably lesser or greater rate of deposition within the fortress in the post–Roman period.

From an archaeological perspective, it is perhaps difficult to predict the effect that the Roman defences would have upon the general pattern of deposition within and without the fortress. If the evidence from beneath the Minster is extrapolated (Phillips *et al* 1995), for example, it might be expected that a significantly greater deposition would be apparent in the intramural area, whilst the environmental evidence from the north–eastern corner of the fortress (Kenward *et al* 1986) would imply a sparsely settled area and consequently *less* deposition than that caused by any settlement outwith the defended area.

Before examining this question in slightly more detail, it is necessary to briefly discuss aspects of the evidence for late Roman and immediately post–Roman use of urban space across the province in order to place the sparse — and potentially contradictory — York evidence in context.

As Ottaway (1992; 82–119) discusses, the late fourth century marked a period of relative decline in British cities, with little new construction, and repeated evidence of changing usage of existing structures as well as a significant degree of degradation in the urban fabric. In the immediate post–Roman period, the picture rapidly becomes extremely confused with total abandonment of some settlements, partial occupation of others (*eg* Frere 1983) and possibly significant occupation of others (Barker 1975).

At Winchester, for example, (Biddle 1983; 111–112) many of the Roman town houses appear to be demolished in the years after AD 350, and several others are abandoned and left to fall into disrepair. In the ruins of the demolished structures, new timber buildings are put up and there is significant evidence for industrial working in and around these new buildings.

In York itself, sites in the very heart of the fortress (Hall 1997) show evidence of organic deposition in the later Fourth century, along with a marked reorganization of some barrack blocks in order to transform the previously communal spaces into private quarters, possibly for the families of soldiers or officers. On the other side of the Ouse, evidence from the Stakis Hotel site (`siteno 1987.24`) suggests a diminishing level of municipal or military control as the main cross–river road begins to fall into disrepair (Ottaway 1992; 115–116). Wooden structures constructed in the late Fourth century directly impinged upon this roadway, and nearly 0.80m of deposits were laid down in this area in the years after *c* AD 390.

The only Roman settlement showing clear evidence of extensive construction in the immediate post–Roman period is Wroxeter (Barker 1975, White 1990) where sectors of the Roman city were deliberately levelled in order to allow the construction of wooden structures. Current work (Gaffney *pers comm*) is re–examining this important city in order to better understand the factors at work here and the changing relationship between town and hinterland.

One factor common to all of these — and other — late Roman settlements is the deposition of significant quantities of 'dark earth' (Macphail 1994) amongst the structures of the urban fabric. Although widespread, there is some controversy as to the meaning of these organic — often artefact rich — deposits, with interpretations ranging from dark earth as evidence of abandonment (Biddle 1976) to the more modern idea that dark earth represents the now–homogenised evidence of a previously highly complex stratigraphy (Yule 1990). Under this hypothesis, dark earth represents a *change* in urban landuse rather than a *cessation* thereof. Changing practices of waste disposal are also frequently identified as contributing much of the material laid down in these deposits.

Biological explanations have been attempted for the build-up of these thick homogenous layers with Macphail and Courty (1985), for example, proposing a biological alteration (or bioturbation) of existing occupation sediments. Parallels are drawn with processes observed in the bomb damaged cities of Europe after the Second World War (Yule 1990).

In the fortress area at York itself, the evidence for late– and post–Roman occupation remains inconsistent and inconclusive. The well known evidence from beneath York Minster (Phillips *et al* 1995, `siteno 1967.1`), for example, would appear to suggest some form of continued occupation, while evidence from Blake Street (Hall 1997, `siteno 1975.6`) shows restructuring of military accommodation blocks and the deposition of dark earth in the later Fourth century, with abandonment apparently following soon after. Environmental evidence from the north–east quadrant of the fortress (`siteno 1974.13`) paints a very different picture, although only for the slightly later period ad 740 ± 80:

> There is every reason to suppose that this set of samples gives evidence for what was essentially a waste–ground environment... There is nothing to suggest urban life, not even in the supposed background component of the insect assemblages... The biological evidence thus suggests a largely neglected and somewhat marshy area.
> (Kenward *et al* 1986; 276–277)

With contradictory evidence inside and no identifiable sub–Roman settlement in the immediate extra–mural zone, archaeologists are faced with the difficult task of rationalising the clear evidence of Roman and Anglian power base with the confused picture emerging of the intervening years.

With city–wide predictions of deposit survival offered by the YAA GIS, it becomes possible to begin the search for evidence of this sub–Roman period and to begin clearing away some of the confusion surrounding this little understood period in the development of urbanism. It must, of course, be remembered that the computer model is only able to build upon existing knowledge of the city's deposits and that further archaeological work in poorly understood areas of the city may unearth data capable of radically altering the picture emerging from these analyses. Further, archaeological examination of the model is required in order to 'ground truth' the results and to provide critical dating information as well as further data with which to refine the model.

In this case, it is suggested that the obvious physical barrier represented by the fortress and its walls would have had an effect upon later settlement in the area. It appears likely that sub–Roman inhabitants of the area would *either* have avoided (or robbed) the ruined fortress leading to a correspondingly lower intra–mural deposit build-up *or* actively settled within this area, with a concomitant increase in levels of deposition with respect to the area immediately outwith the walls. In both cases, the model relies upon an assumption of waste disposal practices less advanced than those of the Roman occupation, and deposition of midden material in close proximity to the settlement site.

To explore the question, a model of deposit build-up in the sub–Roman period was constructed by subtracting the Roman deposit surface from that of the Anglian period. The result of this process for the area surrounding the fortress itself is shown in Figure 37. The angular nature of the deposit model reflects granularity within the data and serves as a reminder to the observer not to attempt detailed hypothesis testing with such coarse data. Given output in this form, it is difficult to draw conclusions about relative levels of deposition within and without the fortress. To clarify the picture, transects were laid across the fortress from north east — south west (roughly along the fortress' *Via Decumana* and *Via Praetoria*) and from north west — south east (along the *Via Principalis*) as shown in Figure 37.

The detail of these transects is shown in Figure 38, and the markers along each transect depict the start and end of the transect, as well as the point at which the transect encounters the fortress' extramural road and the rampart itself. Transect A–A' also has a marker at the point where the transect crosses the *Via Principalis*.

The coarseness of the model displayed in Figure 37 is also apparent in Figure 38, with the spikes and troughs almost certainly representing spurious results of the modelling process. Despite these anomalies, the general trend from the transects would appear to be towards greater deposition within than without the fortress.

If borne out by further archaeological work, these results suggest continued use — albeit, if the Bedern evidence (Kenward *et al*) is to be believed, on a small and positively 'non–urban' scale — of the fortress area into the sub–Roman period. The evidence from beneath York Minster may therefore mark one aspect of a wider occupation rather than the anomaly it has often been held to be.

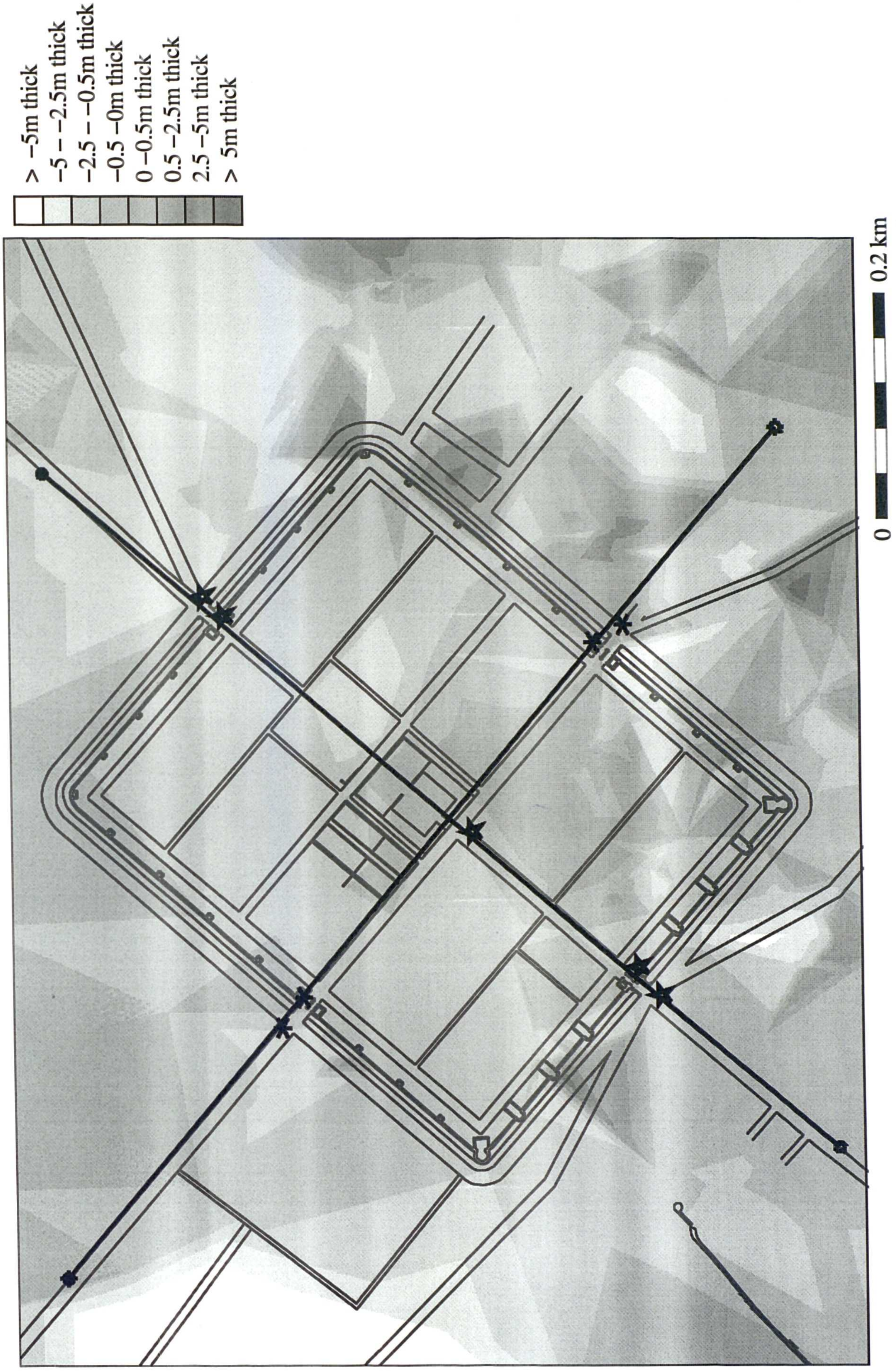
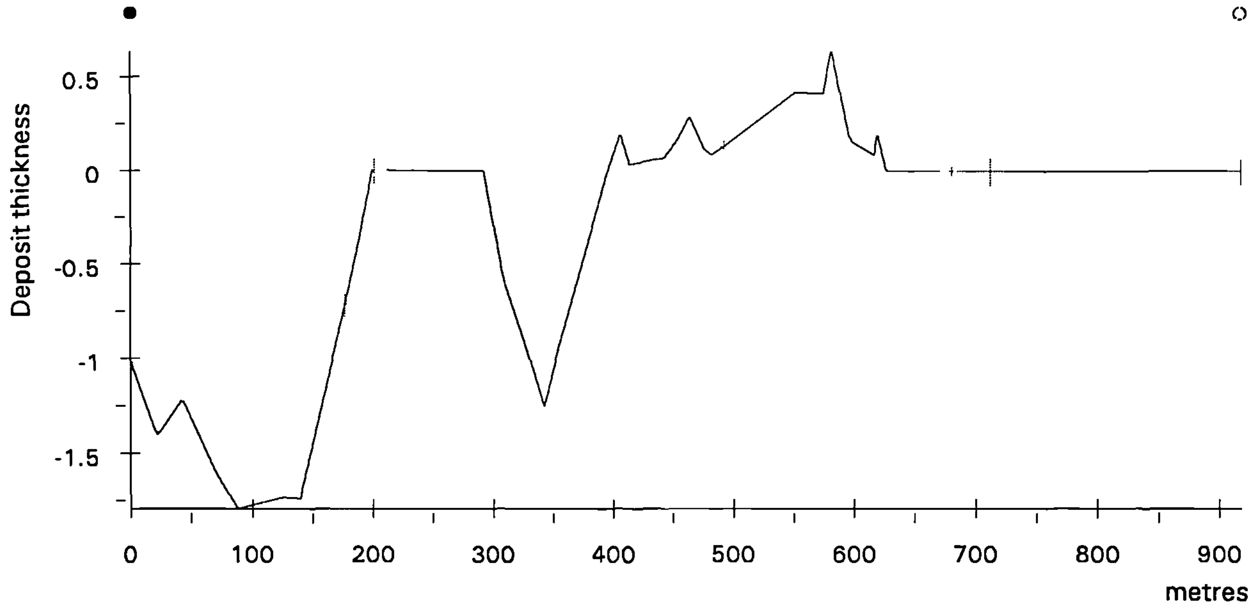
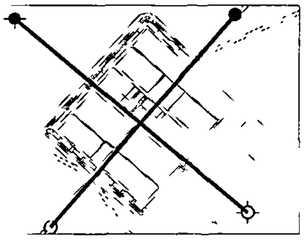


Figure 37: Anglian deposit thickness around the Roman fortress, plus transect lines

Transect A –A'





Transect B –B'

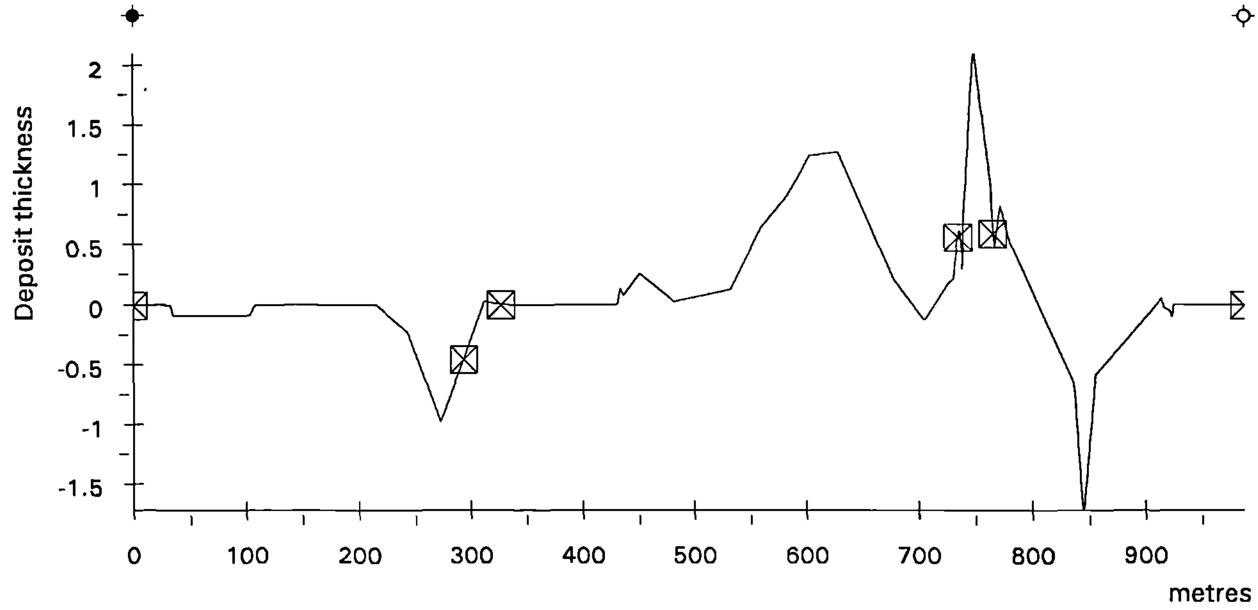


Figure 38: Transects through Anglian deposits near the Roman fortress

Developing a deposition index for York

Identifying the tidiest York residents

Over the 2,000 years or more of human occupation in York, the topography has been shaped by natural and human forces to such an extent that the landscape of today bears little resemblance to that facing the army of Petilius Cerialis back in the first century AD. The build–up of deposits over time has not occurred at a uniform rate, with major building programmes or the waste management strategies employed by the inhabitants all having an effect upon the rate of deposition.

While the temporal resolution of the data is not sufficient to identify individual building events, they should be sufficiently precise to enable the identification of general trends in deposition. It should be noted, as discussed in **Chapter 2** (pages 38–40), that the crude period labels used in this case study are a relic of the available data, and that the resulting necessity to consider temporal spans of several hundred years as a single 'period' curtailed any ability to identify the potentially significant changes *within* any of these periods. Indeed, the nature of the data rather reinforces the appearance of changes *between* periods, and the results should thus be observed with caution.

In order to derive this trend from the project database, elevation models were constructed for each major period in the database (Modern, Medieval, Anglo–Scandinavian, Anglian, Roman and Natural) and then each was subtracted from the surface directly beneath it in order to create a 'surface' of deposit thickness (*eg* `$PAUL_TMP/roman_thickness = $DTM/roman - $DTM/natural`) for each period. Each of these new thickness surfaces was then converted to a matrix of 3,000,000 height values stored within the GIS as a point coverage and analysed using the `statistics` function within *Arc/Info*. The results are presented below.

Deposit	Mean thickness (m)	Minimum thickness (m)	Maximum thickness (m)	Standard Deviation (m)
Modern	2.54	-6.28	13.54	2.15
Medieval	0.44	-3.06	19.72	1.57
Anglo–Scandinavian	0	-4.29	7.97	0.58
Anglian	-0.2	-18.31	8.22	1.59
Roman	0.64	-5.26	18.39	1.66

Table 11: Deposit thickness details for each period of study

The results presented above clearly indicate gaps in the available data, with the large number of negative results representing areas where the stratigraphically lower of the two surfaces was found to be physically *above* the stratigraphically higher surface. Valid archaeological reasons for this result include deliberate truncation of deposits in antiquity, but many of the observed cases within the GIS are in reality due to low data resolution.

The large differences between minimum and maximum values, especially for the Roman and Medieval deposits, are likely to be the result of spurious data within the model, as Roman deposits of more than 18m hardly seem feasible. The small variance represented by the figures for standard deviation offers a more realistic measure of the differences between minimum and maximum deposit thicknesses for each period. It should be remembered, though, that the standard deviation value is for a ***single*** deviation about the mean and that valid thickness values will also lie outwith these bounds along with the more spurious values contributing to such unlikely results as 18.39m thick Roman deposits.

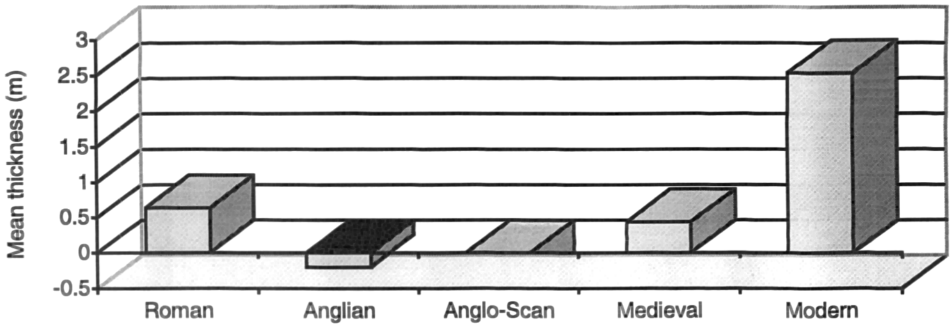


Figure 39: Mean thickness (m) of York deposits

In order to draw any conclusions from the data represented in Table 11 and Figure 39, it is necessary to generalise the data in order to allow for the differing temporal spans of each period.

In order to accomplish this, the mean thickness value for each period (as presented in Table 11) was divided by the length of time occupied by the period in question (to the nearest 0.1 centuries). The result of this may be seen in Figure 40, which represents a measure of deposition per century.

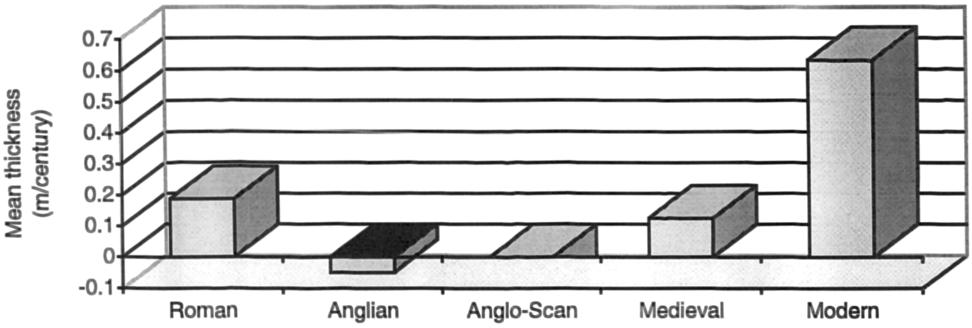


Figure 40: Mean deposition of York deposits (m/century)

In order to make the figures easier to compare, the values from Figure 40 were ranked in order to create a 'Deposition Index' of values from 0 (lowest deposition) to 1 (highest deposition), as shown in Figure 41.

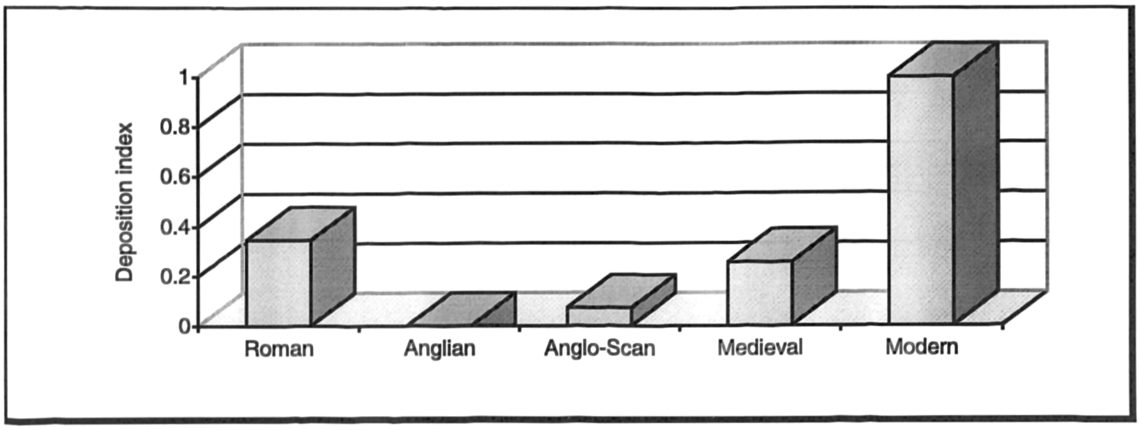


Figure 41: Deposition index for York deposits

The effects of massive urban regeneration in the post–Medieval period may be clearly seen, but the incomplete nature of elevation data for the Anglian and Anglo–Scandinavian periods is undoubtedly having a skewing effect upon the other results, as evidence from sites in the Coppergate/ Ousegate area (*eg* Hall 1984) would clearly suggest significant deposition in this area at least during the early Medieval period.

Patterns of deposition

Building upon the data presented, above, it becomes possible to investigate zones of the city in order to identify whether deposition in any one period is greater or less than the mean level of deposition for that period across the city. This trend may be represented graphically and clearly indicates the areas of the city in which deposition is greatest in each period (Figures 42–44). Each figure shows areas of the city with less than expected deposition, those with 'expected' deposition (any deposits within one standard deviation of the mean), and those with greater than expected deposition.

Whilst the areas identified below are on the whole largely unsurprising, the technique does represent a way in which deposition deviating from a 'norm' may be highlighted. Given data of greater resolution than that available in the project database, more detailed classifications would be possible, and 'hot spots' could be accurately located.

Even lacking the resolution to make detailed classifications as suggested, it is possible to identify general trends within the deposition, and to identify archaeological 'reasons' for these trends. In Figure 42, for example, build–up can be detected in the lower areas along the banks of the River Foss, as well as along stretches of the Ouse and at some of the margins of earlier occupation areas. In Figure 43 the most obvious area of increased deposition is between the rivers on the site of York castle, where a motte and bailey castle was constructed in the late 1060's. This site remained an important focus for centuries afterwards, unlike the contemporary Baile Hill which may also be seen directly across the Ouse, just by the more modern bridge shown on the map. Figure 44 shows greatest deposition in the *canabae* area between fortress and river, and in the *colonia* to the south–west of the Ouse.

It might be argued that the areas of significant deposition represented in Figures 42–44 are self–fulfilling, with those areas expected to offer 'good' deposition being more prone to extensive archaeological work, and thus more likely to deliver those 'good' deposits. However, the distribution of points from which these figures are constructed is more widespread than the areas of significant deposition displayed, being derived from borehole data and all forms of archaeological intervention rather than merely high–profile excavations on deep strata. The nature of the mathematical techniques used to derive these figures, too, is such that any 'unexpected' results would be displayed in exactly the same ways as those results that a human might predict.

Road network & modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown (c) reserved

Figure 42: Modern deposition pattern

Figure 43: Medieval deposition pattern

Road network & modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown (c) reserved

Figure 44: Roman deposition pattern

Case Study 3: Intra–site analysis

The bulk of this thesis examines the application of GIS modelling techniques across a large area of central York, but there is theoretically no reason why the techniques applied at the macro landscape scale and the midi urban scale may not be applied to the micro scale of the individual trench in the same manner as other GIS techniques (Biswell *et al* 1995, Gaffney 1995, Huggett 1996).

As well as examining the application of deposit modelling to the individual excavation trench, this case study addresses wider issues regarding the applicability of excavation archives to research beyond the mere compilation of a site report.

Two sites within the Case Study area have been selected (Figure 45), offering an early (1975) example of composite planning and a more recent (1989) application of single context planning. Both sites were excavated by York Archaeological Trust, and the archives for both are deposited in the YAT archive. Neither site has been published, although both are mentioned in a variety of other publications (*eg* Pearson 1990*a*, 1990*b*, Monaghan 1993).

In each case, data for constructing the elevation models were extracted directly from the archives of York Archaeological Trust, rather than from the lower resolution YAA project database. During data collection for the Swinegate excavations, Leigh Symonds of York's Department of Archaeology aided in the gathering of elevation details and the construction of the site database.

City Garage, 9 Blake Street (1975.6)

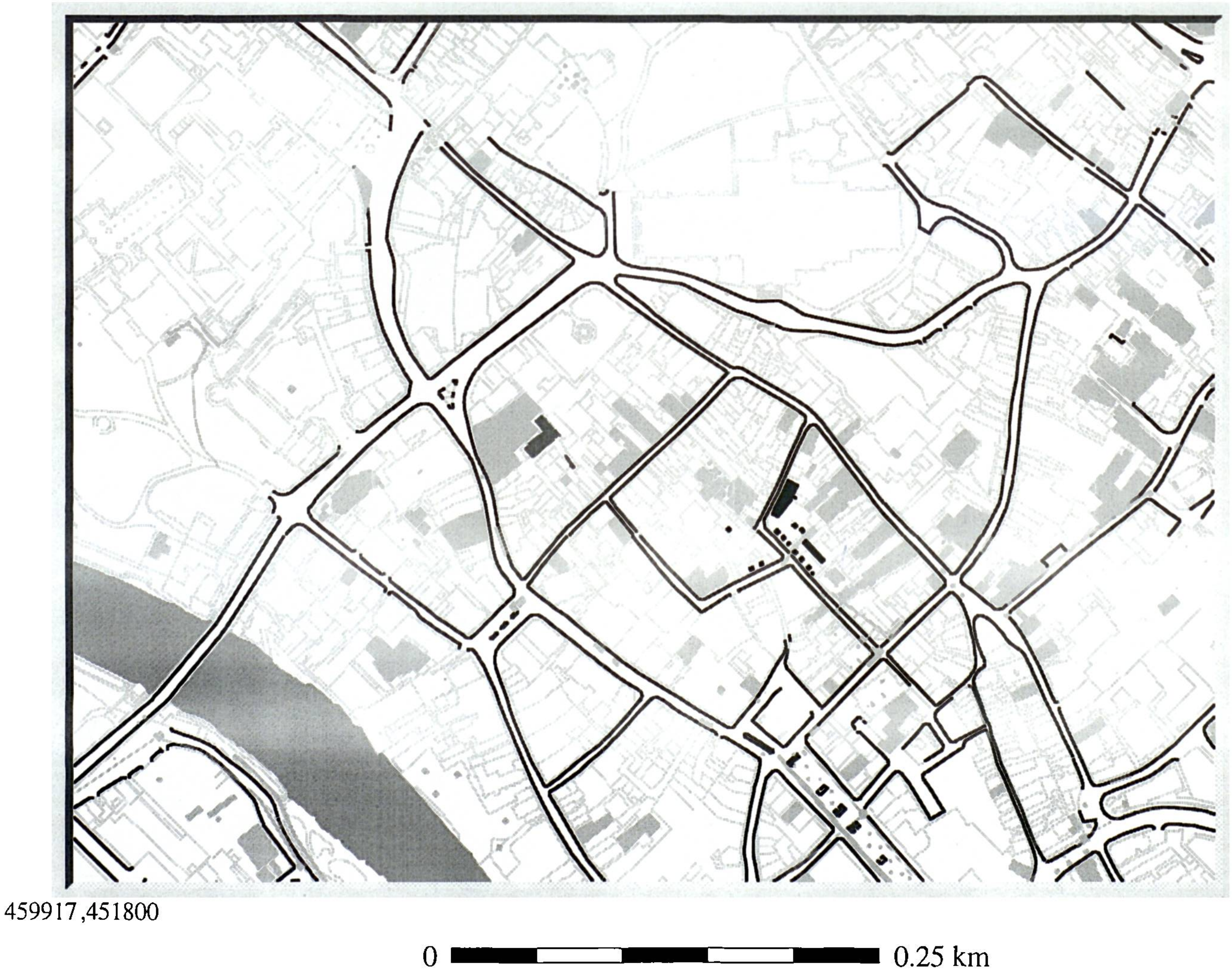
City Garage, Blake Street, (`siteno 1975.6`) sheds light on the Roman military occupation of York, from the very earliest military structures through to the changes and upheavals towards the end of the Roman period. This site lies within the fortress, in an area of barrack buildings and officers' quarters close to the *Via Praetoria.*

The extant archive very much marks this excavation as a product of the 1970's rescue mentality, and inconsistencies within the recording occasionally made comparisons even between individual contexts within a Phase difficult. Planning was by means of large composite plans rather than today's single context approach, and several of the important plans lacked vital information such as plan orientation and relation to the site grid. Unusually, no level III archive was ever produced for the site, with YAT intending to move straight from the level II on–site records and associated post–excavation phasing to full publication. With Richard Hall's site report not yet completed at the time of research (Hall 1997), it was necessary to work directly with the site records themselves — something that proved extremely difficult on a site of which I had no other knowledge.

A major problem with gathering data for the site was the inconsistent extent of the defined area of excavation through time. Due to operational considerations on site, the edges of the trench did slope

YAA

Figure 45: Site locations for Blake Street and Swinegate excavations



A P Miller 1996

Ordnance Survey 1:1,250 digital map data

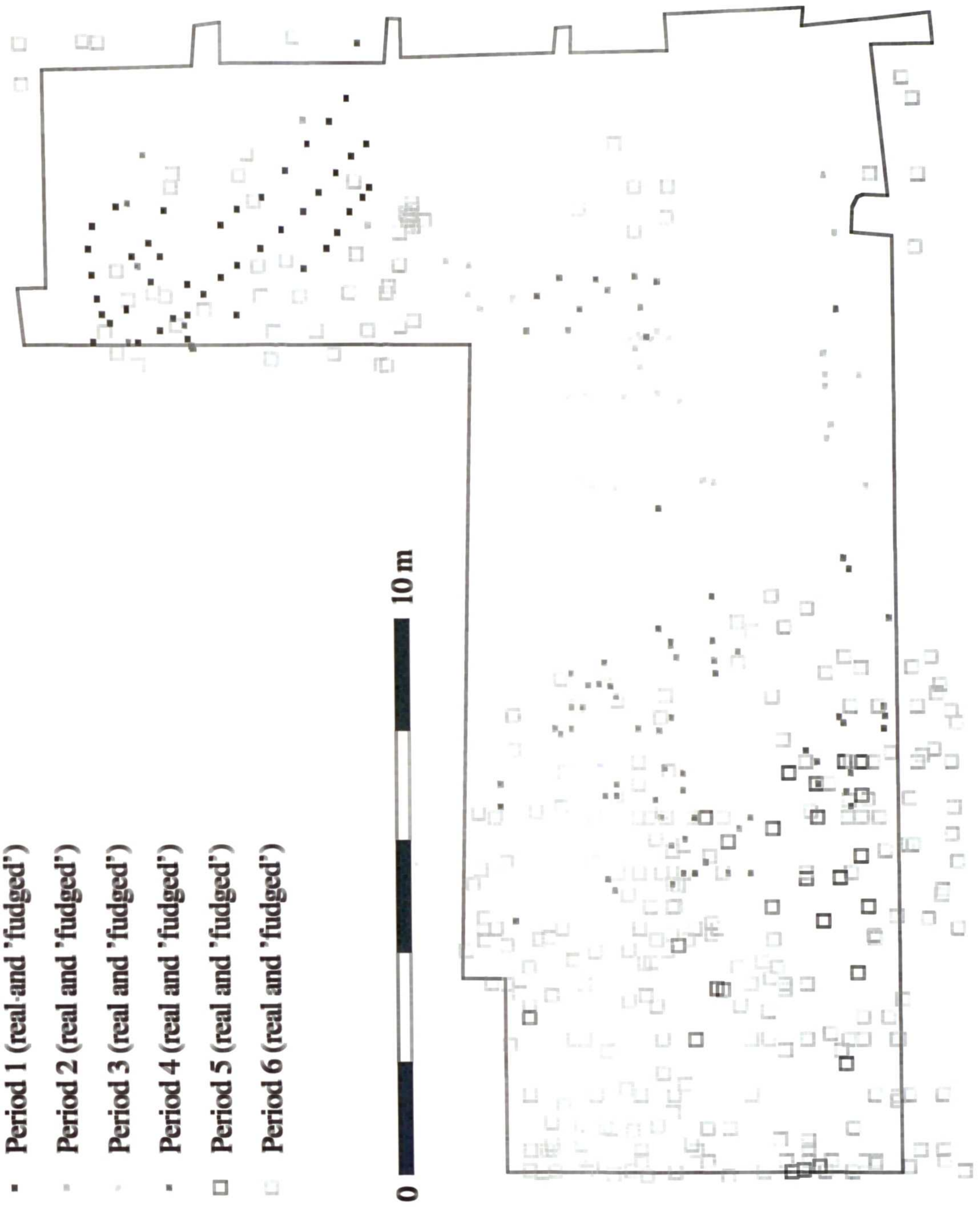


Figure 46: Data points gathered for all periods, 9 Blake Street

Figure 47: Data points for Period 4, 9 Blake Street

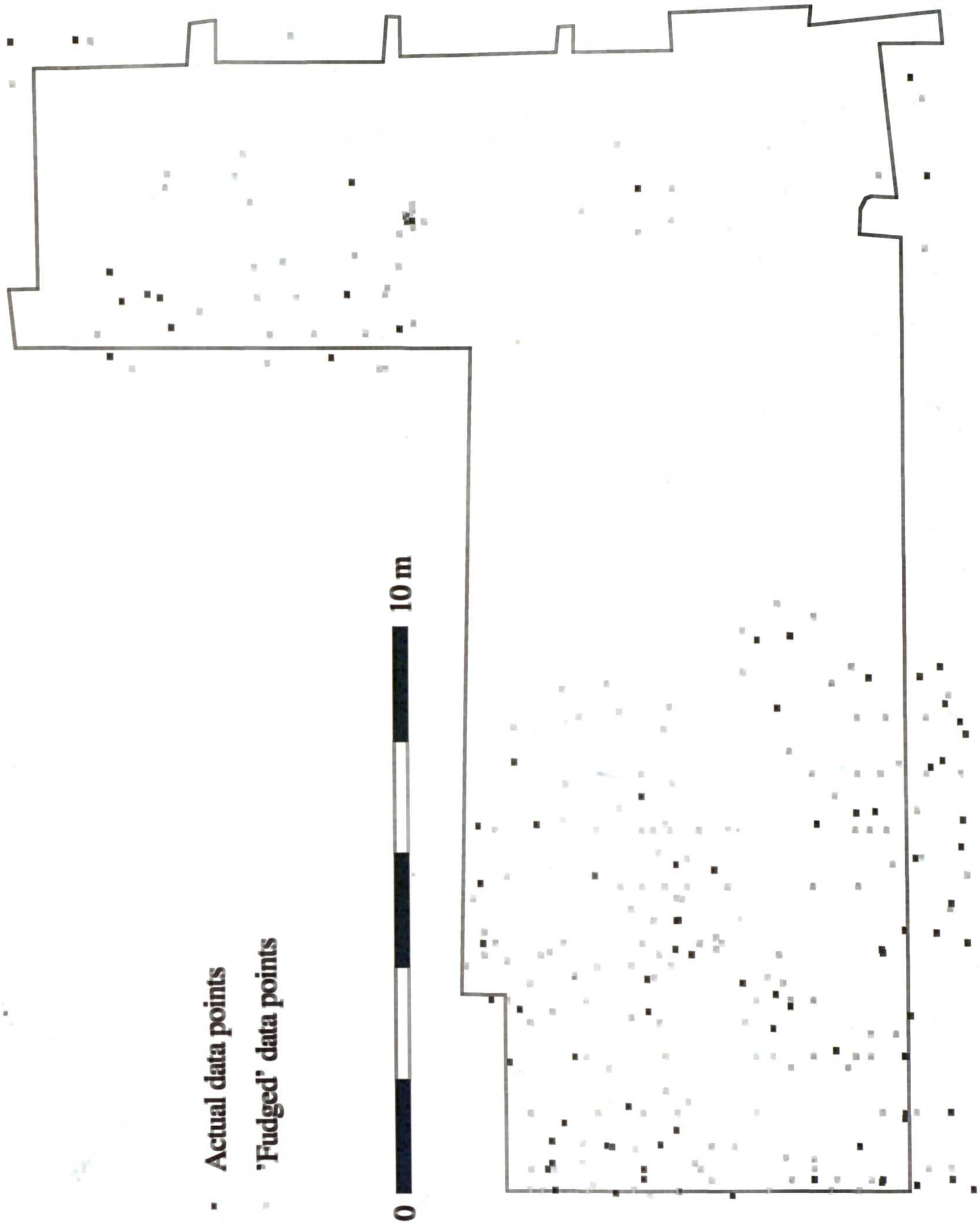


Figure 48: Data points for Period 6, 9 Blake Street

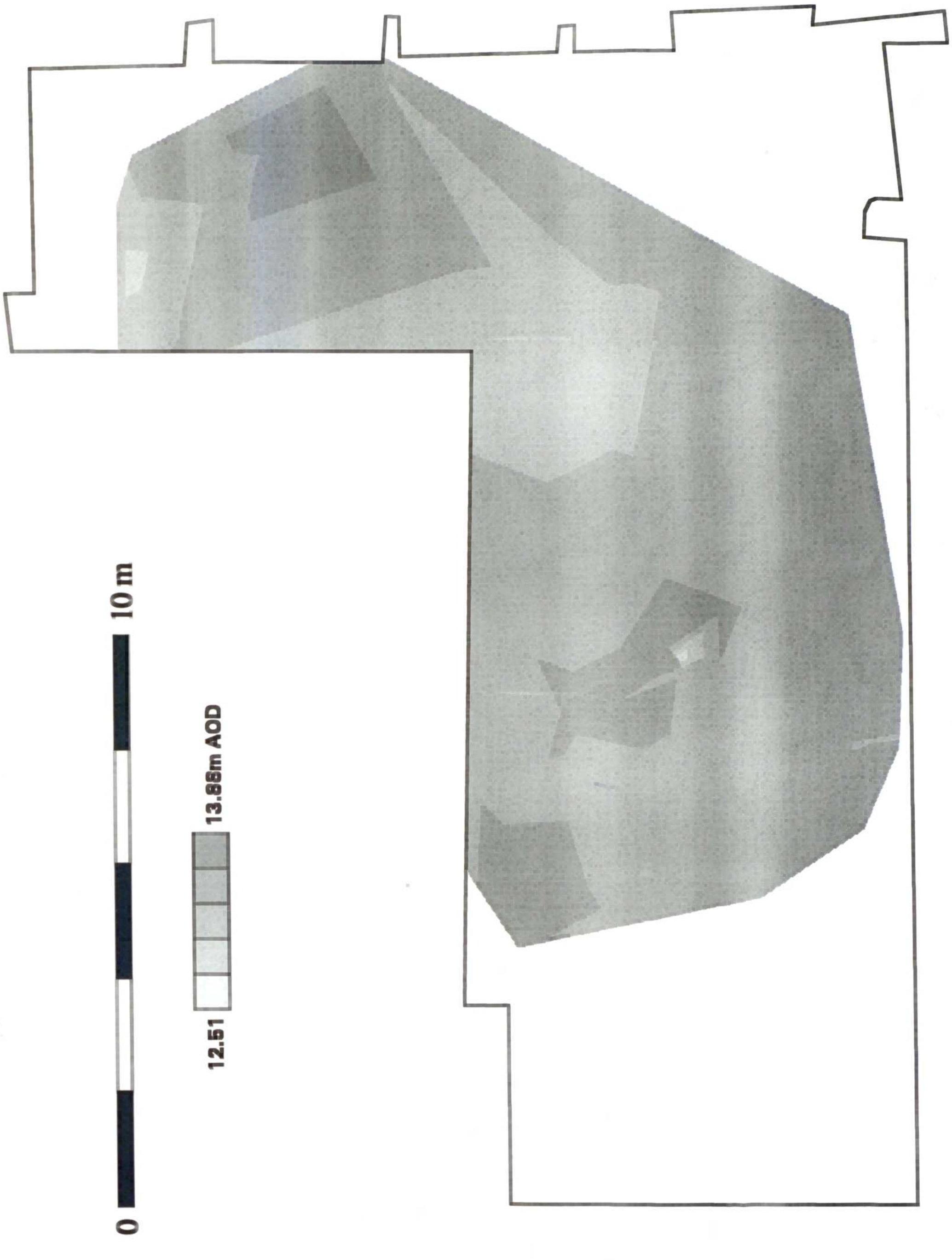


Figure 49: Surface model for Period 4, 9 Blake Street

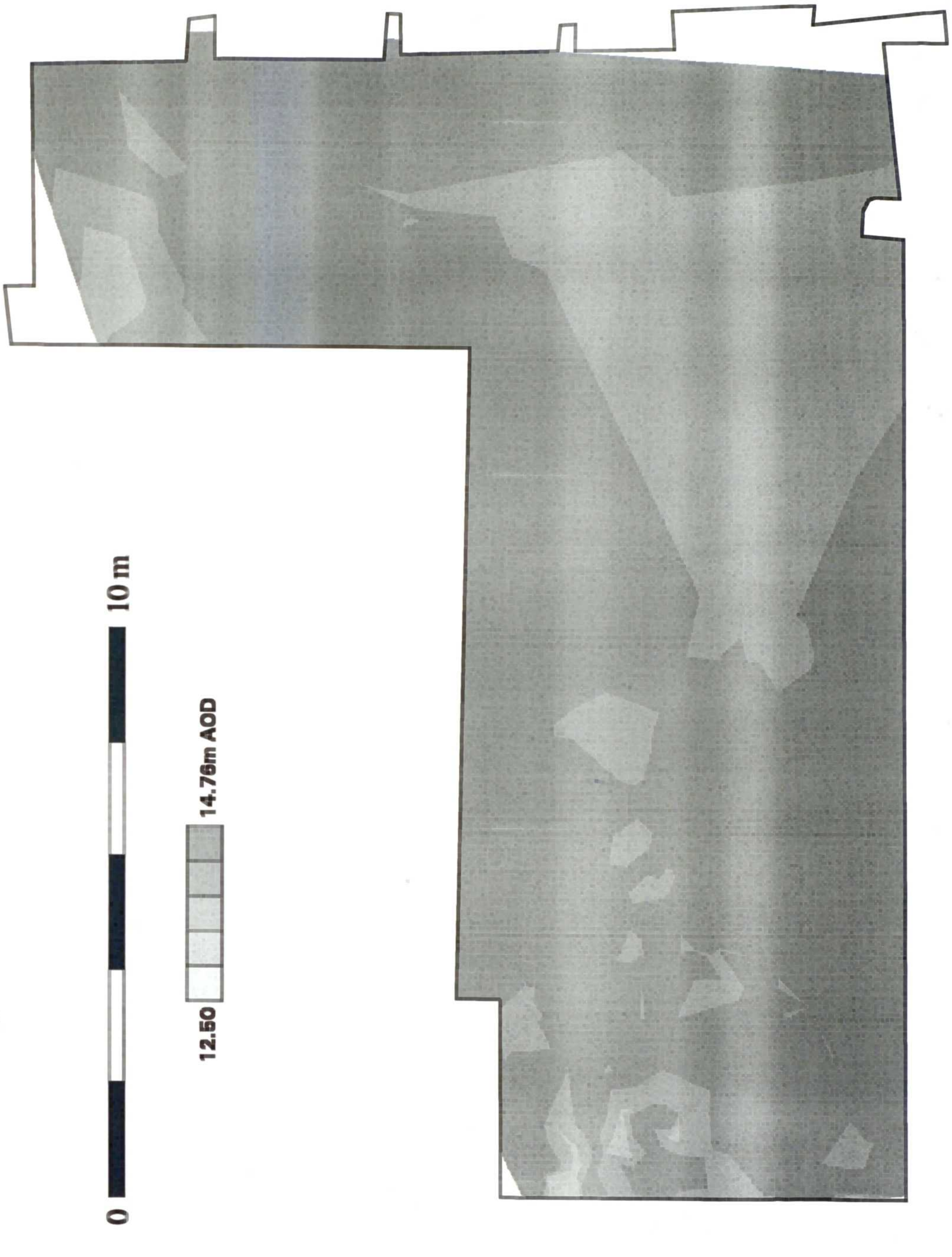


Figure 50: Surface model for Period 6, 9 Blake Street

inwards, making the earlier phases smaller than those above, but it proved difficult on many of the plans to define where exactly the edge of excavation was, and still harder to deduce whether the edge was that for the layer under excavation, the top of the trench or the bottom of the trench. After some confusion, a single site outline was defined and used throughout this case study. It is unclear whether this represents an actual site outline at any point during the excavation or an amalgam of several. The excavator divided the site occupation in to six main periods, ranging from the 1st century AD Roman military structures to the post–Medieval period. The methodology involved in extracting elevation data from the site archives focused around the identification of those plans containing the *earliest* contexts in each period, and the recording of all heights within each of those contexts. Additional 'fudge' heights were also interpolated manually from the plans in an effort to aid definition of topographic features such as pits and gullies.

In total, 78 plan sheets were identified providing information on 121 contexts. Given the need to refer to phasing descriptions, context cards and site plans in order to gather each height, it is estimated that incorrect references between these sources accounted for the loss of some 30–40 extra contexts.

From the plans it was possible to gather only 483 points, of which a worrying 319 were interpolated 'fudge' points rather than heights lifted from on–site survey. Of these 483, 47 were actually *outside* the most commonly encountered site outline, leaving only 436 usable points to describe six period surfaces.

As Figure 46 shows, the spread of these points is uneven both spatially and temporally, and the only periods with sufficient points for modelling were Period 4 (84 points) and Period 6 (294 points). Figure 47 and Figure 48 show the distribution of points for these two periods, and the division between real and interpolated points.

The surfaces produced for Period 4 (Figure 49) and Period 6 (Figure 50) are extremely disappointing, and facilitate no new or improved understanding of the deposits in question. Indeed, the large areas of null data across the surface render the image largely misleading to the observer and suggest that the technique is of little or no use on a site such as Blake Street.

12–18 Swinegate (1989.28)

12–18 Swinegate (`siteno 1989.28`) represented the excavation of a large area within the heart of the city (Figure 45), and offered the opportunity to explore change over a period of 2,000 years. Preservation on site was excellent, with wattle property boundaries, wooden coffins and leather goods all surviving well.

Unlike Blake Street, electronic forms of recording were employed on site, with context record sheets input into the site context database and major context details digitised from the hand–drawn site

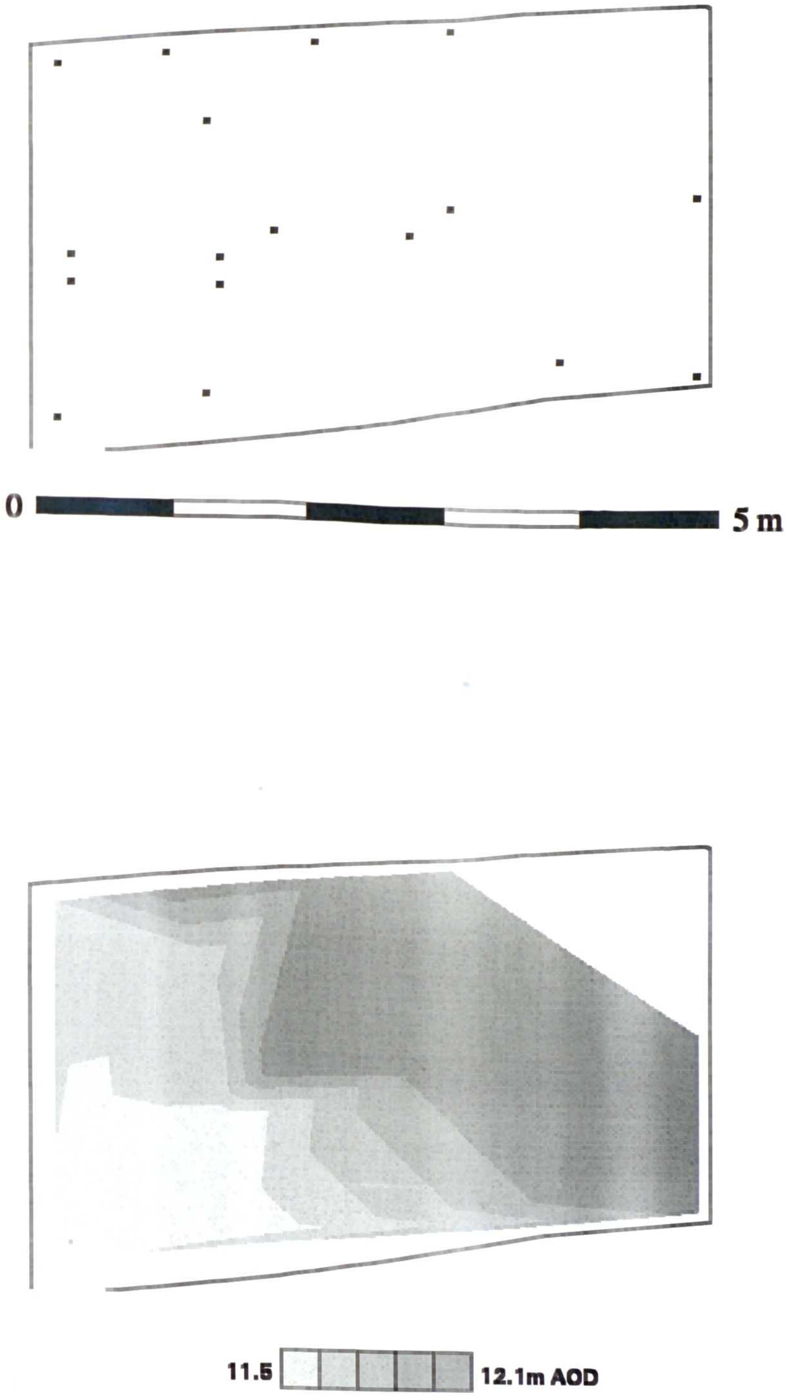


Figure 51: Data points and elevation model, 12-18 Swinegate (Period 1)

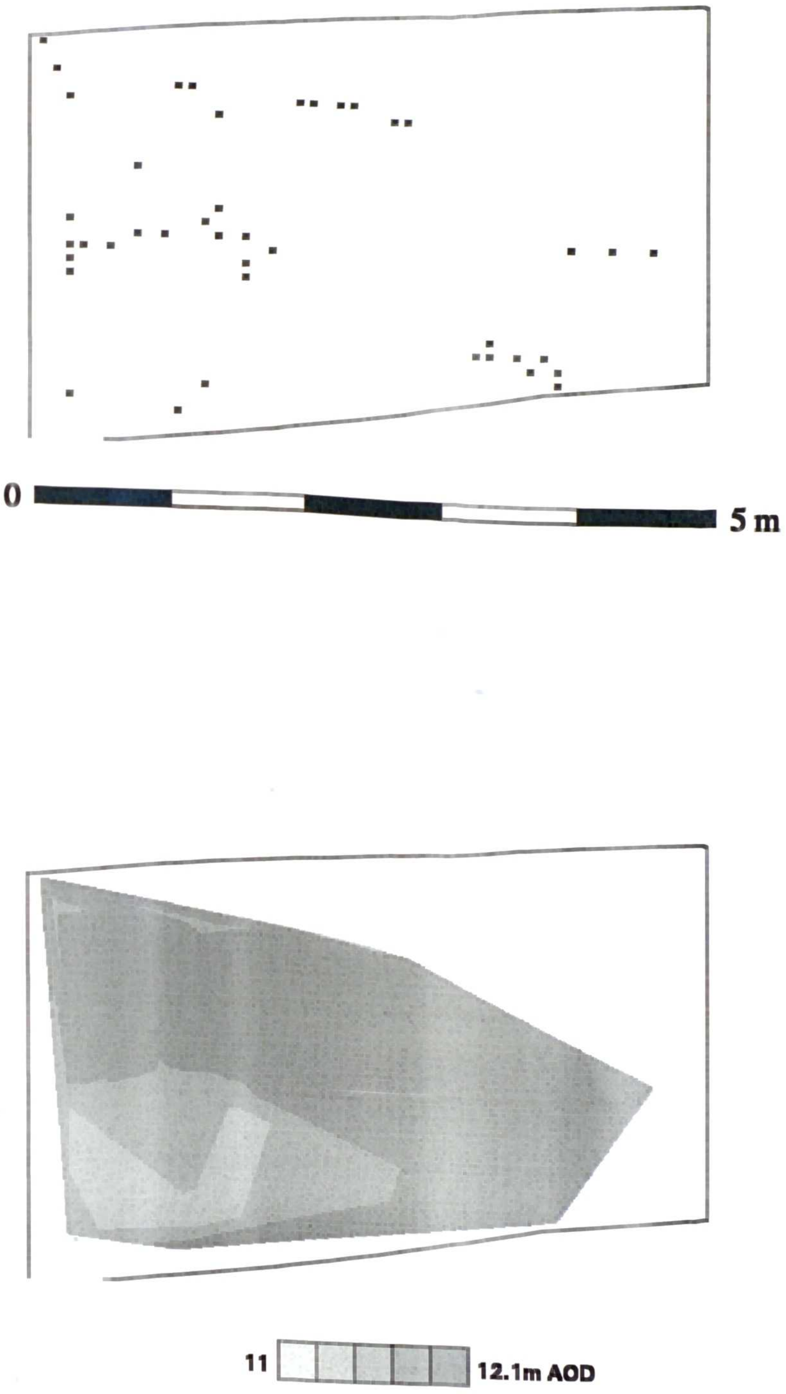


Figure 52: Data points and elevation model, 12-18 Swinegate (Period 2)

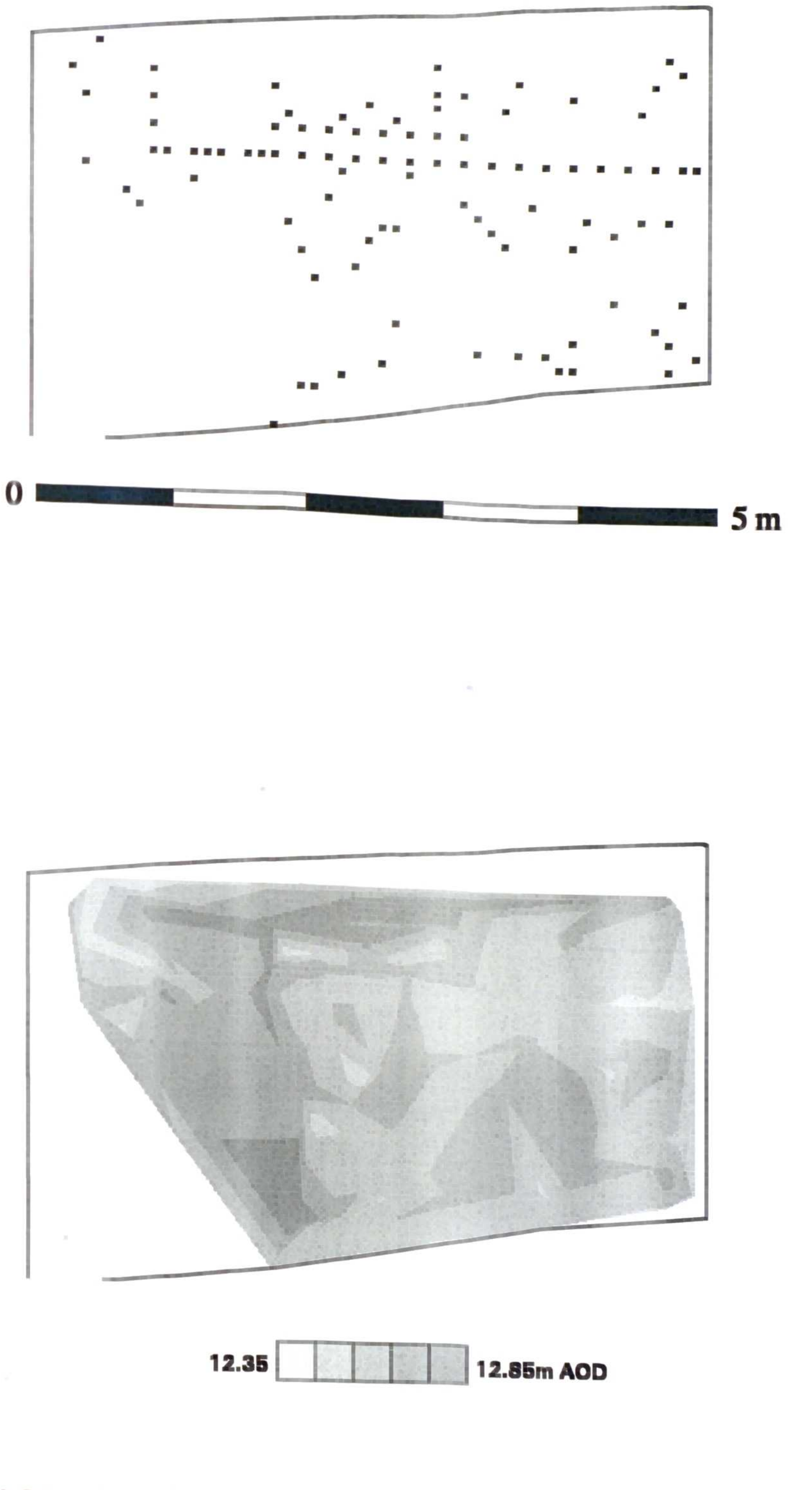


Figure 53: Data points and elevation model, 12-18 Swinegate (Period 3)

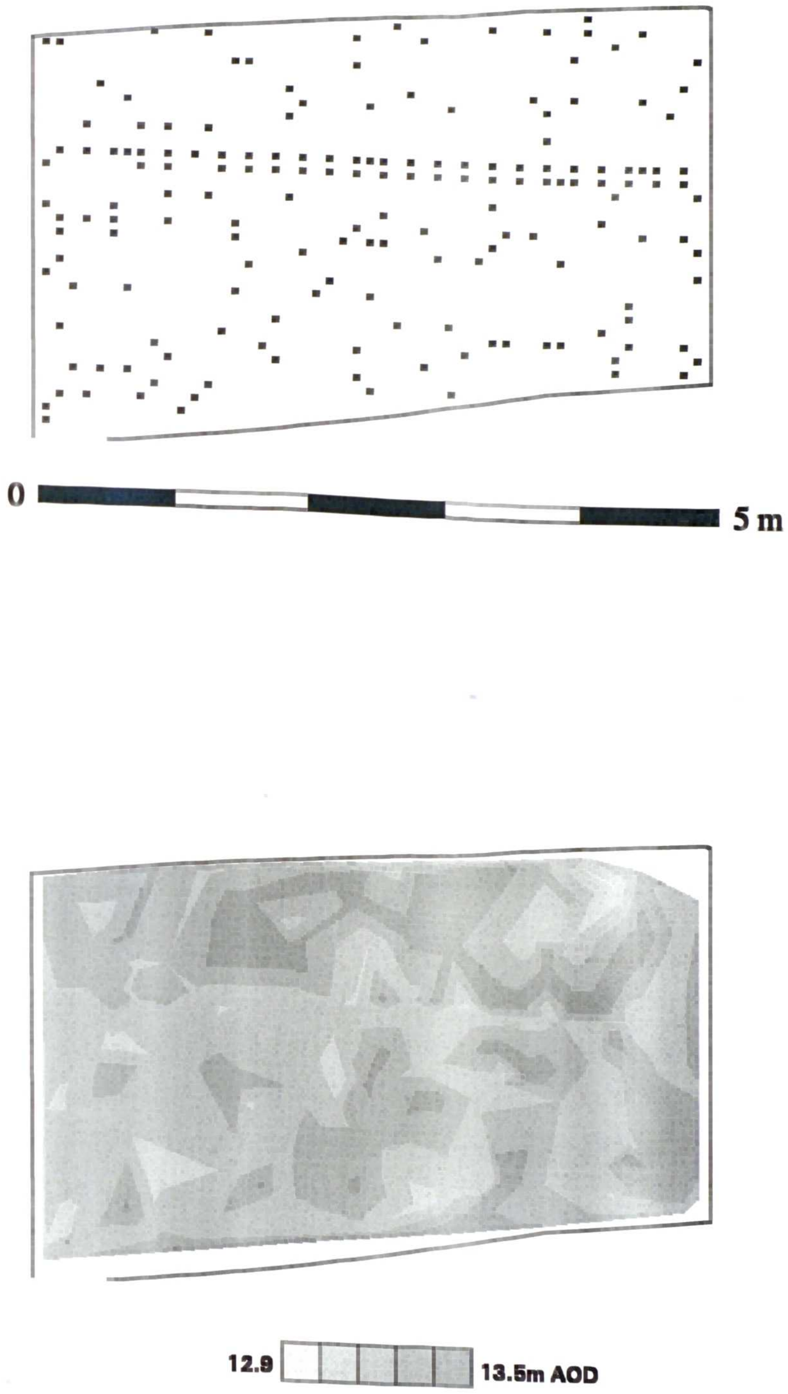


Figure 54: Data points and elevation model, 12-18 Swinegate (Period 4)

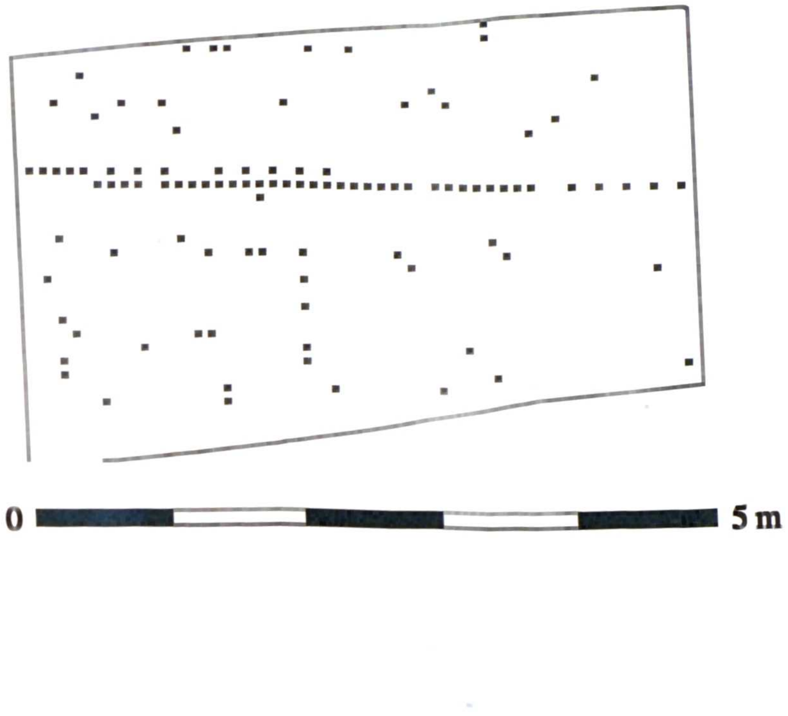


Figure 55: Data points and elevation model, 12-18 Swinegate (Period 5)

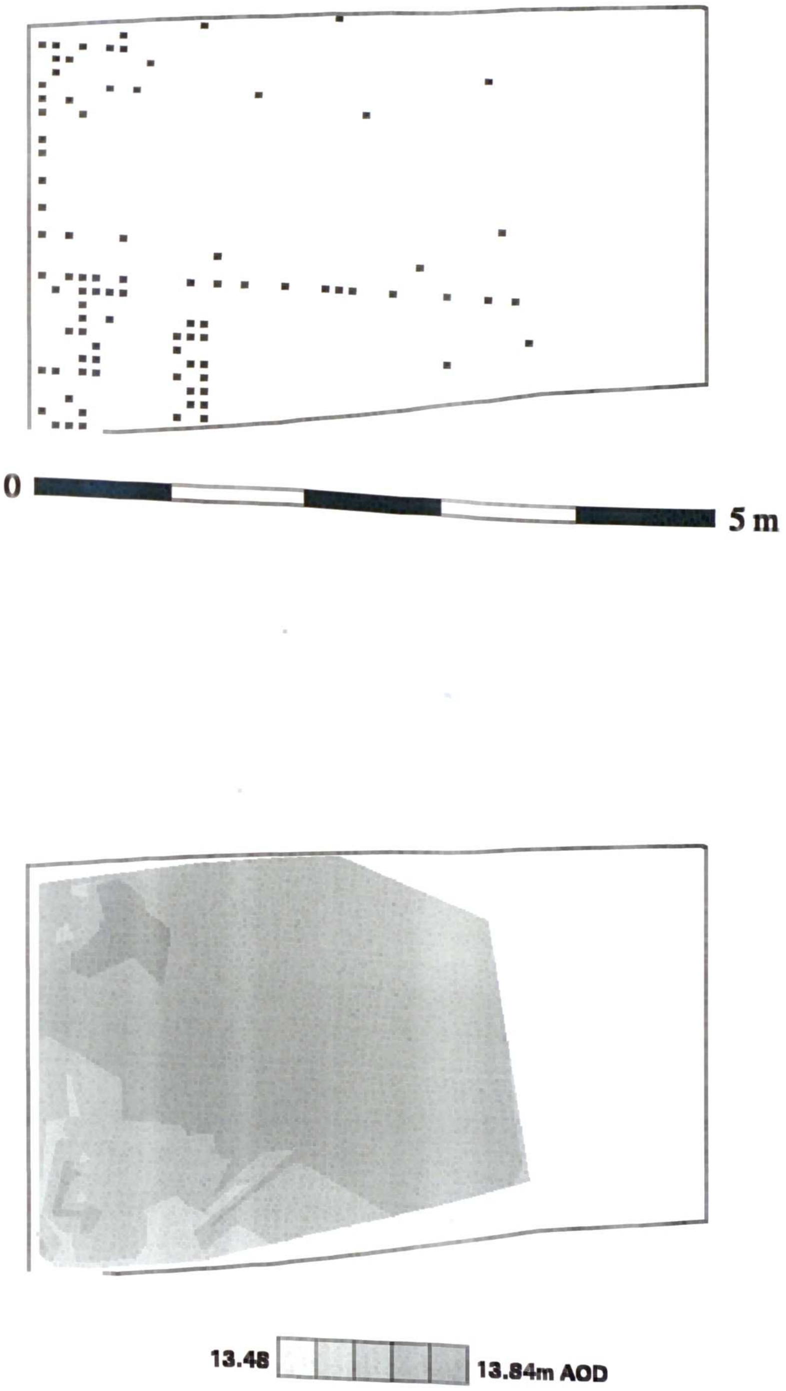


Figure 56: Data points and elevation model, 12-18 Swinegate (Period 7)

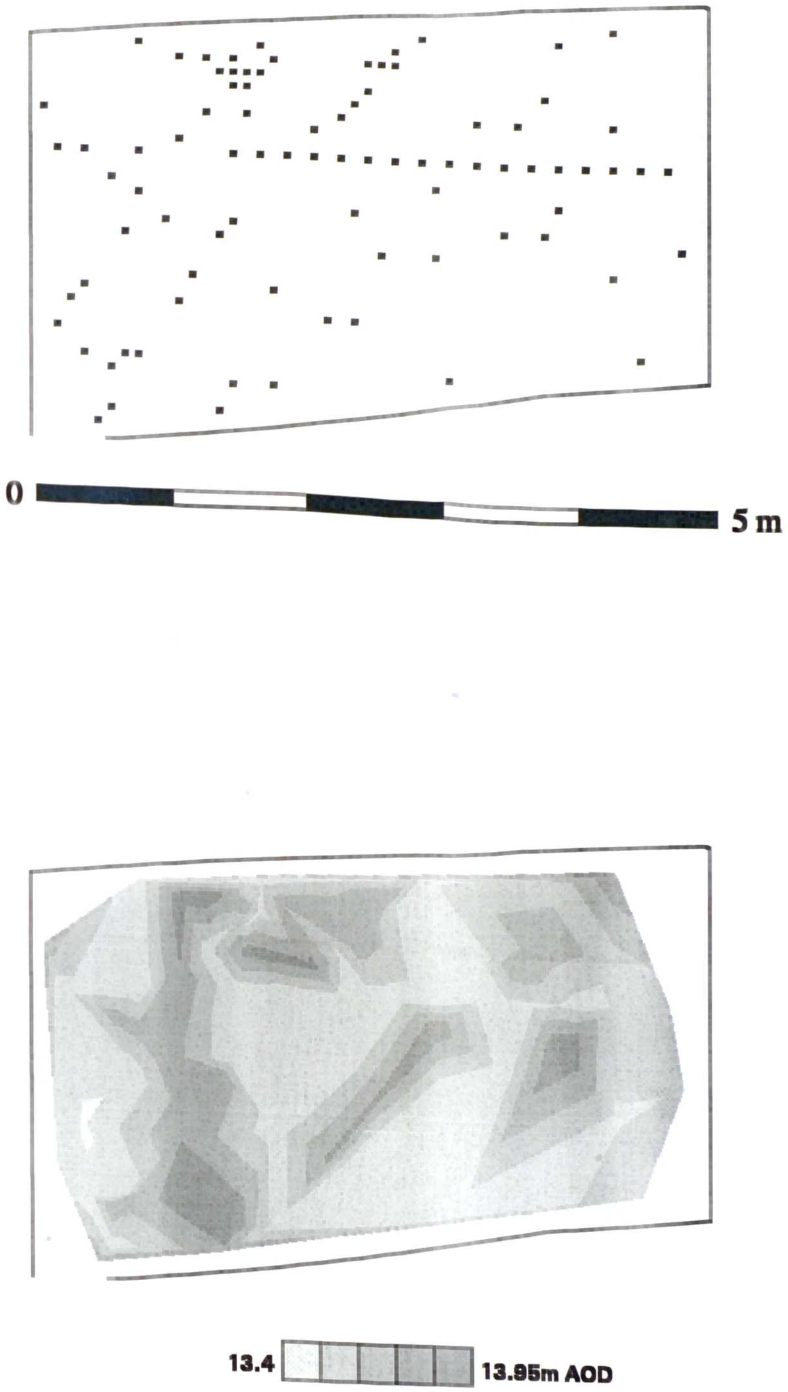


Figure 57: Data points and elevation model, 12-18 Swinegate (Period 8)

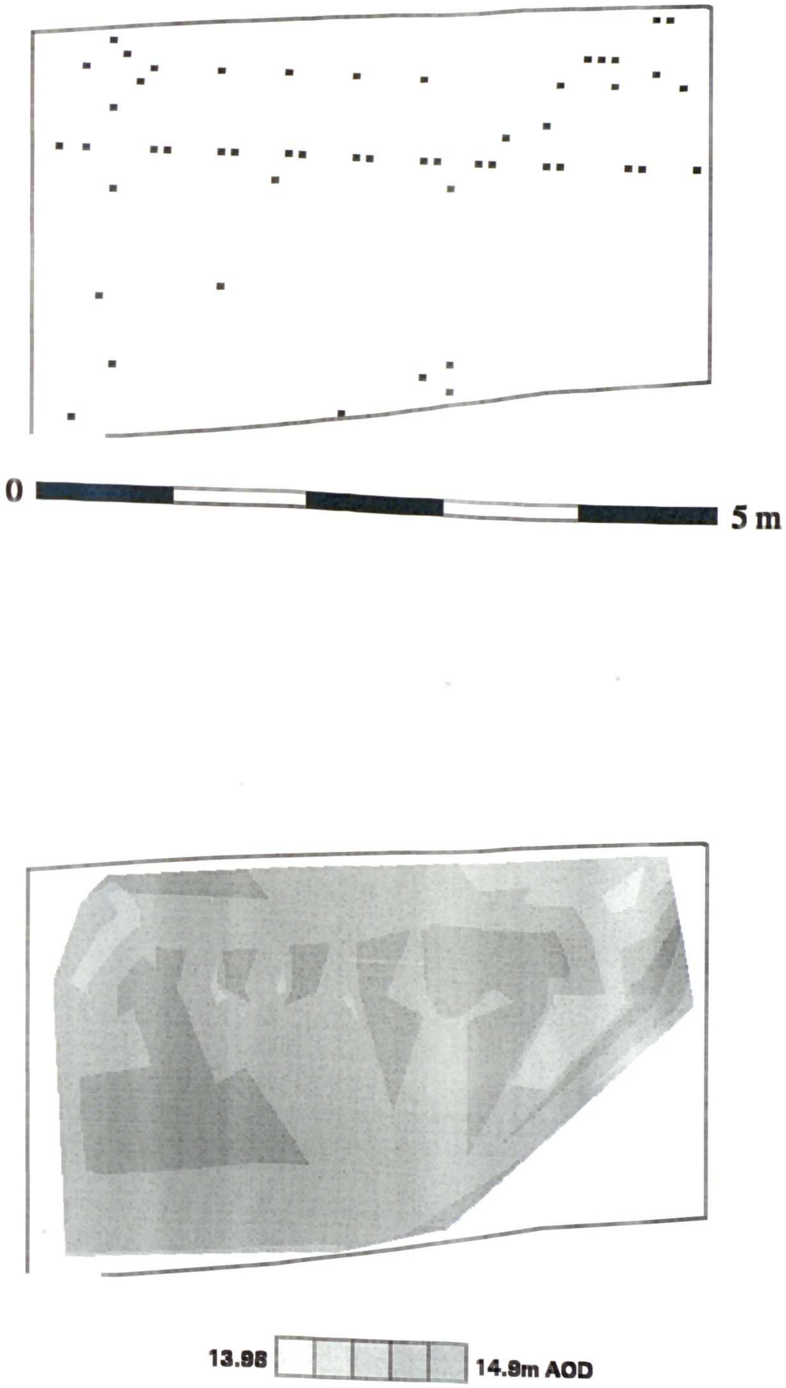


Figure 58: Data points and elevation model, 12-18 Swinegate (Period 10)

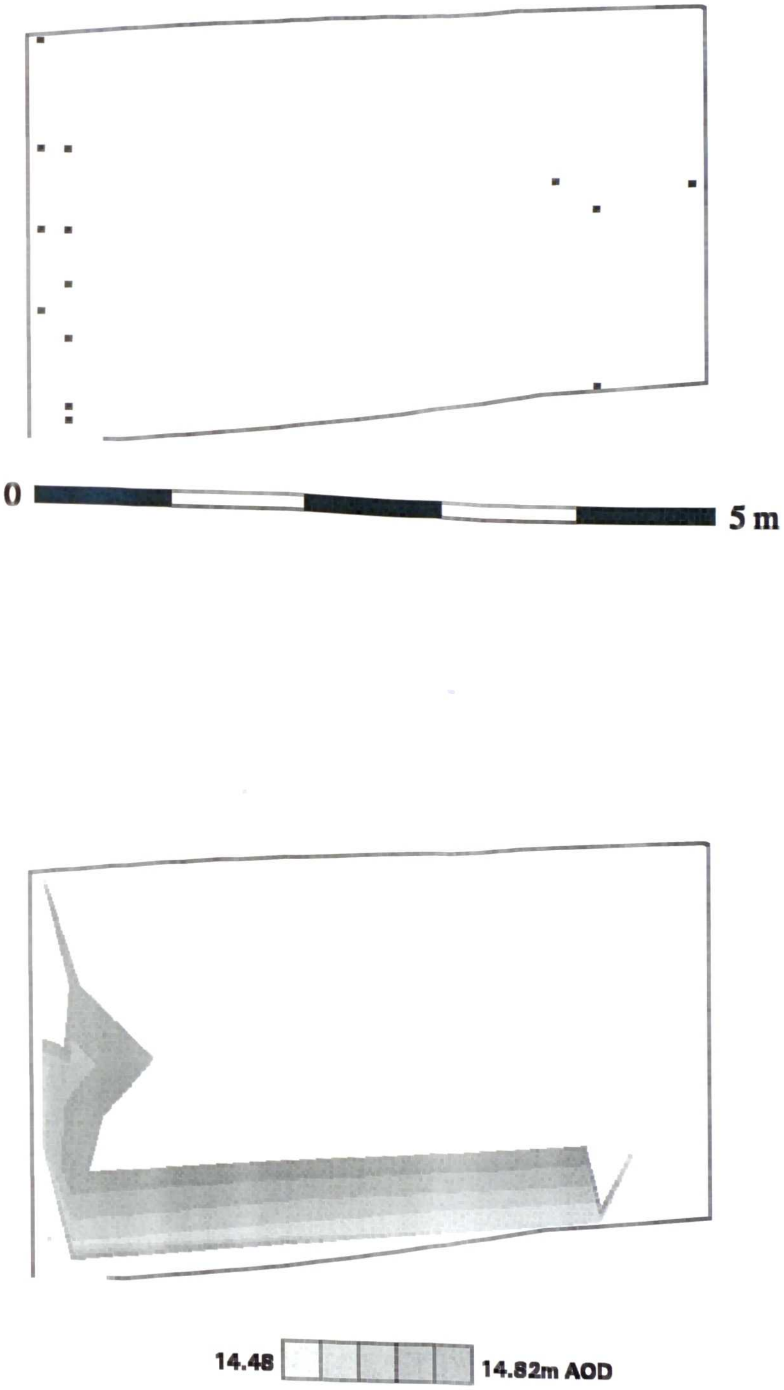


Figure 59: Data points and elevation model, 12-18 Swinegate (Period 13)

plans. Significant feature boundaries for several of the site periods were made available by YAT in digital form, and were used in enhancing the resolution of period surfaces during this case study. The effects of these breaklines are demonstrated below, and the concept of breaklines is introduced and demonstrated in **Chapter 4** (pages 105 and Figure 25).

With the move from composite planning to single context plans during the 1970s and 80s, the number of heights recorded also increased, and the single 14.6m^2 planning square studied produced 813 valid data points, compared to the 117 *real* points collected from the much larger 195m^2 Blake Street site discussed above.

In the case of Swinegate, none of the 319 'fudge' points collected for Blake Street were felt to be necessary given the relatively high point density and the availability of digital feature outlines, both of which added to the resolution of the model without the need to resort to manually interpolating further points.

Figures 51–59 show the surfaces produced for each period at Swinegate, with the periods themselves corresponding to those defined within the site archive and reproduced in Table 12. For periods 1–5, 10 and 13, digital outlines for the major topographic features were available. Reconstructing the surfaces for these periods with the added control offered by breaklines along these feature edges produces results as shown in Figures 60–66. Figure 67 shows the difference between pre– and post–breakline surfaces for periods 3 and 4, both of which had relatively high numbers of data points.

Period	Period description
1	'Natural' deposits
2	Initial use of site (third quarter of First century AD)
3	Second phase of building, with stone construction (first half of Second century AD)
4	Continued use of Period 3 buildings (second half of Second century AD)
5	Final use of Period 3 buildings (late Third/ Fourth centuries AD)
7	No phasing/ burials (Eleventh & Twelfth centuries AD)
8	Site–wide deposition/ end of cemetery (Eleventh & Twelfth centuries AD)
10	Further organic deposition (Twelfth & Thirteenth centuries AD)
13	Machine clearance (Sixteenth century AD onward)

Table 12: Excavator's initial phasing for Trench 3, 12–18 Swinegate (YAT archive)

The site excavators at Swinegate consistently recorded heights along two running section lines on most occasions when contexts crossed these lines, enabling the accurate construction of a cross–section through the deposits in this area of the site. Figure 68 illustrates the shape of a computer–generated site profile placed between these two section lines.

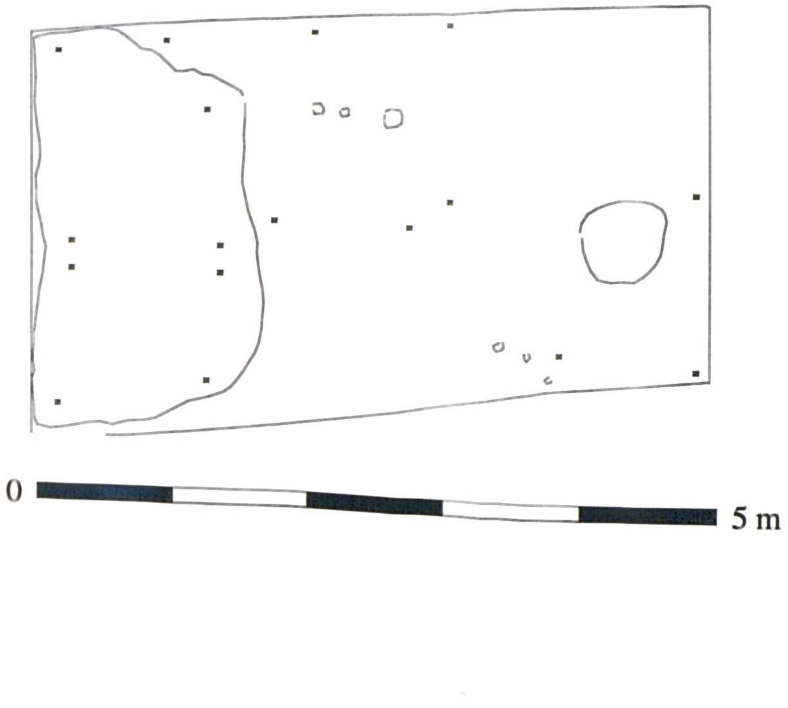


Figure 60: Data points and elevation model generated with breaklines, 12-18 Swinegate (Period 1)

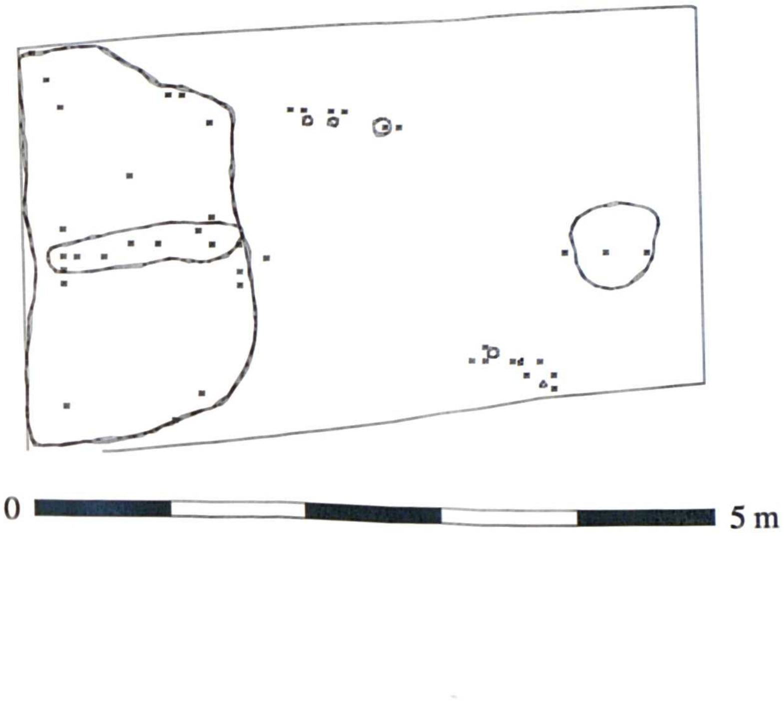


Figure 61: Data points and elevation model generated with breaklines, 12-18 Swinegate (Period 2)

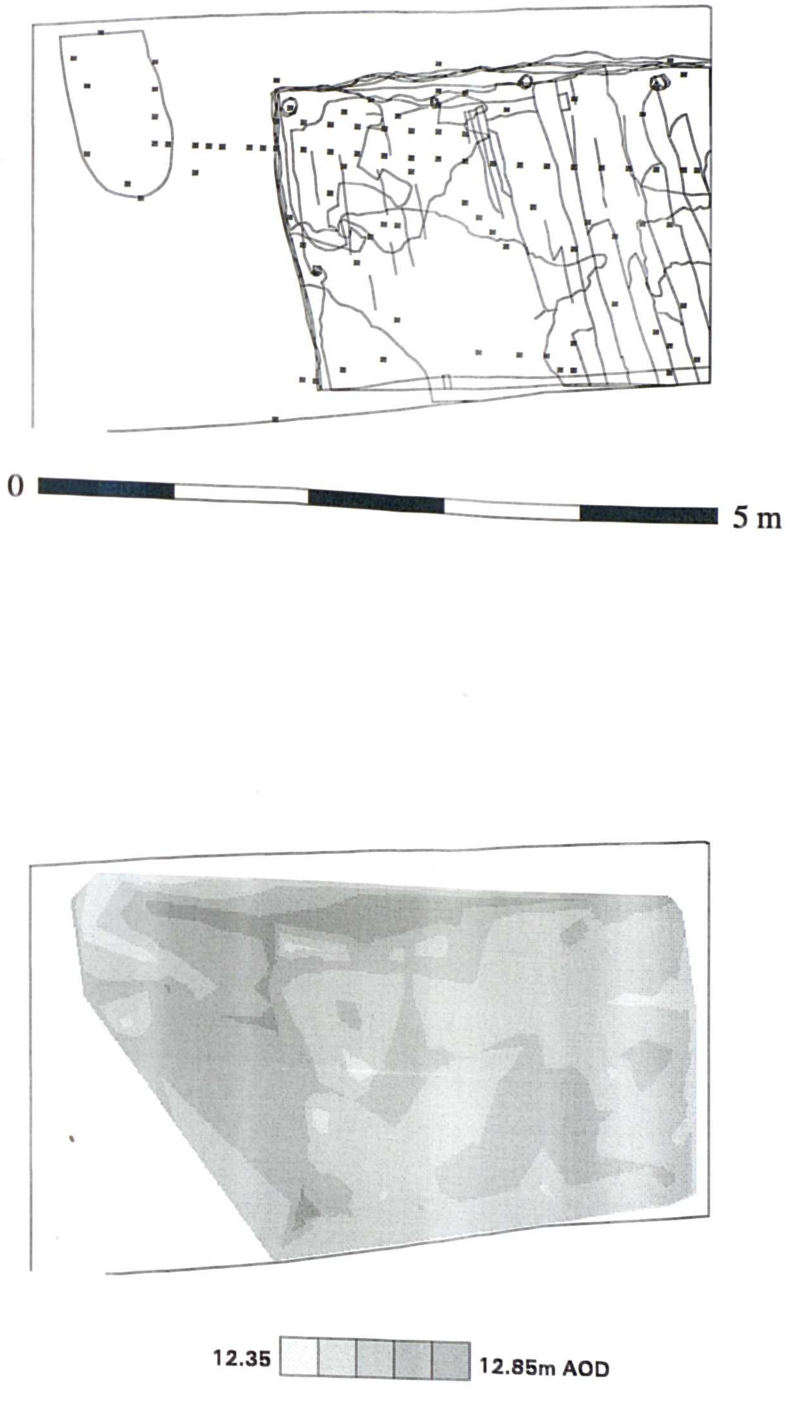


Figure 62: Data points and elevation model generated with breaklines, 12-18 Swinegate (Period 3)

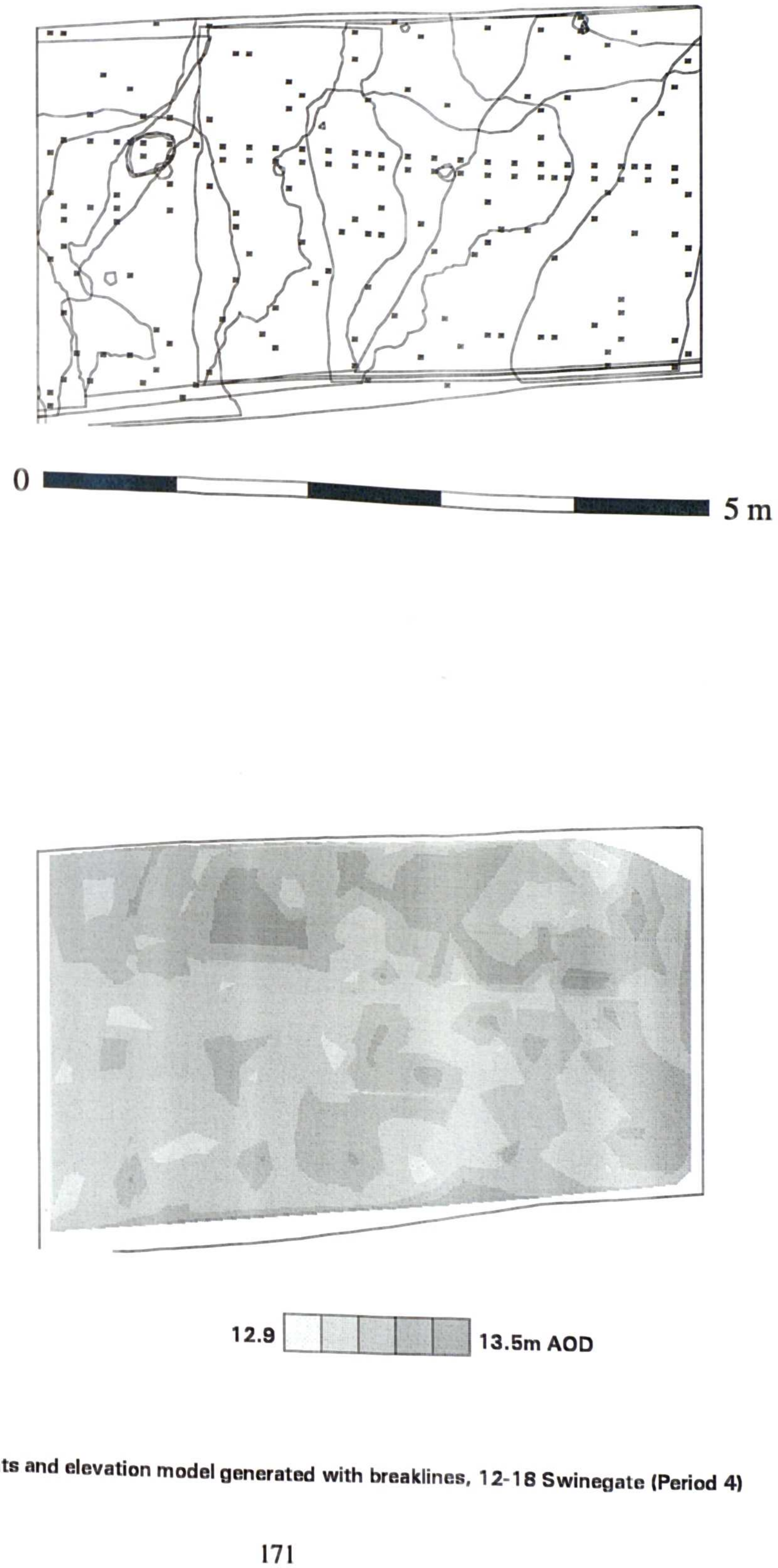


Figure 63: Data points and elevation model generated with breaklines, 12-18 Swinegate (Period 4)

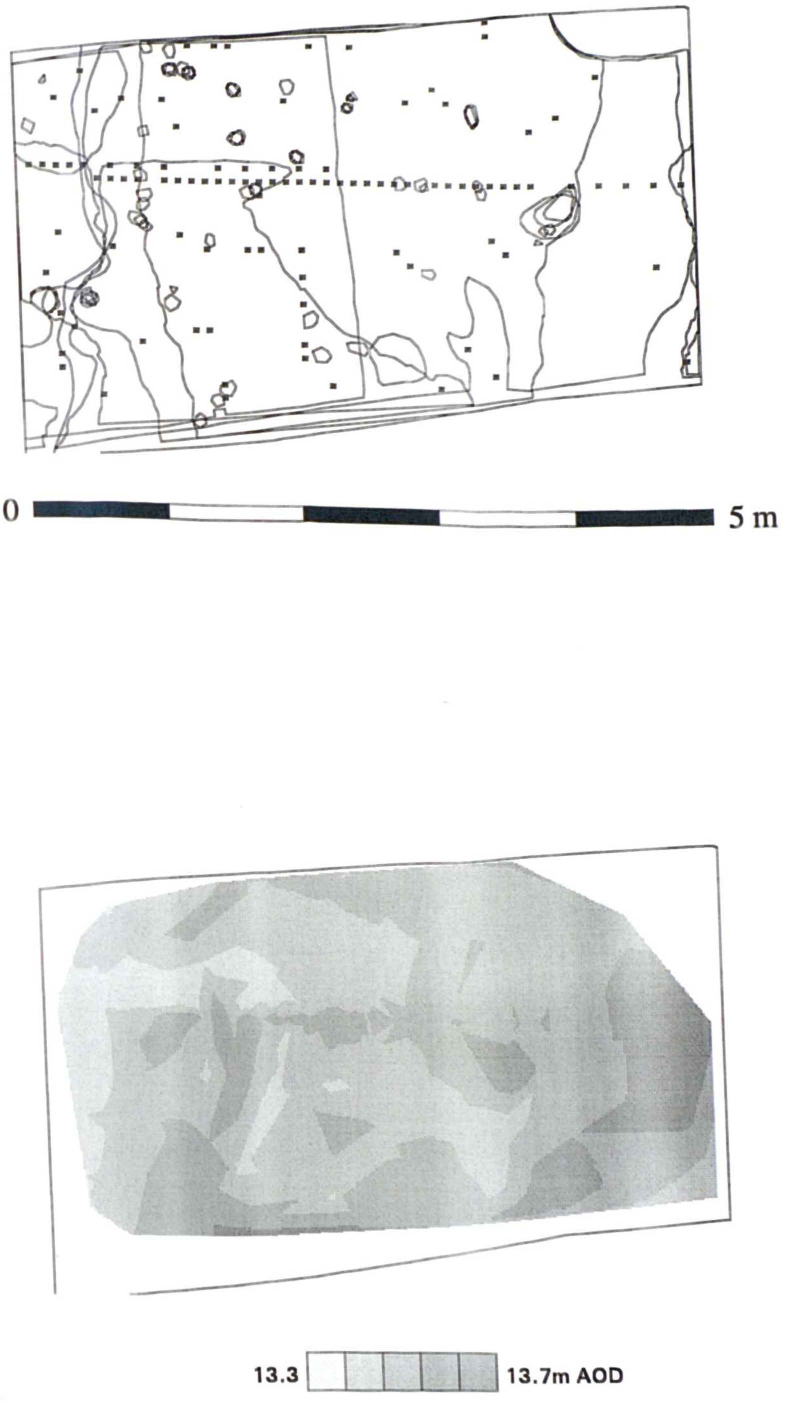


Figure 64: Data points and elevation model generated with breaklines, 12-18 Swinegate (Period 5)

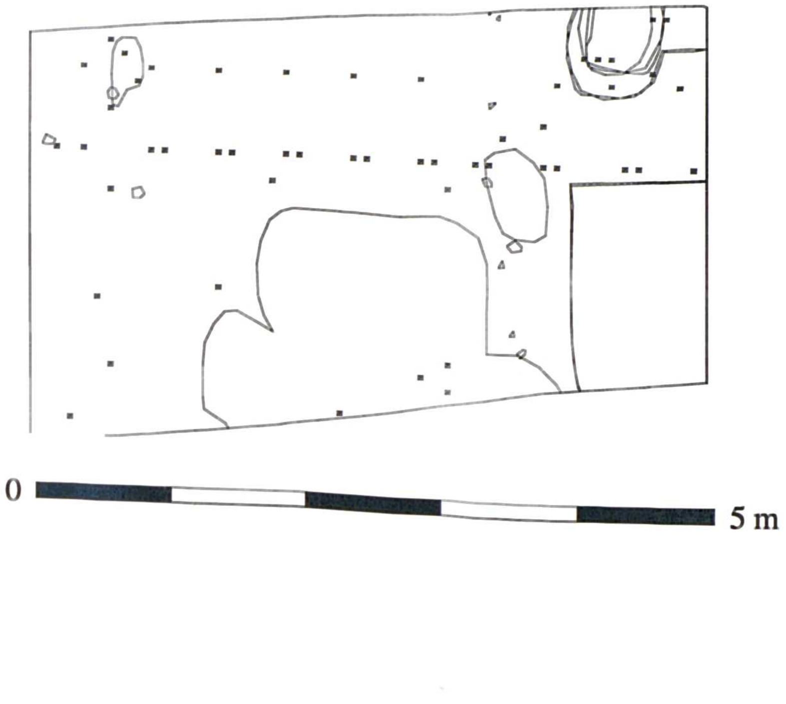


Figure 65: Data points and elevation model generated with breaklines, 12-18 Swinegate (Period 10)

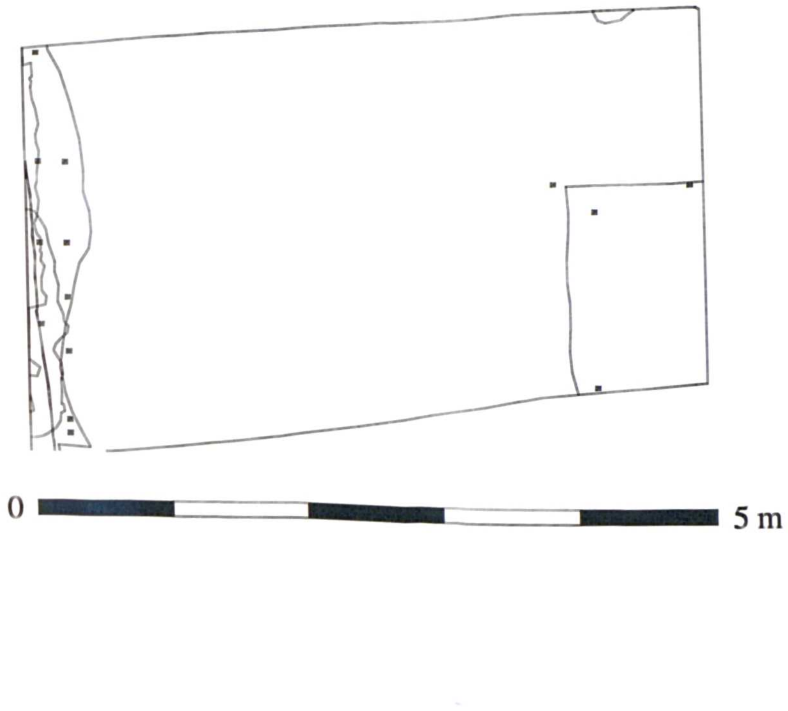


Figure 66: Data points and elevation model generated with breaklines, 12-18 Swinegate (Period 13)

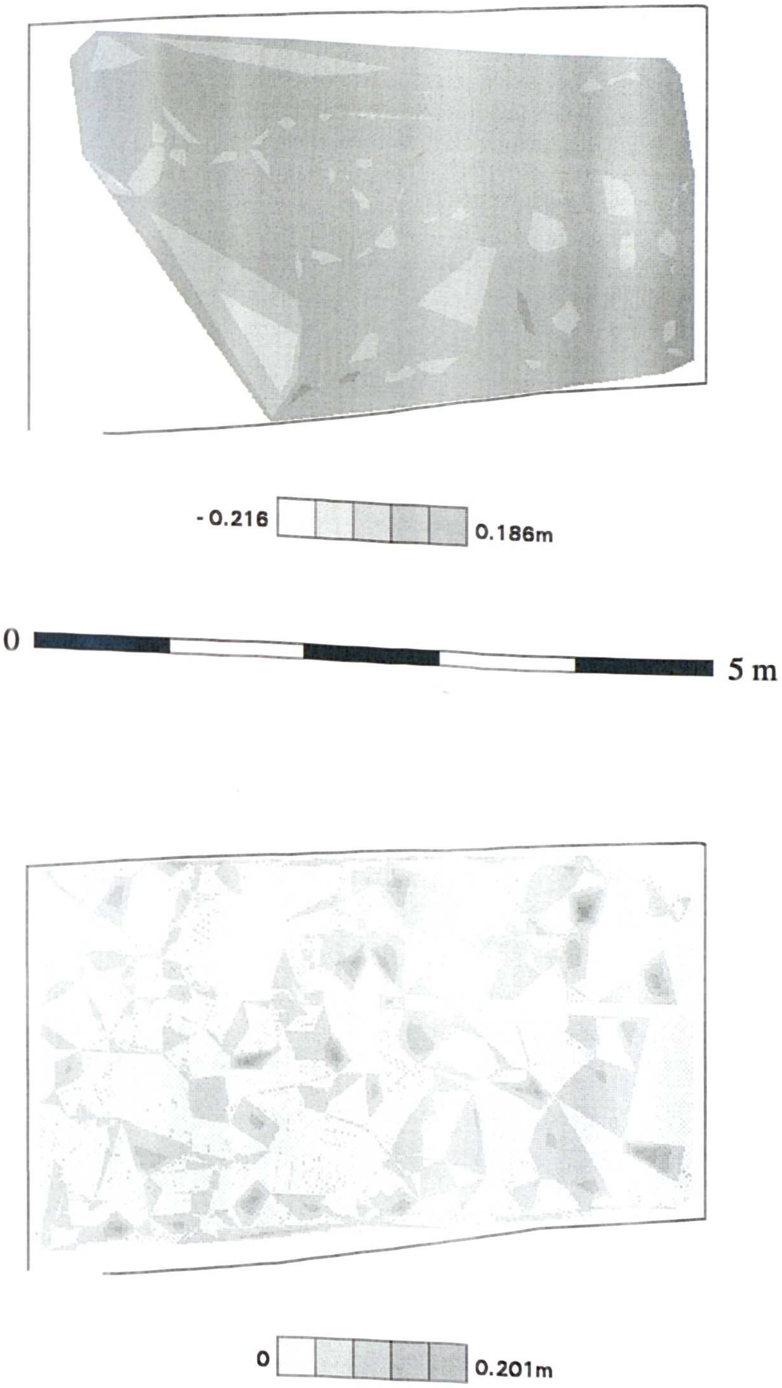


Figure 67: Difference in elevation model with and without breaklines for Periods 3 (top) and 4 (bottom)

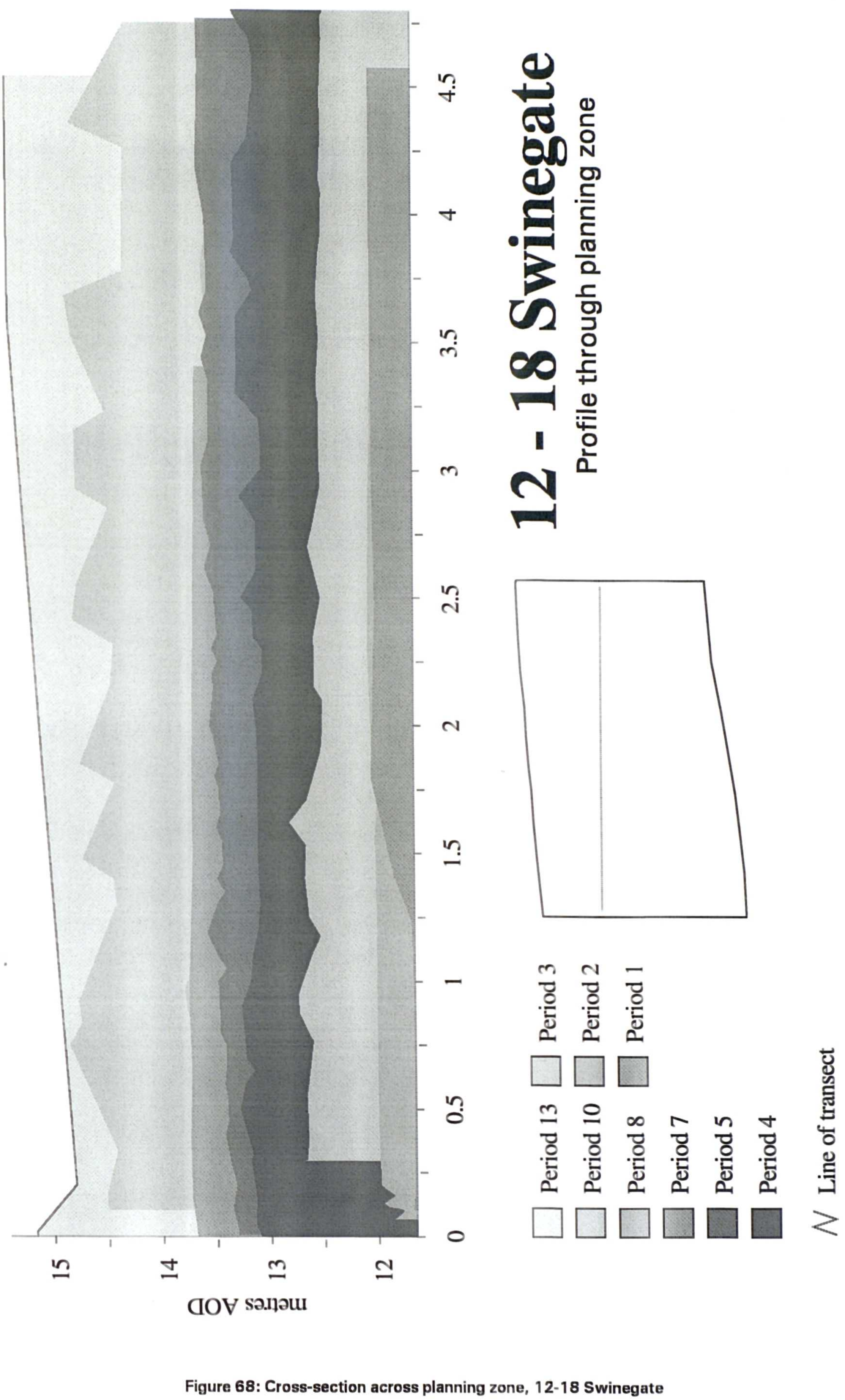


Figure 68: Cross-section across planning zone, 12-18 Swinegate

Intra–site analysis: Conclusions

As can be seen, results from both the 1970's Blake Street excavation and the — far more data–rich and therefore apparently 'better' — Swinegate are poor, and fail either to offer interpretable visualisations of the changing topography or to pick out archaeological questions that might be asked of the data (or answers arising from them).

The majority of the problems are caused by the fact that the changes in height with respect to distance are poorly represented in the erratic distribution of data points; Figure 61, for example, describes an area no more than 5m long, but in which variations of height of more than 1m occur. Looking still at Figure 61, it is also readily apparent that the distribution of points is wholly inadequate for describing the topographic variation suggested by the outlines of cut features. The pit–like feature to the extreme right, for example, has the base of its cut defined by two points, but the top of the feature is only defined by a single height. Even with the effects of the encircling breaklines, the topography of this feature will be computed by the computer with respect to the only other points available to it; over 1m away to the south–west and nearly 2m to the north–west. In a planning zone only 5m long, such (necessary, given the data) computer–generated generalisations render the results almost unintelligible. Although disappointing in this Case Study, the data are not wholly worthless. They are certainly sufficient for meeting their intended purpose of aiding in the resolution of stratigraphic and physical relationships during post–excavation analysis and publication, and also provide enough detail for a good archaeological illustrator to recreate the topography on–site, using greater 'intelligence', creativity and flexibility than the more rule–based approach adopted by computer software.

Broader issues are drawn out, below, but it must be concluded that this Case Study is a failure in so far as exploring or representing the topography of two archaeological excavations is concerned. The near–random distribution of elevation values over a very small horizontal space in which rapid variations in elevation potentially occur renders the result essentially unmodelable by the available computer techniques, and the most valuable information is presented in Figure 68, derived from an area of the Swinegate excavation where elevations were primarily recorded by means of a running section, maintained from one context to the next.

Archival issues

The work involved in gathering data for this case study has been useful in illustrating the many problems inherent in utilising archaeological archives for purposes other than the publication of the site itself, especially where further interpretation is carried out by a logical computer, rather than by a more flexible and forgiving human. Changing methods of excavation and recording between sites only serve to exacerbate the multitude of difficulties faced in navigating the archive of a site in the absence of first–hand experience of the excavation itself.

Archaeological archives, by their nature, grow organically with time, and it is difficult to lay down recording and excavating standards that remain valid from one excavation to the next as circumstances and accepted practices alter. As a result, archives can appear chaotic and jumbled, and the prospect of approaching a new site solely through its archival presence is surely a daunting one to even the most experienced excavator.

Despite the accepted evolution in technique over time, archives can be *more* inaccessible than they need be, and the provision of pointers and guides should form an integral part of the post–excavation process if archival material is ever to become of use to anyone other than those preparing the site for publication.

A prime example of the pitfalls awaiting the unwary archive browser is Swinegate, where several site phasings exist together within the numerous boxes and files comprising the extant Level III archive. At first perusal, it is difficult to ascertain which of these phasings is the correct one and in the end it was necessary to consult one of the original site supervisors in order to resolve the confusion. With many sites archived by YAT and others, people such as the original site supervisors and directors are no longer available, and archive navigation becomes fraught with pitfalls.

The YAT archive is well maintained by the Trust archivist, Christine Kyriacou, and she possesses a remarkable knowledge for the location and completeness of each site archive within the whole. Despite this, she cannot have an in depth knowledge of the content of each archive, and without detailed knowledge of the phasing and excavation of each site, she is unable to help with problems such as those encountered with Blake Street (the wandering edge of excavation, for example) and Swinegate (multiple phase diagrams).

Ultimately, provision of a ‘road map’ to the archive should be the responsibility of the excavator, and should take priority over publication or the beginning of new projects. It is surely grossly irresponsible to leave an archive in a near–unusable state merely because the next project has come along.

A number of new projects, such as the York–specific archive assessment (Brinklow *pers comm*) funded by English Heritage and the Archaeology Data Service funded by the Arts & Humanities Data Service (Richards 1996), are addressing many of the issues relating to archival storage, and it is to be hoped that guidelines for future good practice will emerge from each project. As for improving the extant archival resource, only the injection of large sums of capital and the devotion of significant time may resolve many of the inconsistencies and omissions in order to create a resource usable by the researcher who does not have the time, skills or inclination to grapple with an entire archive merely to locate small sections of data. It is to be hoped that organisations such as English Heritage will build upon projects like York's archive assessment in order to create such a resource.

Recording in *n*–space

The results, above, serve to illustrate the less than impressive outcome of applying computer–based deposit modelling procedures to current levels of elevation recording on two British excavations. Indeed, the contents of Figure 68 marks one of the few useful outputs of the exercise.

The higher level of elevation recording on the Swinegate site marks a significant extra investment of staff time during the excavation, but the resulting surfaces — although apparently more complex — do not enable a computer to offer significantly better representations of excavated reality than those for Blake Street. It is also uncertain how the extra levels aid in the assessment of relationships between excavated contexts for other research purposes, and the entire rationale behind this extra data collection must therefore be called into question.

If the reason for further data collection arises from the rescue concept of 'preservation by record' and the now outmoded belief in being able to reconstruct a site from its archive, then the results above clearly show this not to be the case, at least for these two sites and, by extension, in all likelihood for others. Indeed, the extra data points may even lead to a *misleading* impression of greater precision than earlier excavations.

As Harris & Lock (forthcoming) have indicated, current elevation recording techniques on excavations are woefully inadequate for the computerised reconstruction of 'period' surfaces or the volumes between them, and whilst it is admittedly true that few, if any, excavators consciously consider such a use for the data they collect, it appears likely that many archaeologists almost subconsciously believe that such a use would be feasible. Results such as those above and in the Harris & Lock article show this not to be the case.

If archaeologists seriously want to record elevation data that will be of use in rapidly, accurately and digitally reconstructing micro–topography, then the manner in which such data are collected needs to be radically altered.

YAT sites have evolved a methodology by which excavation trenches are divided into a series of fixed five metre planning squares such as the one selected for study at Swinegate. It seems plausible that such a planning square could be further subdivided into, perhaps, 0.5m squares (Figure 69), the edges of which would form a running section line similar to the one collected on a single part of the Swinegate site and reproduced in Figure 68.

During excavation, elevations would be consistently recorded every 0.1m along each of these section lines for every context, and the results stored digitally along with site plans and other context details. Major elevation changes within the individual squares would also be recorded, as would the tops and bottoms of slope (with both elevation and an approximation of the line of the edge recorded).

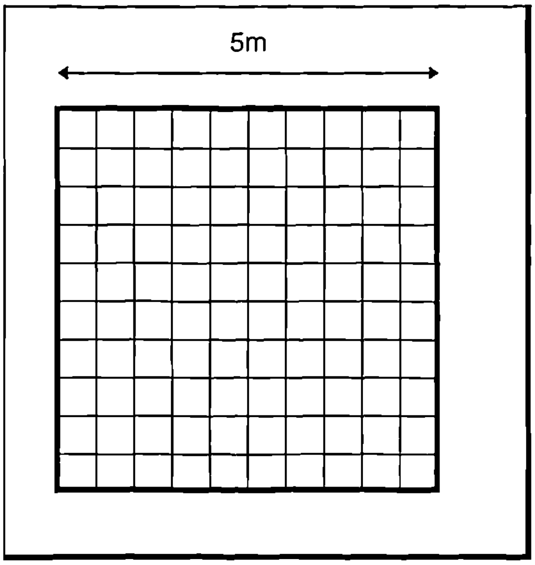


Figure 69: YAT 5m planning zone with hypothetical running sections every 0.5m

In reconstructing topographic detail, the researcher would therefore be able to call upon a detailed — and consistent *between* levels — matrix of elevation data as well as breaklines defining the major topographic variations across the site. The excavator would also have access to data enabling the construction of reliable cross–sections potentially anywhere on the site quickly and easily. The savings in time incurred here by removing the need for manual plotting of sections during excavation might conceivably make up for the increased time required to record elevations, but more importantly, the elevation data collected might actually have some *value* beyond the few situations in which those in post–excavation utilise recorded heights to clarify stratigraphic conflicts. Whilst a technique such as this has yet to be tested, it would be interested to implement experimentally in one section of a site in the near future in order to compare to data collected more traditionally elsewhere on the excavation.

Case Study 4: Locating areas of waterlogging

In cities such as York, waterlogged deposits have proved of great importance in preserving well stratified and archaeologically rich layers of settlement evidence. The Coppergate excavations in York, for example, (Hall 1984) are a world famous example of the wealth of data afforded by these anaerobic sites.

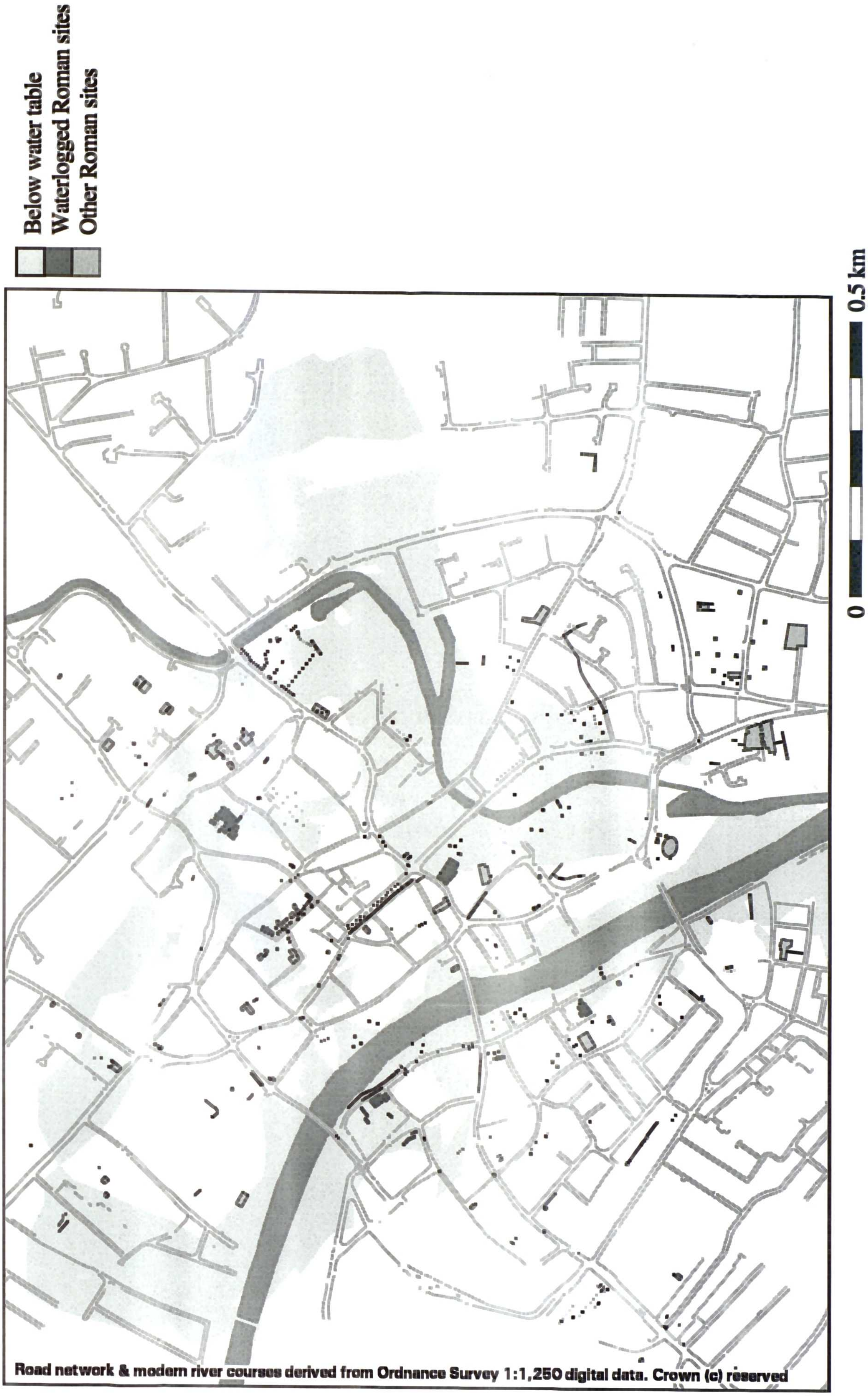
Although waterlogged sites should not always be considered the most valuable (see page 32) element of the archaeological resource, they are often able to shed important light upon the past where their location and the likely deposits held therein both comply closely with the city's research agenda. Also, the presence of waterlogged layers may well have a bearing upon the mitigation strategies adopted during development, whether the site is to be archaeologically examined or not. After all, sufficient evidence does not yet exist for the likely impact upon a waterlogged site of an extensive piling programme, although the likelihood of at least a degree of deposit desiccation must be high.

As with other case studies in this chapter, low resolution within the available data makes detailed analyses impossible, but it remains feasible to attempt identification of broad areas of waterlogging, and to compare these with known excavations of waterlogged deposits.

In undertaking this analysis, similar techniques were employed to those used elsewhere throughout the thesis; namely, the construction of deposit 'surfaces' and the subtraction of one from another in order to derive interfaces between the two. In this particular case, the period deposit surfaces have been supplemented by a surface describing the modern water table as defined by entries in the project database for top of water table and top of perched water. Lacking any information on the *bottom* of either of these, it proved necessary to simply aggregate the two in order to create a single volume representing the water table, rather than the three–dimensionally fragmented space more likely to truly represent the occurrence of sub–surface water. The area of the Roman deposit lying beneath this water table (and therefore probably waterlogged) was defined by simply subtracting the Roman surface (`$DTM/roman`) from the water table surface.

The results of this analysis are depicted in Figure 70, where the extent of likely waterlogging within the Roman deposit may clearly be seen ('Below water table' in the key for Figure 70).

Those YAT excavations recorded in the project database as including Roman deposits are also depicted, shaded to signify whether or not their database entries record them as being waterlogged (`moisture lk wet`) *and* anaerobic (`anaerobic lk y`). It is important to remember that the two measures of waterlogging — area beneath the water table and Roman waterlogged sites — depicted in Figure 70 have been arrived at independently, and that the GIS has not used information from one source in order to aid definition of the other.



Road network & modern river courses derived from Ordnance Survey 1:1,250 digital data. Crown (c) reserved

Figure 70: Roman sites recorded as waterlogged in relation to the predicted extent of waterlogging

It is therefore interesting — although hopefully not wholly surprising — to note the close correlation between the two in Figure 70, where waterlogged sites are encountered almost exclusively within the computed area of potential waterlogging. The larger trenches defined within the database as being waterlogged may clearly be seen to lie within the GIS' predicted zone of waterlogging, while statistics may be used to aid in describing the smaller interventions that are not so easily identified on the map.

	Waterlogged in the database	**Not waterlogged in the database**	
Within GIS' predicted zone of waterlogging	30 (16.54)	204 (217.46)	**234**
Outside GIS' predicted zone of waterlogging	11 (24.46)	335 (321.54)	**346**
	41	**539**	**580**

Table 13: Contingency table showing cross–tabulation between recordings of Roman waterlogged trenches in the site database and Roman waterlogged deposits as predicted by the GIS. Observed values shown first, with expected values if H_0 were true in parentheses.

Table 13 shows the relationship between trenches within the predicted waterlogged zone and those recorded in the database as being waterlogged. The results were derived by using the GIS zone of waterlogging as a clipping coverage within *Arc/Info* to subtract any sites lying within that zone from the set of all YAT excavation trenches with Roman deposits. This resulted in two new coverages containing all Roman sites *inside* the predicted area of waterlogging and all those *outside* it. Both coverages were queried within the database to derive the number of sites in each case that the database believed to be waterlogged (`moisture lk wet` and `anaerobic lk y`) and the number not waterlogged (`moisture lk dry` or `anaerobic lk n`).

In order to test the validity of the claim that sites within the predicted area of waterlogging correlated closely with those recorded in the database as waterlogged, a chi–squared significance test (χ^2) was applied to the results in order to investigate the validity of the hypothesis, H_1.

H_0: 'The distribution of archaeological contacts defined as waterlogged in the database is random across both the area defined by the GIS as potentially waterlogged and the area not defined as such.'

H_1: 'Archaeological contacts defined as waterlogged in the database are more likely than not to lie within the zone of waterlogging predicted by the GIS.'

Selected significance level: $\alpha = 0.05$

The results that would be expected (E_i) if H_0 were true are shown within parentheses in Table 13, along with the results actually observed within the GIS (O_i). Table 14 shows the result of the significance test.

Category	O_i	E_i	$(O_i - E_i)$	$(O_i - E_i)^2$	$\frac{(O_i - E_i)^2}{E_i}$
1	30	16.54	13.46	181.1716	10.9535
2	204	217.46	- 13.46	181.1716	0.8331
3	11	24.46	- 13.46	181.1716	7.4069
4	335	321.54	13.46	181.1716	0.5634
				χ^2	19.7569

Table 14: Chi–squared significance test on the data from Table 13

The value for chi–squared at one degree of freedom with a significance level of 0.05 is 3.84 (Shennan 1988, Appendix 1/A). As the observed value (19.7569) is greater than 3.84, H_0 may therefore be rejected.

Although the results appear promising, it should be remembered that the basis for both computer prediction and statistical analysis is a database where sites have been recorded as either `wet` or `dry` and, for presence of anaerobic conditions, `y` or `n`. Those compiling the original database were forced to make an assessment of a site archive or, often, a brief description of an excavation and decide from this how to code the site, with no scope in the database schema for uncertainty or an element of 'fuziness'. This, coupled with the undoubted difference in perceptions of a site as waterlogged or not between data collectors, introduces an element of uncertainty into the model and any correlations derived therefrom and should be borne in mind during any examination of the data themselves or the statistical analyses.

As such, the GIS predictions for extent of waterlogging would appear remarkably accurate, at least for the Roman period. It would therefore seem advisable that a map such as that shown in Figure 70 be introduced into the Development Control process for future development work within the city. Even in cases where foundations *etc* do not expect to be deep enough to encounter Roman deposits, the information displayed here has important ramifications for the use of piling as a preservation strategy. While some (*eg* Biddle 1994*a*) argue vehemently of the dangers of piling, others (*eg* Carver 1994) present equally convincing arguments for their value. Further research is clearly required to establish the truth behind these counter–claims, but those responsible for preserving York's heritage should certainly be aware of the potential dangers and the tools at their disposal to mitigate against this risk.

Maps similar to Figure 70 may also be produced for other periods, but the low resolution elevation models for these later periods already mentioned elsewhere produced inconclusive results and have not been included. Further work is required in defining these intermediate periods before such techniques may be effectively extended to encompass them.

Case Study 5: Issues of interface design

A piece of software with the complexity of a GIS such as *Arc/Info* presents a daunting front to the user, and makes it difficult for the non–GIS expert — regardless of their proficiency with the data under analysis — to interact with their data in any meaningful fashion. Despite the recent addition to *Arc/Info* of the *ArcTools* interface, the package remains difficult to comprehend, and many potential beneficiaries are scared away.

A major benefit of the *ArcTools* system is the ability for those with only a moderate degree of *Arc/Info* and programming expertise to produce a set of menus tailored exactly to the needs of a particular project. This flexible approach to interface design allows the core *ArcTools* suite of menus to remain small, prevents an unwelcome prescriptiveness being imposed upon the GIS toolkit by the need to conform with a limited number of set menus, and enables applications to be tailored directly to the needs, data, and GIS–literacy of the target audience.

As the current research never intended to produce a fully functional GIS for use by others, extensive effort was not invested in the design of a user interface, but one small aspect of the GIS' functionality was highlighted as suitable for demonstrating the potential offered by tailored user interfaces. The example selected is that of a borehole simulation (called `Dig_It`) capable of providing a prediction of deposit thickness at any point within the study area. As is demonstrated below, input may be in the form of a grid reference typed in from the keyboard or a point selected on screen using a mouse. All of the scripts used in constructing this example are available in **Appendix D**.

The purpose of this Case Study is specifically *not* to assess the quality of the elevation models, nor to quantify the effectiveness of *Arc/Info* in querying them by means of this tool, but rather to demonstrate the manner in which provision of intuitive interfaces might allow access to difficult or involved GIS capabilities.

The Brief

The aim of this series of scripts is to demonstrate the usefulness of a menu–driven user interface to a specific aspect of the YAA GIS.

- It is assumed that the prospective user requires data relating to the archaeological deposits beneath any given point within the study area, as part of a planning related query or for some other reason

- The user should be able to specify the background information displayed (by selecting from a list of GIS coverages) and the degree of magnification in the display

- The user should be able to specify their point of interest either by entering a grid reference from the keyboard, or by simply pointing to a location on the screen

- `Dig_It` should return information on the heights of each major period surface at the point in question
- Data should be provided to enable the user to judge the precision of any values returned
- Help information should be provided to enable any user with an awareness of the *task* to query a location and return valid answers, regardless of their GIS experience
- The system *need not* be platform– or even account–independent; it is written to run from account `apm9` on the University of York Challenge compute server 'tower'. Assumptions may be made within the code that paths and environment variables are configured as in this account. Were this to develop into a non–experimental utility, these assumptions would be overturned, and account–specific coding would require replacement

Data to be utilised

These coverages are discussed in more depth in **Appendix C**.

- *Arc/Info* TIN elevation models for the Natural (`$DTM/natural`), Roman (`$DTM/roman`), Anglian (`$DTM/anglian`), Anglo–Scandinavian (`$DTM/ascan`), Medieval (`$DTM/medieval`) and Modern (`$DTM/modern`) surfaces of York
- *Arc/Info* coverages for the rivers (`$MODERNYORK/bridges`), streets (`$MODERNYORK/roads`), and major monuments (`$MODERNYORK/landmarks`) of York, as well as the overall 1:1,250 Ordnance Survey York map (`$MODERNYORK/york_map`), the Roman fortress and *colonia* outlines (`$OLDYORK/eboracum`) and York Archaeological Trust site outlines (`$DIGS/yat70`, `$DIGS/yat80` and `$DIGS/yat90`)
- *Arc/Info* grid for an aerial photograph of York (`$MODERNYORK/york_ap`)

The Solution

The solution arrived at is based around an ArcPlot window and a series of popup windows which are called and dismissed by the controlling script as required. Initial startup is by means of a short AML script that initialises display parameters and starts the ArcPlot session. This script is run in the normal *Arc/Info* fashion with `&r $SETTINGS/dig_it`, but could equally easily be offered as an option from a higher level menu within a more wide–reaching user interface. Help is provided throughout the utility in four ways, making it easy to navigate through the options:

- menu and icon titles were selected to be as informative as possible, enabling the user to easily deduce the function of each element of the program. Intuitive icons were used wherever possible to enhance clarity

- the main icon window, `Borehole simulation`, offers an option to examine a help file by clicking on the `Help` button

- a short explanation may be gained for all icons and buttons within the utility simply by pointing at the icon or button in question and clicking on it with *the right–hand mouse button.* Descriptive text will appear at the bottom of the currently active window

- elements of the script requiring text input from the user (such as the manual entry of a grid reference in `x_dep_gref.menu`) have defined tolerances. Should a user enter a spurious grid reference, a warning message is displayed informing them of the acceptable range (defined as the minimum and maximum Eastings and Northings for the project area) and requesting that they try again

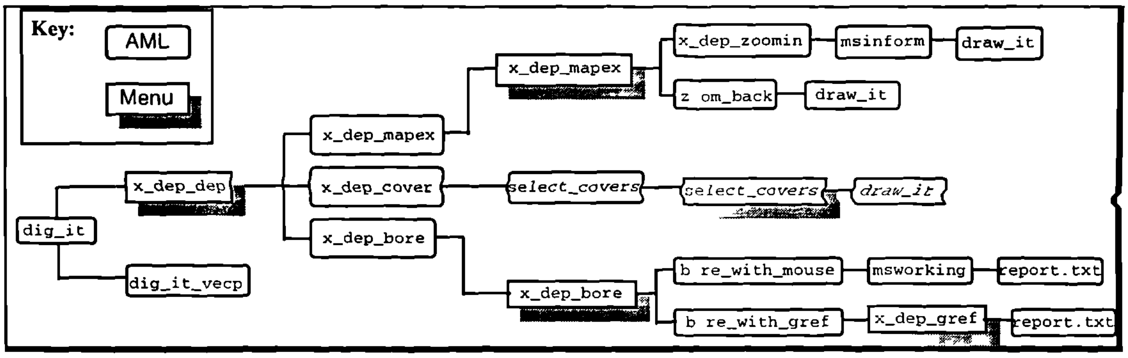


Figure 71: Flow control within the `Dig_It` utility

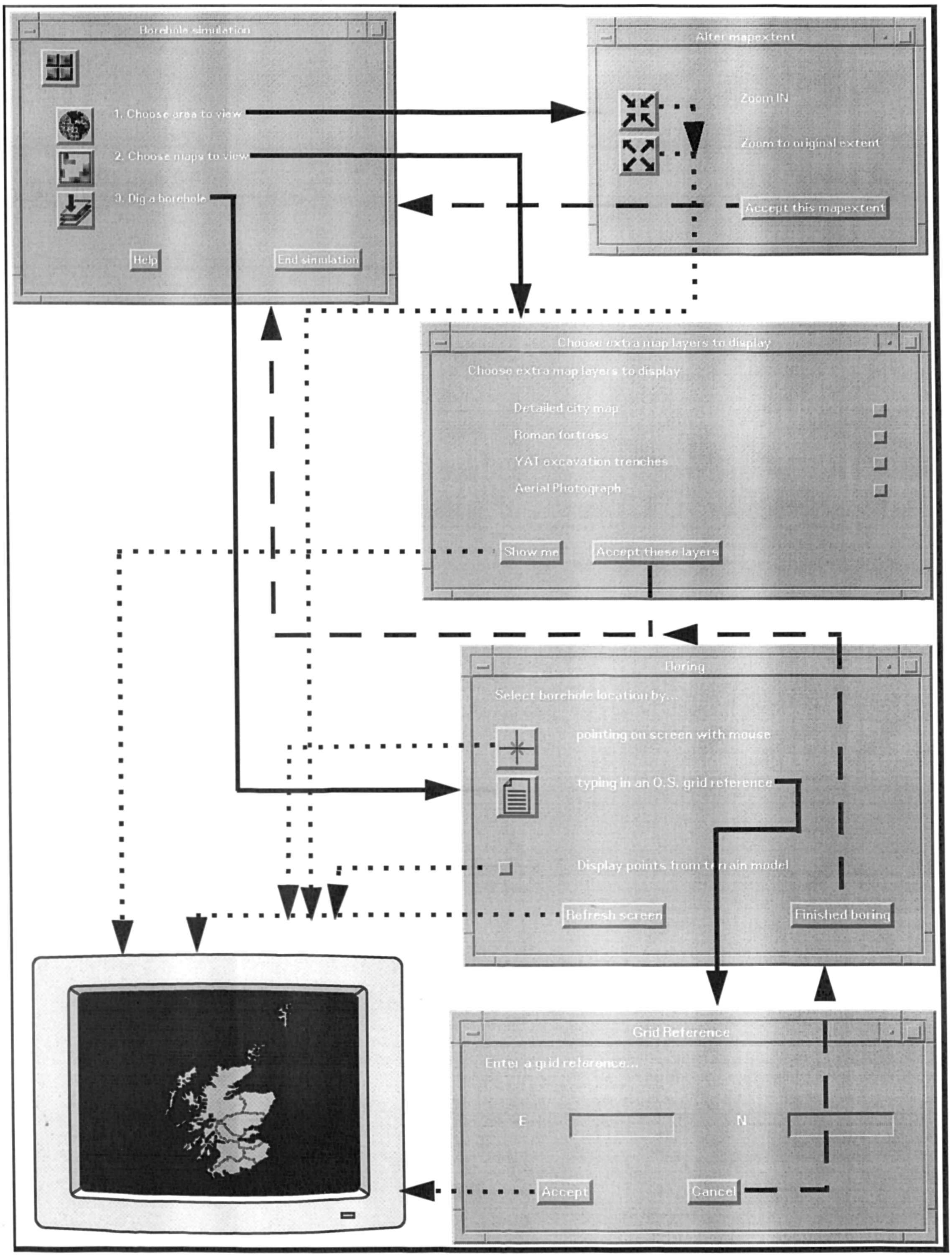


Figure 72: A graphical depiction of flow control between the `Dig_It` menus

`Dig_it.aml` sets the appropriate display parameters, initialises a series of `PATH` statements to enable *Arc/Info* to find the necessary components, launches ArcPlot, spools the programming thread that will track activity within the ArcPlot window independent of events in other windows created by the utility, and then hands control over to a second AML, `dig_it_vecp.aml`, and a menu, `x_dep_dep.menu`, which handles the detailed functioning of the `dig_it` utility proper. Figure 71 illustrates the process of flow control throughout the utility and shows how calls are passed between the associated scripts (`*.aml`) and menus (`*.menu`) as required. This process as it appears to the user is illustrated in Figure 72, where the sequence of menus is presented. Processes indicated as moving to the computer screen allow user interaction with the ArcPlot display window, which initially appears as shown in Figure 73.

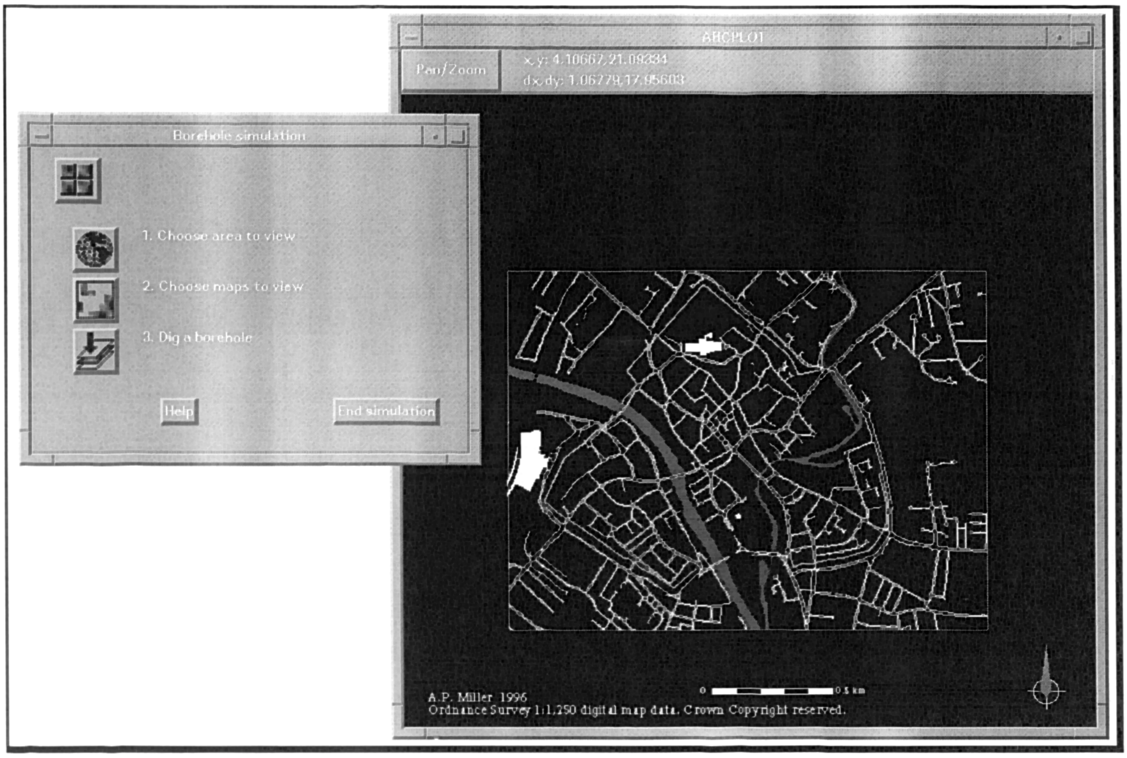


Figure 73: Initial view of `Dig_It`, showing the ArcPlot display window and the main icon window

As shown in Figure 72, the first two icons in `Borehole simulation` enable the user to define exactly what elements of the map they wish to view, but these are merely cosmetic enhancements to the main purpose of the utility, as represented by the third icon which actually allows the gathering of surface information at a specified location.

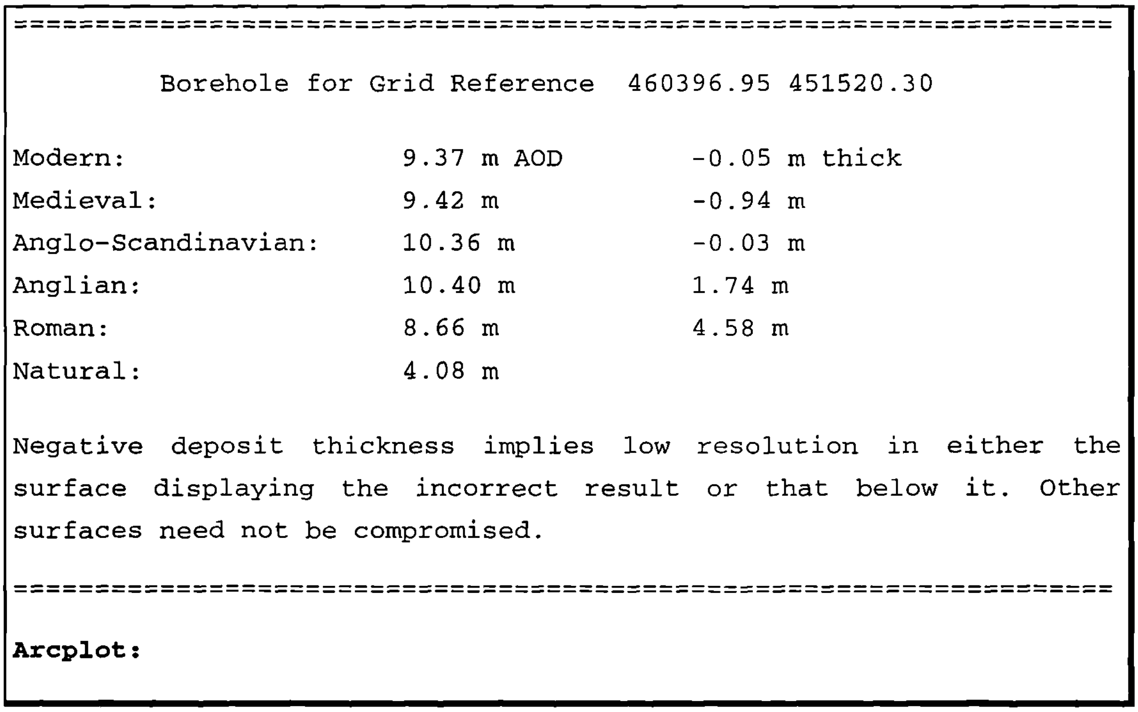
Final output from the utility takes the form of a text–based report (Figure 74) giving the grid reference queried, heights above Ordnance Datum for the Modern, Medieval, Anglo–Scandinavian, Anglian, Roman and Natural surfaces and the deposit thickness for each period. If the 'Display points from terrain model' box was checked in the `Boring` window, all visible data points for each period are also displayed. Assuming that all the displayed data points are of reasonable accuracy, the distribution of data points of any one period around the point of interest allows a crude measure of the likely reliability of that point to be ascertained visually.

Future potential

The application as presented above marked a successful experiment in the provision of an accessible interface to the complexities of *Arc/Info*, albeit only for a small set of GIS functions. In developing any system for use by a number of people of varying GIS competence, the model adopted in this example would have to be followed and expanded upon. A recurrent danger in the creation of user interfaces such as this for a set of ill–defined tasks such as "managing the archaeological resource" is that the interface itself becomes either too prescriptive to be of use, or so all–encompassing that it proves unwieldy. An effective route to follow may be towards a modular solution, where a series of tools such as `Dig_It` are created to fulfil a set of closely defined tasks, thus avoiding the all–encompassing behemoth interface. In order to avoid accusations of over–prescriptiveness, the obvious solution is to provide easy access out of the interface and down to the raw power of the `Arc:` prompt underneath; this suggestion of course assumes that those maintaining the system have a degree of *Arc/Info* competence capable of negotiating command–line *Arc/Info*, even if all of their users do not.

With ongoing enhancements to *Arc/Info*'s cut–down desktop mapping counterpart, *ArcView* (Maguire *pers comm*, **Chapter 6**), it is likely that provision for handling elevation data such as is required for the `Dig_It` module will not be long in coming. Once this functionality is available within *ArcView*, the power of *ArcView*'s Avenue scripting language makes this package an obvious choice for the continued development of a usable interface to the power of the *Arc/Info* GIS which may safely be hidden underneath.

An application of this simplicity is well suited to provision within a distributed environment, or even across a medium such as the World Wide Web (Putz 1994, McCauley *et al* 1996). Assuming that a valid need could be identified for allowing access to this limited subset of information, users at remote sites could be offered access to a web–specific version of the menus, with queries carried out on the host machine running *Arc/Info* and results returned to the browser on the remote machine. It is, however, questionable as to why a remote user would wish to query deposit depths within the city of York without recourse to the GIS database as a whole, and the enabling of a fully fledged Web GIS is still some years in the future (Thoen 1995).



```
==================================================================

         Borehole for Grid Reference  460396.95 451520.30

Modern:                 9.37 m AOD         -0.05 m thick
Medieval:               9.42 m             -0.94 m
Anglo-Scandinavian:     10.36 m            -0.03 m
Anglian:                10.40 m            1.74 m
Roman:                  8.66 m             4.58 m
Natural:                4.08 m

Negative  deposit  thickness  implies  low  resolution  in  either  the
surface  displaying  the  incorrect  result  or  that  below  it.  Other
surfaces need not be compromised.

==================================================================

Arcplot:
```

Figure 74: Example deposit report from `Dig_It`

6. Applying GIS: issues to consider

> The gold rush is on. The hypermedia are happening. Whatever you call it, here come interactive graphics, text, video, all somehow user–chosen. But how will they tie together? If producers knew where all this was going, the rush would rival the advent of the Talkies. Meanwhile, each manufacturer says its gizmo will be the centrepiece of the hypermedia gold rush.
> (Nelson 1992; 157)

Although jointly sponsored by a government research council and an 'industrial' partner — York Archaeological Trust — this thesis presents the results of a body of *research* rather than any concerted effort to implement a working system for everyday use in real situations. The freedom afforded by undertaking research is, of course, of great value in the development of new ideas and techniques as the researcher is enabled to experiment and to evolve solutions in ways unlikely to be possible in a commercial environment.

Based upon the experiences gained while working on this thesis, and with the dramatic increases in GIS power and ease of use, it is likely that a working implementation could be developed for a city such as York relatively quickly, and designed in such a way that extensibility was assured and other practitioners could make worthwhile use of the system. As illustrated repeatedly throughout this thesis, developments both in the power and flexibility of computer systems, and growing talent in using these tools amongst the archaeological community are such that the major impediment to wider implementation remains the existing mass of archaeological data, many of which are simply too crude to be usefully implemented within a computerised system normally created — outside archaeology — to aid in making decisions based upon thousands or even millions of extremely accurate pieces of data.

The sections below outline some of the issues involved in implementing such a system within archaeology, and the final section (see page 209) considers a model of the ideal circumstances under which such a system would be developed. While current political and financial considerations make the achievement of such a goal unlikely in the near future, the provision of the model here offers those implementing any similar system a series of targets towards which they may aspire. The time of the truly integrated GIS cannot be far off for many more years.

Urban archaeological databases

Since the publication of *Managing the Urban Archaeological Resource* (English Heritage 1992), a number of English towns and cities have begun the task of compiling details of the archaeological resource for which they are responsible. Although most of these projects are doing little more than applying the techniques of the rural Sites and Monuments Record to an urban landscape, a few (*eg* Heslop 1992) are recognising the importance of the urbanocentric techniques propounded by the Ove Arup study (Ove Arup 1991) and further developed here.

In implementing an urban archaeological database in a GIS environment, the model outlined by English Heritage and the Royal Commission (English Heritage & RCHME 1993*a*, 1993*b*) is flawed in several respects and would require a degree of modification bringing it closer to the model adopted within this thesis. Several of the flaws within the English Heritage/ RCHME approach to urban databases are outlined in **Chapter 4**, but the major obstacles to GIS implementation will be briefly re-examined — or introduced — here.

GIS unfriendly

Despite the claim that

> The UAD consists of a text suitable for computerisation with maps and overlays capable of being converted to GIS, forming an integrated system,
> (English Heritage & RCHME 1993*a*; 3)

the design considerations outlined below are, in fact, major and would have a significant impact upon the implementation of a GIS–based model of the UAD specification. Notwithstanding the well understood difficulties of computerising large disparate datasets, the design concepts behind the UAD make GIS implementation especially difficult.

Database structure

As outlined elsewhere (page 74), the most effective form in which to implement the database element of a GIS is through a series of linked modules — a *relational* database. Although based upon an Event file and a Monument file, the UAD structure is essentially flat–file in nature, and is replete with unnecessary and error prone duplication of fields.

Whilst not necessarily ideal for every archaeological application, the structural concepts enshrined in the database presented in Figure 14 are closer to the ideal GIS database, allowing complex interrelationships, low levels of data duplication and easy extensibility.

The agencies responsible recognise the need to avoid an explosion in software packages and data recording methodologies, going so far as to state that

> In the 1990s a joint RCHME and EH initiative will create upwards of 30 urban databases, effectively SMRs for major historic towns hitherto poorly covered in existing county based records. Databases for six towns have already been created. We recommend that these urban databases should wherever possible be linked to existing SMRs but at the same time utilise the new RCHME software package for SMRs, so as to avoid the proliferation of different record systems and to serve as a means by which the national record can be readily updated.
> (RCHME 1993)

The problems resulting from the chaotic growth of SMRs during the late 1970's and 1980's have obviously, therefore, been recognised, and English Heritage and the Royal Commission clearly wish to control the erratic spread of differing software and data collection methodologies. In principle, an element of central control is valuable in ensuring that each local record is capable of making a valid contribution to the national archive, but the poorly considered system of recording proposed by English Heritage and RCHME surely suggests impending problems on a scale greater than those caused by the adoption of the *last* set of ill–considered software and recording techniques suggested by a responsible national agency.

In setting a standard for the recording of urban areas, those defining the standard have a great opportunity to advance archaeological recording by assuming GIS–based implementation from the outset, and forming their standard accordingly. Perhaps more importantly, in preparing the model for recording urban areas throughout England, there is the opportunity to invite comment from leading researchers in urban archaeology in order to attempt a definition of urbanism and the future of urban archaeological research. These important opportunities have been missed, and there is the serious danger that, rather than promoting advancement, the UAD proposal will consign urban databases to outdated technology, suspect methodology, and a widening gulf between the increasingly outmoded archaeologists and forward–looking local authority planning departments where GIS and other developments are increasingly to be found.

Topological issues

The manner in which spatial entities are represented within GIS databases is not a new problem, nor one solely affecting the UAD. However, the twin suggestions that an SMR–style model should be adopted and that GIS implementation is an afterthought rather than integrated from project inception suggest both that the problem has not been considered and that resolving it in any eventual GIS will be extremely difficult due to this lack of foresight.

Most archaeological locations of interest are not single points of negligible extent, yet they are frequently represented as either a single grid reference in a database or a single point on a map, neither of which adequately describe a complex entity, and both of which assign the same apparent spatial extent to a single coin find as to a major monument like Maiden Castle. In implementing a database driven UAD complemented by paper maps, it is necessary to either record features as a single point within the database linked to a shape drawn by hand on a paper map, or else to utilise a complex series of database fields to define the feature shape in some way. Within a GIS implementation, this problem is overcome as the database record is directly associated with a digitally stored shape with respect to a digital map. Other problems arise in attempting to define the physical extent of a 'site' (Chartrand & Miller 1994), but these are being addressed by archaeological practitioners on a number of fronts, and are not restricted to GIS implementation.

Conflicting approaches

The arguments presented throughout this thesis in favour of the component based *polis* approach — and against the event and monument model proposed by the English national agencies — are not directly related to any discussion of applying GIS to a UAD–style problem. Rather, they represent a fundamental difference in the manner in which urban space should be considered.

Given adequate resolution of the problems raised above, either technique could be utilised in developing a GIS solution, and both would probably work to varying degrees. The *polis* approach advocated here, however, encourages a more reflective consideration of what the clustered interventions, events and monuments actually *mean*; they are part of a whole, an urban space, and together they are far more important than the sum of their parts. Accepting the *polis* concept encourages the archaeologist towards a coherent view of the evidence, and makes it difficult to fall into the trap of considering individual excavations or other data sources in isolation, rather than as part of a complex and evolving organism that may be recognised and studied at a variety of levels throughout its existence(s).

Within this research, the project database (**Chapter 4**) was constructed — within the limitations of the data from which it was derived — to avoid the creation of artificial 'monument' groupings. Rather, data were grouped solely according to the excavations from which they were captured, and sufficient flexibility was built into the database model that the data could then be studied and combined in a variety of very different ways according to *research* needs. Experiments such as Case Study 2 maximised the benefits of such an approach, and — problems with data notwithstanding — explored a unit of space across time, rather than being trapped into a temporally discrete monument–based approach which would have directed the research more towards consideration of a discrete Roman fortress, a post–Roman *something* (possibly undefineable in a monument–based view of the area), and an Anglian Minster. Other Case Studies, too, explored an entire area of urban space, rather than a varying number of interventions or monuments *within* that space, allowing the possibility of identifying pattern, process and change, free of artificial distinctions imposed by the modern researcher.

GIS developments

The field of Geographic Information Systems continues to develop rapidly, with improvements in established techniques as well as the development of new areas of integration between GIS and related technologies. Over the years of this research, the rapid development within the core product used, *Arc/Info*, has superseded many of the early products of the YAA, especially in the areas of data import and presentation. The complex routines developed at York to import data from a PC database, for example, were superseded by a single command, `dbaseinfo`, in a recent release of *Arc/Info*. As a result, much of the early development work has been bypassed by developments within the industry, and new GIS projects are luckily faced with a far simpler task than that facing those starting out early in the 1990's or before.

Many of these developments are clearly visible in the literature, and some of the most important to archaeology are outlined below.

GIS on the desktop

Microsoft

With the release of *Excel* 7 and *Autoroute Express* 4 (Microsoft Corp. publicity 1995), the huge Microsoft Corporation entered the arena of spatial information presentation with as yet uncertain implications for the rest of the industry.

The current (Spring 1996) Microsoft offerings bring basic mapping functions to their leading spreadsheet product, and increase the distribution of the *Autoroute* routefinding program recently purchased with the UK company, Nextbase. Functions within *Excel* are licensed from Mapinfo Corporation's flagship product, *MapInfo*, and offer the spreadsheet user the ability to display data geographically on top of base maps provided within the software. While functionality is currently limited and *Excel* is certainly not a GIS, with the release of these two products Microsoft has clearly stated an interest in spatial information and more comprehensive products can no doubt be expected soon.

Desktop GIS

Microsoft is not the only company offering accessible desktop products capable of analysing and presenting spatial information and, indeed, the other offerings in this field are more powerful and flexible than the programs offered by Microsoft. Microsoft, however, has the capital and marketing power to make a significant impact in this area, and GIS vendors would do well to learn from the misfortunes of large companies in other areas of computer software where Microsoft took an interest and rapidly gained ascendancy.

GIS products have traditionally run on large and expensive Unix workstations. The software has been large, complex, and expensive and often based around proprietary formats for data and output. Packages such as these still exist and have an important role to play in managing large and complex databases, but enabling non–GIS professionals to manipulate geographic data is becoming increasingly important and has led to the evolution of new, desktop, GIS tools. While a large local authority or national archaeological body will undoubtedly have need of a traditional large GIS, these will be maintained by a team of highly qualified and specialised support staff. Until recently it has been difficult to enable other members of an organisation to access the stored data without designing comprehensive user interfaces to disguise the underlying complexities from them. Even with such an interface, it is often difficult for the casual user to extract data from the system in such a way that it may be integrated with their other computer tools such as spreadsheets, word processors, and database packages, all of which will normally be running in a PC rather than workstation environment.

The advent of desktop GIS systems such as *ArcView* and *MapInfo*, whilst not offering the user the functionality of a larger system, enables anyone with a basic awareness of mapping or database systems to query and map data from a large — and potentially distant — GIS database. In implementing these systems, a major danger is that dubious or misleading mapping may be produced as easily as meaningful output, and with large numbers of people having access to the technology, the probability of chance or malicious misuse of map data is high. Implementation of good working practices and the introduction of 'rules' (Miller 1995*c*) will go a long way towards alleviating these risks, but effort is perhaps required in training users and viewers alike to view map–based output with more caution than they do at present. The assumption that maps cannot lie must be overturned to enable us all to make better use of this valuable tool.

The potential benefits to archaeology if everyone were to have easy on-line access to GIS information through an interface such as *Windows* which they use in their everyday work are enormous. The benefits increase with the Microsoft assertion (Microsoft publicity material 1995) that maps are to be included as core components of the OLE specification, enabling seamless integration within a larger suite. In effect, clicking on a map on screen could launch a graphics program to illustrate an artefact, start a wordprocessor to display a report, or open a statistical program to allow analysis of an assemblage, all from the same familiar environment.

Usability

> Part science and part traditional art, making a good map is like making a good wine, produced by a few experts for the benefit of all. The GIS product, by contrast, is more like what comes out of a kit for do–it–yourself chemistry experiments: it can be tailored to one's desires, it is endlessly varied, often surprising, frequently hard to understand, sometimes insidiously lethal, and the (amateur) maker and (naive) user are often one and the same.
> (Couclelis 1992; 6)

At the same time as developments in desktop GIS, with all the usability associated with the *Windows* and Macintosh interfaces, the larger Unix–based GIS have also been gaining in usability. Whether the threat from Microsoft has worried the big GIS developers enough to force this frenetic drive towards usability or, perhaps more likely, the HCI side of GIS has finally caught up with the rapid expansion in system functions and complexity (Medyckyj–Scott & Hearnshaw 1993, Green & Rix 1995), the daunting command line interface of packages such as *Arc/Info* is finally being supplemented by usable graphical user interfaces, and powerful tools are being provided to allow developers to add to these with mission specific menus such as those demonstrated in **Case Study 5**.

Increased usability raises the same issues as those raised by the advent of desktop GIS; namely increased access to data for all at the same time as an increased danger of improper use of mapping. It remains worrying that a modern GIS can be so easy to use that *anyone* is potentially capable of producing a map and that, without expertise *and* access to the original data, no one has a chance of being able to tell whether the final map is a meaningful representation of those data or not. Perhaps developers should now delay development of even friendlier GIS', and turn their efforts towards implementing rule bases (Miller 1995*c*) within their presentation modules in order to curtail the worst excesses of 'mapitis'. Similar problems arose with the widespread adoption of the word processor and laser printer in the 1980s, as users became free of the skilled professional typesetter and were able to use whatever fonts they pleased. This 'fontitis' resulted in a spate of typographically appalling documents, littered with different fonts and poor layouts. Although a badly laid out page is of course more visible than a badly analysed dataset presented in map form, the problems with fonts gradually receded as users became bored with experimenting, and as — through experience — they began to recognise the problems themselves. With training and patience, perhaps the same will one day be true with maps.

Developing standards

For many years, GIS developers have produced largely proprietary products, often relying upon custom data formats and making use of bespoke interfaces. The picture of these disparate and competing products is now beginning to change, with the development of standards for storage and exchange of data (Miller 1996*a*, Rowley 1994, 1995, Walker 1995) and the efforts of the Open GIS Consortium (Aybet 1995, Glover 1995) beginning to bring existing products closer together.

National, European & International Standards

A large number of standards documents relate to GIS work (Green *et al* 1995; 322–323) in some manner, from the International Standards Organisation's ISO 8859 relating to graphical character sets to the more obviously relevant British Standards Institute's BS 7666 defining geographical referencing in spatial datasets.

Perhaps the most important of these standards are two which are currently incomplete; one from Europe and one an international standard. These two, along with the others already in place, are extremely important in enabling system developers, data providers and end users to more easily gather, use, and share data within a distributed environment. With archaeological GIS users often making use of systems actually bought for another purpose within organisations such as local authorities, it becomes especially important that certain standards are in place to ensure that the important archaeological information may be moved around without complication. Indeed, archaeological bodies such as the Royal Commissions and Institute of Field Archaeologists should be making their case to CEN, ISO and the AGI to ensure that data issues of importance to archaeology are considered at this stage.

The European standards body, Comité Européen de Normalisation (CEN), established a technical committee (TC 287) in 1992 to investigate standards in geographic information, with a mandate to look beyond the traditional issues of data transfer towards problems with data description, referencing and processing (Walker 1995; 1.20.1).

The developing European standard, CEN/ TC287, takes a different approach to the International ISO/ TC211 (Geographic Information (Geomatics) Standards) set up in 1994. The ISO group at present appears to take more of an interest in issues of data transfer than the European group.

The specific details of these, and other, standards are not important to the end user of GIS. The important issue is that standards are being developed, and that the user is therefore able to look forward to being able to reliably use data in a GIS system that could have come from another very different system.

Open GIS

Related to the development of standards is the work of the Open GIS Consortium in bringing independent GIS products closer together. OGIS can be defined as the need to

> specify technology that will result in the ability of an application developer to use any geospatial data and any geospatial function or process available on 'the net' within a single environment and a single work flow
> (Glover 1995; 1.23.2)

A development such as OGIS holds great potential for the user of GIS within a wider integrated environment, and will be important in any serious movement of GIS functionality towards the desktop. The findings of OGIS committees will contribute to the workings of ISO/ TC211, and will therefore be integrated within the developing international standard.

New data

New and better data are being released onto the market all the time, and accessibility is increasing to long established data which are now entering the public domain and being freely shared across the Internet. Even with commercial data such as those from the Ordnance Survey, Service Level Agreements with Local Authorities mean that archaeological units attached to local government have access to digital Ordnance Survey data for their region. Talks underway at the end of 1995 suggest that JISC and the Ordnance Survey may be about to reach a similar agreement with universities, although there are issues of unfair competition between commerce and academia to resolve. Commercial units will, unfortunately, be required to continue paying the standard prices for Ordnance Survey data.

The data on offer are of increasing quality, with the topological problems involved in using the Ordnance Survey data for York (Figure 12) largely overcome with more recent releases of map data such as the topological OS93 data structure (Wesley *et al* 1995). The National Topographic Database (Nanson *et al* 1995, Rhind 1995, Wesley *et al* 1995) promises increased flexibility and integration between the current suite of Ordnance Survey mapping products.

Remote Sensing data continue to become increasingly widely available, with the major satellite sources (NRSC 1995) used in a growing number of archaeological landscape projects. The release of high resolution Russian imagery, along with the Shuttle Imaging Radar (SIR) carried by NASA's space shuttle (Freeman 1995) mean that spaceborne imagery is beginning to be of more than merely cosmetic value to projects of smaller geographic extent. The tools to manipulate these data are also more available than ever, and leading products such as ERDAS' *Imagine* are closely tied to the more powerful GIS systems enabling easy integration of imagery with GIS databases.

Archaeological data, too, are becoming increasingly amenable to insertion into computer–based systems such as GIS. Survey data are increasingly captured digitally with consistent — and quantifiable — precision, and excavations, too, are computerised to a greater degree, both in the field and during the post–excavation process. Importantly, the potential offered by computerisation is also leading to a gradual re–think of the types of information recorded, and the uses to which they might be put. Even in older Sites & Monuments Records, for example, where elderly equipment and procedures prevent the recording of sites as *polygons* rather than area–less *points*, there is an increasing recognition of the need to consider the archaeological record as truly spatial and multi–dimensional. In more advanced applications, (*e.g.* Foard *pers comm*, Murray *pers comm*), it is becoming routine for modern survey data to be fed into centralised computer systems in such a way as to maximise the benefit gained from these data. Indeed, effort is now being directed more towards the practical problems of integrating these largely excellent data with the less flexible older records, rather than considering the potentials likely to be offered by high quality data in the abstract.

New dimensions

Perhaps the most exciting developments at present are those which extend GIS dimensionality and narrow the gap between true GIS and ViSC products, bringing analytical power closer to visualising power to the betterment of both areas of study.

In a field such as deposit studies, major constraints are placed upon the potential of GIS solutions by the problems inherent in displaying several variables in a multidimensional space by means of a two dimensional display medium such as paper or the traditional CRT.

> 'What a useful thing a pocket map is!' I remarked.
>
> 'That's another thing we've learned from your Nation', said Mein Herr, 'map making! But we've carried it much further than you. What do you consider the largest map that would be really useful?'
>
> 'About six inches to the mile.'
>
> 'Only six inches!' exclaimed Mein Herr. 'We very soon got to six yards to the mile. Then we tried one hundred yards to the mile. And then came the grandest

> idea of them all! We actually made a map of the country on the scale of a mile to a mile.'
>
> 'Have you used it much?' I enquired.
>
> 'It has never been spread out yet', said Mein Herr: 'the farmers objected: they said it would cover the whole country and shut out the sunlight! So now we use the country itself, as its own map, and I assure you *it does nearly as well.*'
> (Carrol 1894; 616–7, emphasis added)

A map, no matter the medium used in its display, is in essence an abstraction of reality. At the most blatant, this abstraction involves the cartographer in making decisions about what elements of reality are to be omitted and how complex features such as topographical variation are to be represented. More subtly, decisions are made about the symbology to be used in representing different features and the result may well influence the manner in which a viewer conceptualises the represented reality. In mapping threespace to flatland, many features are exaggerated in order to make them more visible on the map, either to emphasise their importance or to render that which would be invisible at any scale other than the extremely large visible at smaller scales. These techniques are most often applied to linear features such as roads and railways, where the feature width would render it almost invisible at normal mapping scales of between 1:50,000 and 1:250,000. In a similar vein, linear features are often displaced from their true position in order to accommodate these alterations in feature width. Roads, railways, boundaries and water features often run close together following contours of the natural topography and with their width increased by the cartographer, these features often overlap or obscure one another upon the map. Common cartographic practice therefore endorses the moving of such features in order to allow the production of clearer and less cluttered maps.

These, and other, techniques are a necessary part of the cartographic toolkit invoked in the representation of single surfaces. Abstraction techniques of greater complexity are therefore likely to be required in the coherent visualization of volumetric spaces such as the deposits lying beneath towns and cities. Providing that sufficient metadata procedures are implemented to record the ways in which abstractions are applied to reality — as often *fails* to occur with the techniques discussed above — these new techniques should not be viewed as distortions but rather as the means by which current technologies may allow the human brain to grasp the inherent complexities of multidimensional space; a task for which the majority of modern technologies and methodologies are poorly suited.

In contemplating visualization of subsurface remains, archaeology is moving closer to the state of the art research into visualization of extra–terrestrial data at centres such as NASA's Jet Propulsion Lab in Pasadena or the conceptual and perceptual thinking of MIT's Media Lab, British Telecom's Martlesham lab, or Hewlett Packard's UK research centre than to its more traditional partners of history, anthropology and geography.

Whilst a system such as that described on page 208, below, remains little more than an experimental concept in the most advanced of research centres, technology has advanced to such a degree that steps can be made in the correct direction, given only the investment of time, equipment, and suitable staff.

Similarly, the conceptual frameworks for working in many dimensions are taking shape, with mathematics providing the language of *n*–space and a host of disciplines defining the parameters within which work can proceed.

Although no one product yet exists to fulfil the requirements of a true deposit modelling system, recent developments from a number of companies and groups point to the potential building for the creation of such a system.

VirtualGIS *from ERDAS*

Announced late in 1995, and currently only available on well specified Silicon Graphics workstations, ERDAS' latest addition to their *Imagine* image processing suite adds a degree of three–dimensional functionality to their flexible product (ERDAS promotional material 1995, Wells *pers comm*).

The current release of ERDAS *Imagine* to UK universities, 8.2, includes the Perspective module which allows users to drape any *Imagine* layers over an elevation model and view the result from any angle. With *VirtualGIS*, this functionality is extended to allow the *interactive analysis* of the draped layers within the Perspective module itself. In effect, almost any *Imagine* function may be accessed and viewed on a perspective view rather than in plan. Routines also exist for the easy generation of fly–throughs of the terrain, of great value in presentation of results.

Regions from ESRI

A traditional difficulty within GIS has been the resolution of overlapping boundaries within objects of a single class. Normally, objects of a single class (national borders, for example) are stored in a single coverage and are assumed to be discrete; each nation has a single, clearly defined, boundary without overlaps or gaps.

Such a data model creates problems in the description of real world objects where the assumptions above are found not to be true, and the Region concept from ESRI is one of the ways in which applications vendors are attempting to provide solutions.

According to *Arc/Info*'s online help system, ArcDoc, regions may be considered as:

> **Overlapping polygons** — many features overlap, such as the habitat areas for wildlife species, and lease data for the oil and gas industry.
>
> **Nonplanar features** — data may occur in different 'planes', for example, soil data may be collected for various soil depths.
>
> **Area feature/ complex objects** — footprints of buildings with a common address may be considered as one feature.
>
> Regions' ability to handle overlapping, noncontiguous and nested areas makes real–world features easier to represent and analyze. Data management is more efficient, as each region only requires one attribute record.
> (ESRI 1995; entry 'Introduction to regions')

In the past, the only GIS solutions to overlapping polygons have involved using separate coverages for each polygon (the thematic layer approach) or else storing polygon 'A', polygon 'B' and the intersection of 'A' with 'B', 'C', as three separate polygons in the same coverage. Neither of these approaches have proved altogether effective and the Region model has been put forward as an alternative.

Although only a new addition to the generic *Arc/Info* data model, and topologically difficult to understand at first, the Regions approach may well prove a valid step towards the manipulation of overlapping or fuzzy real–world objects within a primarily non–fuzzy computer paradigm.

VRML

The World Wide Web has developed at a phenomenal rate since its creation at CERN (Conseil Européen pour la Recherche Nucléaire, in Geneva) in 1989, and use of the Web for distributing information of all forms is now common practice around the world.

Efforts have been applied to distributing geographic data via the Web in an interactive manner (*eg* Massam 1995), but these efforts have so far fallen short of providing effective interaction between a GIS server and remote client (user). The level of interaction with a GIS across the Web is limited at present, due to limitations in a number of areas including bandwidth, the Hypertext Transfer Protocol (http) used by the Web, and GIS themselves.

Perhaps the best known application at present is Xerox PARC's (Palo Alto Research Center, in Palo Alto, California) Map Server (Putz 1994), which allows the user to select an area of the globe to zoom in on. The system offers several levels of map complexity for certain areas of the world, allowing the user to add and remove features such as hydrology and US State boundaries.

Related to the development of Web–based GIS is the rapid development of another Web innovation, the Virtual Reality Modelling Language (VRML). This developing concept allows the creation, distribution and manipulation of three dimensional 'worlds' across the Internet, and has great potential for the dissemination of multi–dimensional information. Linked with the parallel developments in Web–based GIS, the developing VRML standard (Bell *et al* 1995, Silicon Graphics *et al* 1996) offers potential for models similar to those within ERDAS' *VirtualGIS* (ERDAS promotional material 1995) being available across the Internet, albeit with far less interaction and speed than afforded from a highly specified local workstation.

Among the best implementations of VRML is the work underway at the University of Bath's Centre for Advanced Studies in Architecture (CASA). Already well known for their complex computer models of buildings — and even all of Bath — CASA are currently involved in bringing the interactivity of VRML to their three dimensional models (Bourdakis 1995) and are investigating the GIS–style linking of basic data to the building objects within certain models (Bourdakis *pers comm*).

British Telecom are also involved in using VRML and related technologies in visualization of complex data (British Telecom 1996). In many ways, their innovative representations of the telecommunications network (Walker 1995) are of more relevance to deposit visualization than the renderings of real–world objects produced by CASA. In both deposit and network visualization, the researcher is dealing in many cases with intangibles, and with rendering the invisible and complex visible and comprehensible.

Integrating GIS with ViSC...

An increasing number of applications are appearing in the ViSC field capable of tackling elements of the visualization requirements of urban archaeology, but these applications universally lack the data handling aspects of good GIS systems. In order to analyse *and* visualize complex data, it will be necessary for the fields of ViSC and GIS to move closer together. As discussed by Hearnshaw & Unwin (1994), this integration is beginning to occur.

Implementation

In actually implementing a GIS solution, the product eventually purchased from the GIS vendor is often far from the most important element of the final system (Cassettari & Lawrence 1995, Huxhold & Levinsohn 1995).

Fitness for purpose

The sections below examine the important elements making up any effective Geographic Information *System*. In all of these, fitness for purpose should be borne in mind, as even data of the highest quality are of little use to a project if they do not refer to objects of interest in the same way as other elements of a project. In the same way as high quality deposits in **Chapter 2** could be seen to occasionally be of low value, all of the sections below depend upon the item under consideration being fit for the purpose it is intended to fulfil. It is important in GIS applications to identify user requirements at an early stage and to have a good idea of what is *required* before talking to data suppliers and other interested parties.

Data

Good data are vital to effective use of GIS, as are the means by which data may be referenced and categorised. In many cases, such as the construction of excavation phase models in three dimensions, the technology exists to allow the creation of imagery for which suitable data are not yet widely available. The elevation data collected on UK excavations, for example, are rarely suitable for the generation of surfaces at the context level of resolution but, rather, are capable of little more than contributing to the generation of more generalised models over larger areas. Despite this, volumetric software packages exist capable of generating soil volumes for contexts and, worryingly, generalising the jagged edges of such a surface so as to render a more realistic — and apparently accurate — impression.

Metadata should form an important element of any modern database, recording information such as the date and resolution of original data capture, the types of transformation performed upon the original to result in the current data set *etc*.

To be effectively utilised within computer–based analytical tools, both the quality and resolution of archaeological data require greater precision and consistency. As discussed in **Chapter 2**, and demonstrated in **Chapter 5**'s Case Study 2, the regular use of loose, constraining, temporal labels such as 'Roman' or '4th Century AD' prevents the discovery and representation of underlying trends within data; these labels may well be effectively meaningless with respect to many of the trends under study, yet their presence within the data set often prevents the researcher from gaining access to the true patterns. Therefore, temporal data should be gathered — and stored — to the highest possible level of precision, and generalised *later* if necessary.

Spatial data, too, are occasionally subject to such generalisation, although less so with modern data, where *x*, *y* and *z* locations are increasingly recorded with sub–centimetre precision. Nevertheless, as **Chapter 5**'s Case Study 3 demonstrates, even precise spatial data are rendered less useful to computer–based analyses due to their patchy and erratic coverage across archaeological sites. Whilst current levels of recording — such as that seen at Swinegate in Case Study 3 — are more than adequate for providing deposit information to a city–wide model, aiding in the post excavation stratigraphic analysis and publication of a site, and even facilitating the creation of artistic representations of on–site topography, they remain far from adequate for computer–based topographic modelling at the intra–site level. Should such intra–site analysis prove desirable, a greater number of elevations will need to be captured, and in a far more systematic fashion than undertaken presently.

The quality of data commercially available, and relevant to archaeologists, is improving greatly. An important aspect of data sets based upon *polygons* — such as a street map of modern York — is topology. As discussed in **Chapter 4**, the mass of lines making up the streets, buildings and property boundaries of York are only given form with the addition of topology, enabling both computer and user to identify, select and manipulate recognisable *features* (a building, for example) made up from several lines. At the start of this project, truly topological data were unavailable from Ordnance Survey for the study area, and significant amounts of time were expended (see **Chapter 4**) in cleaning up just one of the 12 Ordnance Survey tiles used in this research. Once cleaned, it became possible to identify — and extract — individual features or groups of features, such as the Listed Buildings illustrated in Figure 31. Ordnance Survey's data for the city are now claimed to be fully topological, which should make such tasks much simpler in future. Similar issues, however, are still worth considering with respect to archaeological data themselves. The site outlines provided by York Archaeological Trust required similar cleaning to the Ordnance Survey map tile before it became possible to have the computer identify and manipulate the trenches of individual excavations. Data based upon *polygons* (such as the outline of an excavation trench or survey area) are generally more useful in the long term than a data set based upon *points* (where two excavation trenches would each be represented by a single dot on a map, regardless of their shape or size), but there is an implied overhead in terms of the cleaning required in order to turn the surveyed *lines* into a set of topological *polygons*.

Staff

Good staff are central to the implementation of an effective system, and require a grounding in both the technological aspects of GIS and the methodological concepts, as well as possessing a knowledge of the subject matter for which the GIS is being developed.

Technology

The technological ramifications of effective GIS are great, with GIS on any platform often requiring greater resources than most other applications. GIS are often implemented within existing computing environments and the false economy of having highly qualified and expensive staff wasting time waiting for overloaded computers or having to share scarce resources is rarely spotted until it is too late. GIS requires a large investment in equipment capable of inputting, correcting, storing, manipulating and outputting complex data models, and this investment should be identified at an early stage. The frequent attempts within Local Authorities and archaeological units to start small with a PC package and grow later as needs dictate are usually dogged by trouble as their requirements rapidly outgrow their equipment and transferring to new hardware or software proves more difficult than anticipated.

Systems Integration

Perhaps the most important issue in implementing GIS is that of systems integration. The undoubted power of a GIS is greatly increased when directly interfaced to other systems running within an organisation in such a way that departments and individuals have access to all the information relevant to completion of their tasks in a coherent and near–seamless fashion.

The Manx government's MANNGIS system (Lowe & Hilder 1995) is an excellent example of an integrated solution, where data from throughout the Manx government are stored, and referenced by means of the unique land parcel code by which every land parcel on the island is identified. Such a system represents the target to which British initiatives such as BS 7666 aspire. With an archaeological system already in place on the island (Robinson 1993) using the same GIS and the same locational system, direct integration of archaeology with the rest of the Manx government's role will not be far away.

Towards Xanadu...

Imagine, if you will, the following scene. Although not possible with today's widely available technologies, the scenario builds upon currently available systems and the results of research already underway. A vision such as this may not be as far away as many would imagine...

...the archaeologist sits at his desk, wearing a VR helmet and data glove. With a wave of his hand, the room appears to fade away and he hovers high above York, looking down upon the Minster and the busy city streets.

Clenching his fist causes a control panel to appear hovering in the air in front of him, from which the GIS subsystem is accessed to run a program. The view shimmers slightly and the rivers appear to rise out of their beds to move up the banks and through the streets. A soft computer-generated voice can be heard, "Flood of February 1997, based upon EA logs and ESA IR imagery, 3/2/97. Original data available, plus supplemental press reports".

Selecting another program from the control panel causes the whole scene to shimmer once more, and change to show the topography and hydrology of Roman York; "Simulated model of Eboracum, c. AD *120, derived from borehole logs and excavated evidence. View data points?"*

Overlaid upon the view, a series of points appear to represent the data points. Each location glows with a colour corresponding to the weight it played in defining the model, with the highly detailed locational information from sites excavated using the revolutionary new microtrowel glowing a brilliant white, and the crude Antiquarian recordings of the Nineteenth century appearing a deep, dangerous, red.

Reaching out to touch one of the points causes ancillary information to scroll past in a corner of the view, relating details of the excavation, cross references to the artefact libraries, and links to the other phases of the site.

Clearing the simulation from the control panel, the image returns to the original view of modern York. Reaching forward with the glove, the city streets appear to rush upwards as the viewpoint drops down towards — and then below — ground level.

All around now, the view is filled with ghostly shapes defining known and assumed structures buried beneath the city streets. The occasional 'solid' feature represents a sewer or deep cellar intruding from above. Looking up, the modern street map can be seen from below, allowing easy integration *between super– and sub–surface worlds. As the viewpoint moves, a constant stream of text and images complements the audio dialogue as information is provided about the view.*

In the hands of a trained individual, such a system offers undoubted productivity gains in enabling the visualization of a large number of complex data sets in a flexible manner. However, even with safeguards such as the colour coding of data accuracy, the dangers of superficial impressions misleading the unprepared are greatly increased by the ease of use and apparent realism involved.

Perhaps the greatest obstacle standing in the way of this possible future, as with the implementation of any system today, is data. Archaeological excavations generate increasing quantities of data, and the digital archive represents a growing percentage of the output from many modern excavations, yet procedures remain only erratically applied and the distribution of these data across the landscape under study remains patchy, placing a great reliance upon the ability of computer software to *interpolate* values into unknown areas, rather than simply draw upon surveyed evidence. The increasing use of small–scale evaluations within the urban core, allied with the work of groups such as the National Geospatial Data Framework's (NGDF 1997) working parties and the archaeological Spatial Data Standards Working Group is leading both to an increase in the distribution of valuable data across our towns and cities, as well as increasing comparability in the manner in which these data are recorded. The widespread availability of high quality data across a usefully large area of any city remains some way off, however.

Even with the GIS of today, it is far easier to draw information from large discrete data sets than ever before and — other than for the original data collators and system designers — the remarkable ease with which data may be drawn together and transformed into high quality–looking output means that users may not always be as aware of inadequacies in the underlying data as they might have been had they collected it themselves and laboriously plotted it by hand.

The most important advance in modern GIS is the increased interactivity offered by all the developments in interface design and hardware technology. Such interaction enables the user to visualise complex data sets rapidly, and makes 'what if' style analyses a reality, as variables may be altered in response to near–instantaneous feedback from the computer. Such a development is undoubtedly a huge advantage, but the dangers of this ease of use have been highlighted several times, above. It would be a mistake to reverse such a development because of the dangers inherent within it. Rather, system developers and, especially, trainers, should make every effort to train users and viewers to *consider* the possible consequences of their interactions with system and data, and to examine resulting images with understanding and caution, rather than with blind belief.

An archaeological GIS for York

In implementing an archaeological GIS for York, the most effective home of such a system is the office of the Principal Archaeologist within the York Unitary Authority. Although managed by the local authority, however, the expertise available elsewhere in the City should also feed into the system, and be involved in the policies shaping its evolution.

Given the current growth in data bandwidth in the York area and the proximity of the local authority to the University Archaeology Department, the GIS could potentially be linked to the University and the offices of York Archaeological Trust in order to allow input and easy use for research. After an initial period of investment to create an effective system based upon current data, the supply of archival data in specified computer formats — complying with guidelines from organisations such as NGDF and ADS — should be stipulated in all archaeological evaluations and mitigation strategies in order to feed new information quickly and efficiently back into the system.

Purpose of system

Were such a system to be created, it would serve a number of roles and would need to be designed in such a way as to be able to fulfil them all. The major roles may be identified as:

- input to the planning process: including integration with other local authority systems
- repository of spatial archaeological information: effectively an interface to more traditional archives as held by York Archaeological Trust, the Yorkshire Museum *etc*
- research tool: capable of handling generalised queries of the associated databases within a research environment
- presentation tool: potential should exist for public interaction with elements of the database, as part of wider strategy of public accountability

In all of these, integration with existing systems and standards is important. Whilst direct compatibility with ageing systems should not be enforced at the expense of functionality in any new system, issues relating to the exchange of information with such systems should be addressed.

If based within the local authority, the primary role would be in enabling the smooth operation of the planning process and the speedy resolution of archaeological obstacles to development. As such, close integration with other local authority mechanisms would be essential, and integration with developing local authority policies on GIS seems sensible.

In acting as the primary point of contact for those wishing access to archaeological data stored elsewhere, the system would need to encapsulate elements of the English Heritage-funded archive assessment underway within York Archaeological Trust at the end of 1995 (Brinklow *pers comm*). The work contained within this thesis has shown that archive contents appear to be of less use to work other than the direct publication of the site concerned than was at first thought. With the archive review concentrating on these issues in more detail, guidelines may emerge for the ways in which data of differing provenance may more effectively be utilised within a single information providing resource. One step is the inclusion of further 'quality' fields within the database design, capable of assessing the quality of not only the deposits themselves, but also the excavation recording and the state of archival material. Deposits of high value that are only poorly recorded may therefore be flagged and treated differently to those with greater degrees of recording precision. The mechanics involved in implementing a GIS–based front end to traditional archives are largely in place, enabling users to search by excavation site code, address, geographic area, or a more complex query based upon any variables stored within the database. To complete the system, links could be provided to York Archaeological Trust's CRS and CIFR systems as extra modules, or a module could be created to provide archive–specific information about excavations. Due to the nature of the York Archaeological Trust fascicule system, these paper reports could easily be linked to the database by means of a simple search system, allowing users online access to the published texts.

GIS offers great potential as a tool for research, as has been shown by this thesis. In order to further the research potential for GIS–aware users, data of far greater precision are required for the city, as well as links to other sources of data such as the Local Authority land use classifications which are currently only available in paper form. In enabling less computer–literate researchers to undertake research, significant work will be required in providing introductory documentation and custom user interfaces such as that discussed in **Chapter 5**. The nature of research makes it difficult to design an interface sufficiently flexible to enable valid research, and at the same time simple enough to use without having to contend with large numbers of menus. The best solution is, perhaps, a modular series of tools, with some form of control system enabling the modules to be linked together in different ways by the user to fulfil different tasks.

Computer technology has a great deal to offer in public presentation, either in the form of museum displays, interactive systems for use in education, or even at public inquiries where a number of possible scenarios may require presentation. If already in use elsewhere, a GIS may well be suitable for any form of public presentation, although care would be required in order to prevent misuse and in making sure the system was configured in such a way as to be useable by the viewer.

The system designed for this research is, in its present form, not wholly suitable for implementation in so diverse an environment as that suggested, above. The YAA GIS was designed and built as a *research* tool for a single individual and, as such, user interfaces such as the one demonstrated in **Chapter 5**'s Case Study 5 were kept to a minimum; maximising the system's flexibility as ideas and processes changed, yet minimising the ease with which the system might be introduced to a new user, unfamiliar with the inner workings of GIS.

Were such a GIS to be implemented in a mixed environment, comprising potentially novice GIS users undertaking routine development control tasks, potentially novice users undertaking research–oriented and therefore potentially varied tasks, and expert users possibly undertaking both forms of task, there would be a need for at least three forms of potential interaction with the system. For those undertaking routine and clearly defined development control tasks, restrictive interfaces such as the one demonstrated in **Chapter 5** could be designed, perhaps with one for each type of task. Such interfaces would guide the user through the routine steps of their task, and disguise from them the complexity of the underlying commands. For the advanced research user, the existing system is sufficiently useable, providing they read **Chapter 4** in order to understand the underlying data model, and the limitations of the data themselves. The third class of user, however, is more difficult to cater for, requiring as they do the hand–holding of the interface driven approach *and* the flexibility of access to commands and functions offered by the raw command line. As has been argued elsewhere (*e.g.* Tufte 1990, Hearnshaw & Unwin 1994), there appears to be a direct relationship between increasing interface sophistication and declining flexibility, whereby improvements in user interface make it *easier* to undertake simple or 'normal' tasks, and that much harder to do anything complex or out of the ordinary. Many research–driven tasks, unfortunately, are likely to fall into this latter type.

The implication suggested by this difficulty is that GIS (and/or archaeological) knowledge is unnecessary for the undertaking of relatively routine, process–driven tasks such as those to be found in much of the Development Control system, but that archaeologists wishing to utilise a tool such as GIS within their *research* work are required to become familiar with the workings of the GIS they use; and that there is no way around this. Despite the greater usability offered by products such as *ArcView*, *MapInfo* and *Idrisi*, the archaeologist is still required to learn more than they might perhaps wish in order to make use of these tools. For a product as complex and potentially powerful as *Arc/Info*, the investment of time and effort may, unfortunately, be more than the average archaeological researcher is prepared to invest.

Data abstraction, an integrated GIS and politics

An integrated archaeological GIS for the city of York such as that alluded to throughout this thesis offers many potential benefits to all those involved in archaeology within the city, but there are also dangers involved. It falls to those tasked with eventually implementing the system to ensure the ascendancy of the positive aspects while making every effort to control or eradicate the ever present negative elements.

Most of these points are addressed elsewhere in this thesis, and are therefore only reproduced here as items in a list. Those points only alluded to elsewhere are explained more fully below.

Positive

- integrated environment for storing and displaying data from disparate sources
- usable interface to potentially complex data
- archives created and curated with public money are rendered potentially accessible to the public
- powerful descriptive and exploratory tools, allowing routine synthetic work to be completed quickly and accurately

- archaeological information easily integrated with other relevant Local Authority datasets
- powerful analytical potential, allowing exploratory data analysis in ways deemed prescriptively slow or labour–intensive in the past
- single point of contact for all archaeological data, whether stored *within* the GIS or merely pointed to *from* the GIS

Negative

- difficulties in integrating data of differing resolution and source
- provision of usable interface potentially leads to curtailment of system flexibility
- increased public access to archives leads to increasing accountability, and potential loss of academic freedom
- numeric — non fuzzy — nature of GIS reports leads to oversimplistic application of league tables, and excessive categorisation of the archaeological resource, especially by non–archaeologists

The difficulties inherent in combining data from very different sources are well understood, and apply far more widely than to the creation of an archaeological GIS. Indeed, the same difficulties occur equally in paper–based attempts to combine archaeological sources.

Possibly more serious is the scope for external interference in archaeological work should a comprehensive system be created. The current trend within local and national government — and, to some extent, within society as a whole — is towards increasing categorisation of variables from unemployment statistics to the 'success' or 'failure' of children passing through the education system. In many cases, these categorisations are applied to poorly understood statistics by individuals who lack an awareness of the real world events they are attempting to reduce to numbers, and result in largely meaningless league tables which fail to address underlying factors and attempt to compare incomparable occurrences in order to arrive at a 'best', a 'worst', and a rigorously defined gradation between.

Given the ease with which GIS can output numbers and statistics, the dangers of blindly applying these outputs are numerous, especially in cases where large developments — and therefore jobs, revenue and prestige — are at stake. Whilst an archaeologist might interpret a GIS–produced measure of deposit quality as little more than an approximate indicator of relative worth, and use it in order to aid in the direction of future research, the same output in the hands of a politician or large property developer may rapidly become a league table of absolute deposit quality against which all calls for archaeological intervention are judged.

The *appearance* of precision within the output also has implications for the regard in which the entire system — and the underlying archaeological procedures — are held; how many times would the GIS have to wrongly predict deposit thickness before developers began to question *any* mitigation requirement placed upon them by the Local Authority?

The two compared...

The dangers foreseen as a result of rigorous application of GIS–produced data are great, and potentially damaging to the Local Authority archaeological procedures, the archaeological community within York and the archaeologist–developer relationship on a wider scale, but the advantages are arguably greater.

So long as those developing and using the system remember the crudity of the underlying data, and avoid where possible the publication of absolute 'answers' by using broad numeric ranges and relative results, the undeniable advantages to practitioners, researchers, students and public of an integrated system offering access to the archaeology of York outweigh the disadvantages that would accrue should dangerous and misleading league tables and statements as to the actual degree by which one area is 'better' than another leak out.

7. Conclusion

My heart is set to praise my home
And briefly tell the ancient cradling
Of York's famed city through the charms of verse.

It was a Roman army built it first,
High–walled and towered, and made the native tribes
Of Britain allied to partners in the task —
For then a prosperous Britain rightly bore
The rule of Rome whose sceptre ruled the world —
To be a merchant–town of land and sea,
A mighty stronghold for their governors,
An Empire's pride and terror to its foes,
A haven for the ships from distant ports
Across the ocean, where the sailor hastes
To cast his rope ashore and stay to rest.

The city is watered by the fish–rich Ouse
Which flows past flowery plains on every side.

(Alcuin, reproduced in Palliser & Palliser 1979)

GIS in urban archaeology

Archaeology has always been quick to adopt technology and methodologies developed in other disciplines, whether the geological laws discussed in **Chapter 2**, the objective analyses of New Archaeology (Trigger 1989), or, more recently, GIS.

With earlier adoptions, archaeologists have tended to lag some way behind the donor discipline in actively critiquing the methodologies in use, and certain techniques have remained in active use within archaeology long after the theoretical paradigms have been superseded in other disciplines (*eg* Grant 1986). This delay is, of course, not always detrimental to archaeology, as it enables us to bypass the difficult introductory periods in which new ideas are formulated and academic opinion swings from one viewpoint to another until new theoretical frameworks become properly entrenched. On the other hand, archaeologists miss out on the opportunity to shape the development of these new theories at a supra–disciplinary level; to the detriment of other disciplines as well as of archaeology.

With the development of GIS, this pattern does not appear repeated to the same extent, and it is gratifying to see archaeologists undertaking discourse at the highest theoretical, methodological and practical levels alongside practitioners from other disciplines. Indeed, discussion on the newly formed `GISARCH` electronic mailing list (Miller 1996*b*) in many ways pushes ahead of the current mainstream in GIS studies, and is attracting comment from some of the leading thinkers in GIS around the world (*eg* Marble 1996).

An initial optimism with GIS is gradually being replaced by a more reasoned assessment of the tool, falling somewhere between the early enthusiasm of writers such as Gaffney & Stancic (1991) and the pessimism of recent publications (Pickles 1995).

Attention is turning increasingly to the limitations of archaeological data, and efforts are underway both to improve extant archives (*e.g.* Brinklow *pers comm*, on the English Heritage–funded assessment of the YAT archive) and to improve the manner in which information is recorded and stored in future (*e.g.* Quine *pers comm*, Lang *pers comm*, Dawson *pers comm*) through the work of groups such as RCHME's new Data Standards Unit, the Spatial Data Standards Working Group, and working parties of the Museum Documentation Association.

Despite the failure of the Urban Archaeological Databases (English Heritage & RCHME 1993*a*, 1993*b*) or the Urban section of the Monuments Protection Programme (Darvill 1992) to recognise the potential of modern computer–based applications to the problems they were attempting to tackle, a trend has clearly now begun towards more innovative applications at the local level (*e.g.* Foard *pers comm*, on Northamptonshire, and Vince *pers comm*, on the Lincoln UAD), and the national agencies are being forced — albeit slowly — to follow suit.

In urban areas, the adoption of GIS continues to grow with some form of GIS in place or under development in a variety of towns and cities including London (Miller *pers comm*), St Albans (Niblett *pers comm*), Newcastle (Graves *pers comm*), Bristol, Wroxeter (Gaffney *pers comm*), Hereford and Worcester (Gaffney *pers comm*) and Lincoln (Vince *pers comm*), although the notable lack of sensible guidance from either English Heritage or RCHME continues to hinder efforts to develop any level of unified solution.

Developments in urban archaeology

In English urban archaeology, the guidelines of PPG16 continue to exert a great influence upon the ways in which new data are gathered about the resource, and it still remains unclear as to whether the 'anti–research' (Biddle 1994*b*) nature of the PPG truly prevents archaeologists from learning anything new about their towns in the Past.

With more of the urban archaeological assessments (English Heritage 1992) approaching completion, it may soon be possible to better gauge the nature of the resource *outside* archaeological hot spots such as York and London, and in the light of this information new research strategies may be forthcoming in order to address and shortcomings brought about either by PPG 16 or the nature of individual urban sites.

The fundamentally flawed format of the Urban Archaeological Database standard (English Heritage & RCHME 1993*a*) is due to be reviewed (Gilman 1996), and those involved with archaeology or GIS in urban areas are being invited — at least informally — to comment upon the ways in which the new standard should evolve. Although perhaps not the ideal solution for every urban area in the form it is presented herein, the concepts enshrined within the York Archaeological Assessment are worthy of wider consideration and shall hopefully be considered by the working party.

Exploring York

Recent developments within the City of York itself bring the prospect of a city–wide archaeological GIS ever closer, with both York Archaeological Trust and the City Council initiating GIS–related work.

Within York Archaeological Trust, *ArcCAD* is being used in conjunction with *AutoCAD* in order to assess the completeness of the site archive (Brinklow *pers comm*), and elements of the existing archive are to be made more accessible to YAT staff by means of an *ArcCAD* GIS–style implementation. English Heritage are providing funding, through which the archive as a whole is being evaluated and upgraded.

For the Local Authority, the Directorate of Development Services — within which the Principal Archaeologist operates — are investigating the purchase of a Geographic Information System for general planning applications (Oxley *pers comm*). At the time of writing, it is unclear which system will be purchased, or how quickly archaeological information will be entered in to whatever is acquired. It is to be hoped that the archaeological service will liaise with the current YAT project in order to have an input into system specifications so that the YAT GIS will be capable of sharing information with that for the City. A wealth of experience exists within the University of York, and this, too, should be capitalised upon by the Local Authority in order to select the best system for their needs and in order to bring pressure to bear upon the national bodies currently reconsidering the original urban database standard (English Heritage & RCHME 1993*a*, Gilman 1996).

The Last Word?

This thesis has explored and integrated possibly the most complex aspects of both GIS studies and archaeology; multidimensionality and urbanism respectively. In doing so, numerous obstacles have been encountered, from the low resolution of much archaeological data to the conceptual and technical difficulties inherent in grappling with multidimensional space.

The difficulties encountered herein are not unique to York, nor to archaeology as a whole, and they are being tackled in different ways all over the world as researchers strive to represent the complexities of space and time within systems designed for producing *flat* paper maps and using theoretical paradigms ill–suited to the complexities of the poorly visualised dimensions beyond the first two.

On several occasions, the examples presented above perhaps fail to fully illustrate the potential of the techniques under discussion, but this is due primarily to the problems of dealing with *real* data rather than flaws in the techniques themselves. While it would have been possible to utilise test data sets designed to show every technique at its best, the primary aim of this thesis was to illustrate the applicability of GIS to urban archaeology within the real world; not in a simulation.

This thesis has demonstrated the power and potential of an urban GIS and it is now up to researchers, field workers and legislators to identify research questions of interest, to define data collection strategies capable of meeting these questions, and to collect the appropriate data accordingly; all within a framework conducive to implementation within GIS.

Of current projects, arguably only Wroxeter (Gaffney *pers comm*) has been designed from the outset with GIS in mind, and the archaeological community watches with interest to see whether a project *designed* for GIS fares better than those more common projects where GIS are applied after data collection is complete, as happened with the York Archaeological Assessment.

GIS are here to stay, and have amply demonstrated their ability to map and analyse even archaeological data. Given the next generation of data collected with GIS in mind, and given the next generation of GIS designed with more than two dimensions in mind, who knows what potential awaits us? I, for one, can't wait to find out, and only hope that the ideas presented above help us all to move a step closer to those next generations.

Appendix A: Computer Hardware

The following hardware was utilised during this research:

Computers

Hewlett Packard Apollo 700–series workstation

Silicon Graphics Challenge compute server

Silicon Graphics Indigo workstation

Silicon Graphics Indy workstation

WYSE text–only terminal

A selection of 386, 486 and Pentium IBM compatible PCs

Peripherals

Apple LaserWriter Pro laser printer

Hewlett Packard LaserJet laser printer

Hewlett Packard ScanJet flatbed scanner

Summagraphics A1 digitising tablet

Appendix B: Computer Software

The following software was utilised during this research:

PC

ArcCAD 11.2

ArcView 1, 2 & 2.1

AutoCAD release 11 & 12 (DOS) and 13 (Windows)

Borland *Paradox* versions 4.0 – 4.5 (DOS) and 4.0 – 5.0 (Windows)

Microsoft *Access* 2.0

Microsoft *Excel* 5

Microsoft *Word for Windows* 2, 6 & 7

Paintshop Pro 3

UNIX

Arc/Info 5.1 – 7.0.4 (β)

ArcView 2.1

AutoCAD release 12

ERDAS *Imagine* 8.2

UNIRAS 5 – 6.3b

xv 2 – 3

Appendix C: Data sources

This appendix lists the sources of the main map coverages used within this thesis.

$DIGS/blake_points

Arc/Info point coverage, derived from spot heights on paper plans within YAT's Blake Street archive.

$DIGS/ove_db

Arc/Info point coverage, containing all non–YAT archaeological contacts from the Ove Arup project database.

$DIGS/yat70, yat80 & yat90

Arc/Info polygon coverages, containing all YAT archaeological contacts from the Ove Arup project database and YAT enhancement thereof. Trench outlines derived from YAT site digitisation project in *AutoCAD*.

$DTM/anglian

Arc/Info TIN depicting computed topography during the Anglian period. Data derived from Ove Arup project database.

$DTM/ascan

Arc/Info TIN depicting computed topography during the Anglo–Scandinavian period. Data derived from Ove Arup project database.

$DTM/blake_per4

Arc/Info TIN depicting computed topography on the City Garage site during Period 4. Data derived from YAT's Blake Street site archive.

$DTM/blake_per6

Arc/Info TIN depicting computed topography on the City Garage site during Period 6. Data derived from YAT's Blake Street site archive.

$DTM/medieval

Arc/Info TIN depicting computed topography during the Medieval period. Data derived from Ove Arup project database.

$DTM/modern

Arc/Info TIN depicting computed topography of modern York. Data derived from Yorkshire Water manhole cover heights, Ordnance Survey 1:1,250 spot heights, National Rivers Authority flood alleviation data, Ordnance Survey 1:50,000 digital elevation model and Ove Arup project database.

$DTM/natural

Arc/Info TIN depicting computed topography during the pre-settlement period. Data derived from Ove Arup project database and Ove Arup geology database.

$DTM/roman

Arc/Info TIN depicting computed topography during the Roman period. Data derived from Ove Arup project database and Ove Arup geology database.

$DTM/water

Arc/Info TIN depicting computed extent of the water table beneath York. Data derived from Ove Arup geology database

$MODERNYORK/york_ap

Arc/Info grid depicting aerial photograph of modern York. Original vertical photograph from Cambridge Air Photo Archive, scanned and rectified within *Arc/Info*.

$MODERNYORK/aai

Arc/Info coverage depicting extent of Area of Archaeological Importance (AAI). Information digitised using *AutoCAD* by York Archaeological Trust from 1:10,000 paper map.

$MODERNYORK/aaiwalls

Arc/Info coverage depicting course of York city walls. Information digitised using *AutoCAD* by York Archaeological Trust from 1:10,000 paper map.

$MODERNYORK/aai_river

Arc/Info coverage depicting courses of the Rivers Ouse and Foss. Information digitised using *AutoCAD* by York Archaeological Trust from 1:10,000 paper map.

$MODERNYORK/boundary

Arc/Info coverage depicting extent of project area. Information derived from 1:1,250 Ordnance Survey digital mapping.

$MODERNYORK/bridges

Arc/Info coverage depicting courses of the Rivers Ouse and Foss, with gaps in the river coverage for features such as bridges. Information derived from 1:1,250 Ordnance Survey digital mapping.

$MODERNYORK/landmarks

Arc/Info coverage depicting major landmarks of the York cityscape; York Minster, Clifford's Tower and York railway station. Information derived from 1:1,250 Ordnance Survey digital mapping.

$MODERNYORK/pilot_study

Arc/Info coverage containing map and associated database for the Pilot Study area. Information derived from 1:1,250 Ordnance Survey digital mapping.

$MODERNYORK/river

Arc/Info coverage depicting courses of the Rivers Ouse and Foss. Information derived from 1:1,250 Ordnance Survey digital mapping.

$MODERNYORK/roads

Arc/Info coverage depicting the major roads of central York. Information derived from 1:1,250 Ordnance Survey digital mapping.

$MODERNYORK/york_map

Arc/Info coverage depicting the map of the project area. Information derived from 1:1,250 Ordnance Survey digital mapping.

$OLDYORK/eboracum

Arc/Info coverage depicting presumed location of Roman fortress and colonia, plus major roads. Map digitised within *AutoCAD* by York Archaeological Trust from paper original.

Appendix D: Program listings

A number of Arc Macro Language (AML) scripts were produced during the writing of this thesis, and the main ones (including those for the production of *every* figure) are available on the floppy disk attached inside the back cover of this volume.

Given the limitations of MS–DOS filenames, the long AML titles used within the GIS have been truncated to apply with the 8.3 naming scheme, and the translation between AML name and MS–DOS filename is presented below. Also included is the expanded path for all the UNIX logical names (of form `$name`) used within the scripts. **Note** that UNIX filenames are case sensitive. *ie* $AML is not the same as $aml.

UNIX logical name mappings

`$AML`	`/usr/fs3/arch/apm9/york/aml`
`$BARTS`	`/usr/datasets/bartholomew`
`$DIGS`	`/usr/fs3/arch/apm9/york/digs`
`$DTM`	`/usr/fs3/arch/apm9/york/dtm`
`$FIGURES`	`/usr/fs3/arch/apm9/york/aml/figures`
`$home`	`/usr/fs3/arch/apm9`
`$MENUS`	`/usr/fs3/arch/apm9/york/aml/menus`
`$MODERNYORK`	`/usr/fs3/arch/apm9/york/modernyork`
`$OLDYORK`	`/usr/fs3/arch/apm9/york/oldyork`
`$OS`	`/usr/datasets/os`
`$PAUL`	`/usr/peters/paul`
`$PAUL_TMP`	`/usr/tmp/paulm`
`$SETTINGS`	`/usr/fs3/arch/apm9/aml/settings`
`$THESIS`	`/usr/fs3/arch/apm9/aml/figures/thesis`
`$VECP`	`/usr/fs3/arch/apm9/aml/vecp`
`$YORK`	`/usr/fs3/arch/apm9/york`

AML — MS-DOS filename mappings

A selection of the Arc Macro Language scripts used in this thesis are available on the disk inside the back cover. These scripts are organised in directories on the disk relating to the UNIX directory from which they were extracted.

$MENUS	A:/menus
`batch_plot_creator.aml`	`batch.aml`
`controlmenu.aml`	`control.aml`

$MENUS/dig_it	A:/digit
`about_x_dep_dep.dat`	`about.dat`
`bore_with_gref.aml`	`bore_g.aml`
`bore_with_mouse.aml`	`bore_m.aml`
`dig_it.hlp`	`digit.hlp`
`dig_it_vecp.aml`	`dig_v.aml`
`draw_it.aml`	`drawit.aml`
`message.txt`	`msg.txt`
`report.dat`	`rprt.dat`
`report.txt`	`rprt.txt`
`select_covers.aml`	`select_c.aml`
`select_covers.menu`	`select_c.mnu`
`x_dep_bore.aml`	`x_dep_b.aml`
`x_dep_bore.menu`	`x_dep_b.mnu`
`x_dep_cover.aml`	`x_dep_c.aml`
`x_dep_dep.menu`	`x_dep_d.mnu`
`x_dep_gref.menu`	`x_dep_g.mnu`
`x_dep_make_hole.aml`	`x_dep_mh.aml`
`x_dep_mapex.aml`	`x_dep_m.aml`
`x_dep_mapex.menu`	`x_dep_m.mnu`
`xdep_zoomin.aml`	`x_dep_z.aml`
`zoom_back.aml`	`zoom_b.aml`

$SETTINGS	A:/settings
`a4_on_a3l`	`a4_a3`

a41	a41
color	color
dig_it.aml	digit.aml
mono_a41	mono_a41
page_layout_a4	page_a4
stat_paul	s_paul

$THESIS	A:/thesis
thesis_page_land.aml	thesis_l.aml
thesis_page_port.aml	thesis_p.aml

$THESIS/ch3	A:/ch3
do_it.aml	do_it.aml
ebor_key1.key	ebor1.key
ebor_key2.key	ebor2.key
ebor_key3.key	ebor3.key
ebor_key4.key	ebor4.key
ebor_key5.key	ebor5.key
eboracum.aml	ebor.aml
vale_of_york.aml	vale.aml

$THESIS/ch4	A:/ch4
admin_key1.key	admin1.key
admin_key2.key	admin2.key
admin_key3.key	admin3.key
admin_key4.key	admin4.key
admin_units.aml	admin.aml
aerial_photo.aml	ap.aml
dep_thick1.key	depth1.key
dep_thick10.key	depth10.key
dep_thick11.key	depth11.key
dep_thick2.key	depth2.key

dep_thick3.key	depth3.key
dep_thick4.key	depth4.key
dep_thick5.key	depth5.key
dep_thick6.key	depth6.key
dep_thick7.key	depth7.key
dep_thick8.key	depth8.key
dep_thick9.key	depth9.key
deposit_thickness.aml	depth.aml
do_it.aml	do_it.aml
make_modern_dems.aml	make_mod.aml
mod_dem1.key	modem1.key
mod_dem2.key	modem2.key
mod_dem3.key	modem3.key
mod_dem4.key	modem4.key
mod_dem5.key	modem5.key
mod_dem6.key	modem6.key
mod_dem7.key	modem7.key
mod_dem8.key	modem8.key
mod_dem_all_key.key	modemall.key
mod_dem_no1.key	modemno1.key
mod_dem_no2.key	modemno2.key
mod_dem_no3.key	modemno3.key
mod_dem_no4.key	modemno4.key
mod_dem_no5.key	modemno5.key
modern_dem_all_points.aml	mod_pts.aml
modern_dem_break.aml	mod_brk.aml
modern_dem_no_break.aml	modnobrk.aml
modern_tin_manholes.aml	mod_man.aml
modern_tin_nra.aml	mod_nra.aml
modern_tin_os.aml	mod_os.aml
modern_tin_ovearup.aml	mod_ove.aml
ove_arup_area.aml	ove_area.aml

river_transect.aml	riv_trns.aml
rivers_transect.aml	rivs_trn.aml
rivers_transect.key	rivs_trn.key
rivers_transect.txt	rivs_trn.txt
rom_dem1.key	rom_dem1.key
rom_dem2.key	rom_dem2.key
rom_dem3.key	rom_dem3.key
rom_dem4.key	rom_dem4.key
rom_dem5.key	rom_dem5.key
rom_dem6.key	rom_dem6.key
rom_dem7.key	rom_dem7.key
rom_dem8.key	rom_dem8.key
roman_dem_all_points.aml	rom_all.aml
roman_dem_break.aml	rom_brk.aml
semi_graph.aml	semi_g.aml
semivariogram.aml	semi_v.aml
transect.key	trans.key

$THESIS/ch5	A:/ch5
angl_dep_trans.aml	angl_t.aml
blake_all_data.aml	blake_al.aml
blake_all_pts.key	blake_al.key
blake_per4.aml	blake_4.aml
blake_per4_tin.aml	blake_4t.aml
blake_per6.aml	blake_6.aml
blake_per6_tin.aml	blake_6t.aml
blake_points.key	blake_pt.key
do_it.aml	do_it.aml
flood_zone1.key	fld_z1.key
flood_zone2.key	fld_z2.key
flood_zone_digs.key	fld_zd.key
fort.key	fort.key
fort1.key	fort1.key

fort2.key	fort2.key
fort3.key	fort3.key
fort4.key	fort4.key
fort5.key	fort5.key
fort6.key	fort6.key
fort7.key	fort7.key
fort_dep_setup.aml	fort_ds.aml
fort_transect.aml	fort_tr.aml
locate_b_s.aml	locate.aml
locate_blake_swine.aml	loc_bs.aml
med_pol_setup.aml	med_p_s.aml
medieval_deposit_pattern.aml	med_d_p.aml
mod_pol1.key	mod_pol1.key
mod_pol2.key	mod_pol2.key
mod_pol3.key	mod_pol3.key
mod_pol_setup.aml	mod_p_s.aml
modern_deposit_pattern.aml	mod_d_p.aml
non_wet.key	non_wet.key
pilot_developments.aml	pilot_d.aml
pilot_listed_bldgs.aml	pilot_l.aml
potential_modern_flood_zone.aml	pot_mfz.aml
potential_roman_flood_zone.aml	pot_rfz.aml
rom_pol_setup.aml	rom_ps.aml
rom_sites.key	rom_sit.key
roman_dem.aml	rom_dem.aml
roman_deposit_pattern.aml	rom_dp.aml
roman_ramm_flood.aml	rom_rf.aml
roman_river_key1.key	rom_k1.key
roman_river_key2.key	rom_k2.key
roman_river_key3.key	rom_k3.key
roman_river_key4.key	rom_k4.key
roman_river_key5.key	rom_k5.key

roman_river_levels.aml	rom_riv.aml
roman_wet_sites_setup.aml	rom_wets.aml
swine_thick.aml	swine_th.aml
swine_tin1.aml	sw_1.aml
swine_tin10.aml	sw_10.aml
swine_tin10b.aml	sw_10b.aml
swine_tin13.aml	sw_13.aml
swine_tin13b.aml	sw_13b.aml
swine_tin1b.aml	sw_1b.aml
swine_tin2.aml	sw_2.aml
swine_tin2b.aml	sw_2b.aml
swine_tin3.aml	sw_3.aml
swine_tin3b.aml	sw_3b.aml
swine_tin4.aml	sw_4.aml
swine_tin4b.aml	sw_4b.aml
swine_tin5.aml	sw_5.aml
swine_tin5b.aml	sw_5b.aml
swine_tin7.aml	sw_7.aml
swine_tin8.aml	sw_8.aml
swine_trans.aml	sw_tran.aml
swine_trans.key	sw_tran.key
swine_trans.txt	sw_tran.key
tidiest_period.aml	tidy_per.aml
tin.key	tin.key
wat_lvl.key	wat_lvl.key
waterlogged_sites.aml	wat_site.aml

$VECP	A:/vecp
`deposit_depth.aml`	`dep_dep.aml`
`north_arrow.aml`	`north.aml`
`scale_bar.aml`	`scale.aml`
`surface_base.aml`	`surface.aml`

List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional
AAI	Area of Archaeological Importance
AAS	Area of Archaeological Significance
AAT	Arc Attribute Table
ACAO	Association of County Archaeological Officers
ad	*Anno Domini* (uncalibrated Carbon–14 date)
AD	*Anno Domini*
ADS	Archaeology Data Service
AGI	Association for Geographic Information
AML	Arc Macro Language
AOD	Above Ordnance Datum
ARC	Archaeological Resource Centre
BBC	British Broadcasting Corporation
BLUE	Best Linear Unbiased Estimate
BS	British Standard
BUFAU	Birmingham University Field Archaeology Unit
CAD	Computer Aided Design
CASA	Centre for Advanced Studies in Architecture
CASE	Cooperative Awards in Science & Engineering
CBA	Council for British Archaeology
CEN	Comité Européen de Normalisation
CERN	Conseil Européen pour la Recherche Nucléaire
CGIS	Canadian Geographic Information System
CHEST	Combined Higher Education Software Team
CIFR	Computerised Integrated Finds Recording (System)

CRS	Context Recording System
CRT	Cathode Ray Tube
DBMS	DataBase Management System
DEM	Digital Elevation Model
DoE	Department of the Environment
DXF	Digital eXchange Format
EA	Environment Agency
EC	European Community
EEC	European Economic Community
EH	English Heritage
ESA	European Space Agency
ESRI	Environmental Systems Research Institute, Incorporated
ETLA	Extended Three Letter Acronym
EU	European Union
GIS	Geographic Information System
GISRUK	Geographic Information Systems Research, United Kingdom
GPS	Global Positioning System
HCI	Human–Computer Interaction/ Human–Computer Interface
HM Government	Her Majesty's Government
HMSO	Her Majesty's Stationery Office
HTTP	HyperText Transfer Protocol
IBM	International Business Machines
IFA	Institute of Field Archaeologists
IR	Infra–Red
ISG	Information Services Group
ISO	International Standards Organization
IUCC	Inter–University Committee on Computing
JISC	Joint Information Systems Committee
JPL	Jet Propulsion Laboratory

LANDSAT	LAND SATellite
MoLAS	Museum of London Archaeology Service
MIT	Massachusetts Institute of Technology
MPP	Monument Protection Programme
MS–DOS	MicroSoft Disk Operating System
MUAR	Managing the Urban Archaeological Resource
NASA	National Aeronautics & Space Administration
NAVSTAR	NAVigation Satellite Timing And Ranging
NCGIA	National Center for Geographic Information & Analysis
NERC	Natural Environment Research Council
NGDF	National Geospatial Data Framework
NGR	National Grid Reference
NMR	National Monuments Record
NRA	National Rivers Authority
NRSC	National Remote Sensing Centre
OD	Ordnance Datum
OGIS	Open Geographic Information Systems
OLE	Object Linking & Embedding
ON	Old Norse
OS	Ordnance Survey
PARC.	Palo Alto Research Center
PAT	Polygon Attribute Table/ Point Attribute Table
PC	Personal Computer
PPG	Planning Policy Guidance
RCHME	Royal Commission on the Historical Monuments of England
RMS	Root Mean Squared
SERC	Science & Engineering Research Council
SIR	Shuttle Imaging Radar
SMR	Sites & Monuments Record

SPOT	Systéme Probatoire de l'Observation de la Terre
SQL	Structured Query Language
TC	Technical Committee
TIN	Triangulated Irregular Network
TLA	Three Letter Acronym
UAD	Urban Archaeological Database
UK	United Kingdom
UNIRAS	UNIversal RASter
US	United States
VE	Visualization Engine
VECP	Visualization Engine Control Program
ViSC	Visualization in Scientific Computing
VR	Virtual Reality
VRML	Virtual Reality Modelling Language
WWW	World Wide Web
YAA	York Archaeological Assessment
YAT	York Archaeological Trust
YEP	York Environs Project

Glossary

Arc: “a line described by an ordered sequence of points. It is a fundamental concept in the vector data model. Two or more **arcs** are joined by a node and several **arcs** may be linked together in a loop to form an area or polygon.” (McDonnell & Kemp 1995; 10)

Archaeological assessment: the procedures involved in evaluating the archaeological potential of an area, whether using intrusive, non–intrusive or desk based techniques. Also the act of implementing these procedures.

Best Linear Unbiased Estimate (BLUE): “the result of an interpolation function, which was optimized with chosen interpolation weights, at a given variable point.” (McDonnell & Kemp 1995; 15)

CAD: “a computer–based information processing system which supports engineering planning and illustrating activities. Many such systems provide advanced features such as solid modelling.” (McDonnell & Kemp 1995; 18)

CEN: “Comité Européen de Normalisation: The regional standards group for Europe... It functions broadly as a European equivalent to ISO and its key goal is to harmonize standards produced by the standards bodies of its member countries.” (McDonnell & Kemp 1995; 19–20)

Component: a single element forming part of a larger whole. The **component** is a fundamental element of the methodology implemented by YAA, and epitomises the difference between modular and monument/site–centric approaches to archaeology.

Database: “a collection of data organized according to a conceptual schema with a set of procedures for adding, changing, or retrieving data held in this structure.” (McDonnell & Kemp 1995; 27)

DataBase Management System (DBMS): “a collection of software for organizing the information in a **database**. Typically it contains routines for data input, verification, storage, retrieval, and combination.” (McDonnell & Kemp 1995; 27)

Flatland: rather disparaging term used to describe the representational techniques applied in mapping three–dimensional objects and spaces in to the two–dimensional space occupied by computer monitors and paper (Abbot 1884, Tufte 1990; 12–35).

GIS: "a computer system for capturing, managing, integrating, manipulating, analysing, and displaying data which is spatially referenced to the Earth." (McDonnell & Kemp 1995; 42)

Interface: "the junction which allows the linking together of two or more computer components. This, for example, might be between software and hardware, between hardware and software, or between human operator and software." (McDonnell & Kemp 1995; 49)

Interpolation: "a series of techniques and algorithms used to estimate attribute values for areas that are unsampled, based on known data at surrounding sample sites. Examples include techniques such as **kriging** and Thiessen polygons." (McDonnell & Kemp 1995; 50)

ISO: "International Standards Organization: a worldwide federation of national standards bodies that defines rules, critera (*sic*), or measurements that are to be adopted as international standards." (McDonnell & Kemp 1995; 51)

Kriging: "an **interpolation** technique based on numerical measurements of the spatial variation of known points different distances apart." (McDonnell & Kemp 1995; 53)

Metadata: "information about data. Examples are data quality information, currency, lineage, ownership, and feature classification information." (McDonnell & Kemp 1995; 61)

Model: "an abstraction and description of the real world or part of it." (McDonnell & Kemp 1995; 62)

***n*–space:** label given to representation or conceptualisation of data or observations in multiple dimensions. Normally applied to complex spaces requiring more than the two dimensions easily visualised on paper or with a computer.

polis*:** a conceptualisation of coherent urban space. The ***polis encompasses both the mapable extent of the physical manifestation of urbanism and the conceptual urban sphere, within which a series of discriminable components combine to form the whole.

Polygon: "an area bounded by a closed line. It is used to describe spatial elements, such as housing and industrial units, administrative and political districts, and areas of homogeneous land use and soil types." (McDonnell & Kemp 1995; 71)

Predictive model: normally a series of maps, either on paper or within a computer, that combine a series of variables gleaned from *known* sites in order to produce zones in which similar sites might be likely to occur. Commonly used within North American Cultural Resource Management.

Preservation by record: an important tenet of the 'rescue' philosophy in British urban archaeology during the 1970's. It was believed that detailed recording of a site would create an archive capable of effectively preserving the now–destroyed site for posterity and — conceivably — even reconstructing it at some point in the future.

Red flag model: 'a site which is costly in terms of either time or money or both' (Altschul 1990; 227). An extension of the **Predictive model** by which specific sites likely to have an adverse impact upon development are identified.

Three–space: more than merely three dimensional display, **three–space** encompasses the actual display and the conceptual framework behind true multidimensional analysis.

TIN: "Triangulated Irregular Network: a form of irregular tessellation based on triangles and used to represent continuous spatial data originating as a set of irregularly spaced points. Unlike a grid, the **TIN** allows dense information in complex areas, and sparse information in simpler or more homogeneous areas. A **TIN** is often used to represent continuous elevation surfaces." (McDonnell & Kemp 1995; 87)

Topology: "strictly speaking, the study of those properties of geometrical figures that are invariant under continuous deformation. In **GIS**, topological relationships, such as connectivity, adjacency and relative position, are usually expressed as relationships between nodes, links, and **polygons**." (McDonnell & Kemp 1995; 88)

Vector data model: "an abstraction of the real world in which spatial elements are represented in the form of points, lines, and **polygons**. These are geographically referenced to a co–ordinate system." (McDonnell & Kemp 1995; 92)

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