

APPLICATIONS OF GEOGRAPHIC INFORMATION SCIENCE IN THE  
ARCHAEOLOGICAL RESEARCH OF THE FINCASTLE KILL SITE (DIOx 5)  
ALBERTA, CANADA, AND TEL BETH-SHEMESH, ISRAEL

**SAM LIEFF**

B.Sc., University of Lethbridge, 2003

A Thesis  
Submitted to the School of Graduate Studies  
of the University of Lethbridge  
in Partial Fulfillment of the  
Requirements for the Degree

**MASTER OF SCIENCE**

Department of Geography  
University of Lethbridge  
LETHBRIDGE, ALBERTA, CANADA

© Sam Lieff, 2006

## Table of contents

<b>Signature Page</b> .....	ii
<b>Table of Contents</b> .....	iii
<b>List of Figures</b> .....	iv
<b>Abstract</b> .....	v
<b>Acknowledgments</b> .....	vi
<b>Chapter 1 - Introduction</b> .....	1
1.1 Introduction.....	1
1.2 Thesis Objectives .....	3
1.3 Thesis Overview .....	4
<b>Chapter 2 - Literature Review</b> .....	7
2.1 Introduction.....	7
2.1 GIS in the Archaeological Sciences, Mapping and Concepts of Data Sharing and Methodology .....	7
2.3 Employing Three Dimensions with Digital Elevation Models and Terrain Variables in Archaeological Analyses .....	13
2.4 High Detail Data Capture and Analysis .....	20
2.5 Archaeological Site Location Modeling.....	21
2.6 Summary .....	24
<b>Chapter 3 – Fincastle Kill Site (DIOx 5)</b> .....	25
3.1 Introduction.....	25
3.2 Site Description and Archaeological Significance .....	26
3.3 On-Site Preparation.....	28
3.4 Field Methods .....	32
3.5 Laboratory Methods.....	35
3.6 Viewshed Analysis .....	42
3.7 Two Dimensional Spatial Density Analysis Using Surface Interpolation Models.....	52
3.8 Three Dimensional Spatial Density Analysis Using Surface Interpolation Models.....	60
3.9 Summary .....	63
<b>Chapter 4 – Tel Beth-Shemesh</b> .....	65
4.1 Introduction.....	65
4.2 Site Description and Archaeological Significance .....	66
4.3 Field Preparation.....	69
4.4 Field Methods .....	71
4.5 GIS Model Generation .....	79
4.6 Site Phasing and Feature Validation Using the GIS Model .....	91
4.7 Feature Validation Using a Chronological Model.....	92
4.8 Summary .....	95
<b>Chapter 5 – Discussion</b> .....	97
5.1 Introduction.....	97
5.2 GIS as an Analysis Tool for Archaeologists .....	97
5.3 The Impact of GIS on Excavation Planning and Field Techniques .....	98
5.4 The Impact of Three-Dimensional Visualization .....	102
5.5 Qualitative and Quantitative Archaeological Analysis with GIS.....	103
5.6 Preservation and Dissemination Benefits.....	107
5.7 Problems with the GIS Model.....	108
5.8 The “High Detail” Model.....	110
<b>Chapter 6 – Summary and Conclusions</b> .....	111
6.1 Overview.....	111
6.2 Research Perspectives .....	112
6.3 Future Prospects.....	114
<b>References Cited</b> .....	116
<b>Glossary of Terms</b> .....	119

## List of figures

<b>Figure 3.1:</b> Location map of the Fincastle Kill Site .....	26
<b>Figure 3.2:</b> 0.5m pixel 2km <sup>2</sup> coverage digital air photo used for orthorectification.....	29
<b>Figure 3.3:</b> Location of base points (BPs) on the dune area.....	29
<b>Figure 3.4:</b> Example of survey equipment (Sokkia Total Station) .....	30
<b>Figure 3.5:</b> Checkerboard pattern in East Block of excavation area. ....	31
<b>Figure 3.6:</b> Example of field methods (measuring the spatial position of an artifact.....	33
<b>Figure 3.7:</b> Example of level graph with graphed archaeological remains. ....	34
<b>Figure 3.8:</b> Digitized graph sheet with digitized faunal remains overlaid.....	39
<b>Figure 3.9:</b> Sample points for DEM interpolation and final DEM with .25m contours. ....	41
<b>Figure 3.10:</b> Viewshed surface used for assessing bison hunting techniques .....	44
<b>Figure 3.11:</b> Comparison of Viewsheds used to assess bison hunting techniques. ....	46-48
<b>Figure 3.12:</b> Viewshed surface showing visible area of bison along a "travel path" .....	50
<b>Figure 3.13:</b> Location of lithic flakes and faunal remains in East Block excavation area. ....	53
<b>Figure 3.14:</b> Two dimensional surface interpolation used for spatial density analysis of lithic debitage ....	56
<b>Figure 3.15:</b> Two dimensional surface interpolation used for spatial density analysis of faunal remains ...	57
<b>Figure 3.16:</b> Lithic and faunal density surfaces compared.....	58
<b>Figure 3.17:</b> Profile of elevation change of faunal remains in East Block prior to the adjustment of elevation values.....	61
<b>Figure 3.18:</b> Profile of elevation change of adjusted faunal remains in East Block.....	61
<b>Figure 3.19:</b> Calculated spatial correlation values. ....	62
<b>Figure 4.1:</b> Map of Israel showing location of Beth-Shemesh. ....	67
<b>Figure 4.2:</b> Area Map of Tel Beth-Shemesh .....	68
<b>Figure 4.3:</b> Example of early GIS models using Tel Beth-Shemesh data. ....	70
<b>Figure 4.4:</b> Example of excavation equipment (pulley system).....	74
<b>Figure 4.5:</b> Example of two 5m <sup>2</sup> excavation units exposed in Area F using Wheeler Box method .....	74
<b>Figure 4.6:</b> View of Area D of Tel Beth-Shemesh.....	76
<b>Figure 4.7:</b> Example of equipment (Total Station and target prism).....	77
<b>Figure 4.8:</b> Example of early digitized site features from Area D and Area F of Tel Beth-Shemesh. ....	80
<b>Figure 4.9:</b> Features of Area F rendered in the GIS model. ....	82-83
<b>Figure 4.10:</b> Pottery buckets of Area F rendered in 3D with baulk shown. ....	85
<b>Figure 4.11:</b> Pottery buckets of Area F rendered in 3D .....	85
<b>Figure 4.12:</b> Excavation layers rendered in model of excavation units in Area F.....	87
<b>Figure 4.13:</b> Area F model shown using phasing scheme from north facing view .....	89
<b>Figure 4.14:</b> Area F model shown using phasing scheme from south-east facing view. ....	89
<b>Figure 4.15:</b> Area F model shown with digitized artifacts. ....	90
<b>Figure 4.16:</b> Example of Area D model.....	90
<b>Figure 4.17:</b> Area F model shown using chronological scheme from north-east view .....	93
<b>Figure 4.18:</b> Area F model shown using chronological scheme from north view.....	93

## Abstract

Many scientists have used the expediency of geographic information science (GIS) for archaeological analyses, such as predictive site location modeling and producing topographical site surveys. However, the use of GIS to explore the spatial relationships among the architecture, geography and site artifacts has rarely been done. This research focuses on visualizing and analyzing these relationships using GIS. The sites of Tel Beth Shemesh, Israel and the Fincastle Kill Site (DIOx 5), north-east of Taber, Alberta, were used as case studies, as they were very different types of sites. Based on field measurements and by using specific GIS applications and software, components of these sites were reconstructed in virtual space as GIS models. Other recorded field data were used as input parameters into the models in order to attain the most accurate representations and analyses of the sites. The analysis at Fincastle Kill Site used two types of GIS models: 1) a viewshed model to assess possible bison hunting techniques and 2) surface interpolation models that delineated correlations between high density and low density areas of archaeological remains. The investigation at Tel Beth-Shemesh used a GIS model to store, visualize, interpret and assess the quality and accuracy of the field data recorded during 2001 – 2004 excavations. Predominately, the work in this thesis did not aim at answering any profound questions about the archaeology of either site, although in some cases it did, but rather focused on developing useful GIS tools for the archaeologist. These GIS models show the value of the applications, and their applicability to archaeological sites around the world.

## Acknowledgements

I would like to thank CURA (Community University Research Alliance) and SSHRC for providing me with the funding required to carry out my research both in the field and at the University of Lethbridge.

There are so many people to thank it is hard to find where to start. Long before this research ever began it was Walter Aufrecht from whom I found support and the motivation to pursue this field. Without his interest in my undergraduate projects I may never have written this thesis. It was also he who sparked my interest in archaeology, but I'm not sure if I should thank him for that or not.

I have had a tremendous amount of support from all my family and friends, not only in school, but also in life's endeavors as well. I must thank my parents for always believing in me and allowing me to pursue my dreams no matter where they have lead. I will never forget any of the people who worked so diligently along side me during the summer of 2004 in Taber, Alberta, and also in Beth-Shemesh Israel. So many of you became my close friends then, and will always be. And thank you Candace McMillen, for spending so many hours diligently helping construct some of the data bases that were so important for this research.

Very special thanks to my co-supervisor Derek Peddle, and my committee member Stefan Kienzle. Thank you for all of your support, input and help, not only with my research and studies as a graduate student, but also during my years as an undergrad. Without the two of you I would not have the knowledge in GIS and remote sensing that I do today.

Most of all, I must thank Shawn Babel. Shawn, I couldn't ask for a better supervisor than you. From the beginning you have given me your undivided support and have always been there for me no matter what. Not only have you been an outstanding guide these past two years, but you have also been an outstanding friend. I will always strive to be as passionate as you in whatever I decide to pursue throughout my life. Without your willingness to believe in me I may never have had the opportunity to be where I am today.

# Chapter 1

## 1.1 Introduction

GIS was developed in the 1960's as a means to store, retrieve and display data associated with geographic phenomena through a visual medium. Since then the applications of geographic information science (GIS) have been used in a variety of disciplines ranging from remote sensing studies (Romano and Tolba 1996), to urban planning (Shiode 2001). Recently, GIS has become a very useful tool to carry out research and analyze information that falls outside the realm of traditional geographical sciences, an area that is typically associated with the use of GIS software (Allen *et al.* 1990). One discipline that has begun to increasingly draw on GIS applications is archaeology (Harris 1988, Romano and Schoenbrun 1993). According to Allen *et al.* (1990), a large portion of archaeological theory is based on the spatial relationships of the features and artifacts that comprise the archaeological site, and because of this it has been established that archaeological research has more in common with geography and the geographic information sciences than most perceive. Many scientists have used the expediency of GIS for archaeological analysis to do things such as predictive site location modeling (Kohler and Parker 1986), and completing topographical surveys of archaeological sites (Romano and Tolba 1994).

A significant amount of GIS work in archaeology has focused on two dimensional applications, however, there has been very little research conducted in regards to three dimensional GIS applications. Two dimensional GIS applications are regarded as planar, predominately focusing on length and width using a top down view, while three

dimensional GIS incorporates a height variable and can be viewed from any angle. A substantial number of the projects that apply two dimensional analysis have mainly focused on the general mapping capabilities of the GIS software to record the layout of the archaeological site, and therefore have mainly used GIS as a graphic database tool and have not explored the analytical possibilities that it has to offer for archaeological research even in two dimensions. Some of the three dimensional archaeological projects, such as the line of site analysis done by Madry and Rakos (1996), have utilized more analytically based approaches in their research but have predominately focused on similar types of analysis.

Based on an initial review of the literature it was evident that research in the area of GIS applications to archaeology is needed. When looking at both older and contemporary GIS use in the archaeological sciences it is apparent that the application of GIS in archaeological research has, in general, remained stagnant for some time. It is also clear that a significant amount of archaeological projects implement the use of GIS, but fail to utilize many of its important capabilities that in turn would be able to provide a far more robust analysis for the modern archaeologist. This thesis begins with an overview of geographic information science and systems research applied to archaeological projects (Chapter 2). The thrust of this research in the remaining chapters of this thesis is to explore and generate new GIS methods for the archaeologist to use as analytical tools for better site understanding.

During the summer of 2004 two very different archaeological sites were excavated. In May, the Fincastle Kill Site, coded DIOx 5 using the Borden site recording system, situated north east of Taber Alberta, Canada was excavated. Then, from mid

June to late July, Tel Beth-Shemesh, on the outskirts of the modern city Beth-Shemesh, Israel was excavated. These archaeological sites were used as the basis for this thesis research. Although these sites are only briefly mentioned in this chapter, they are described in more detail in each of their respective chapters.

## 1.2 Thesis Objectives

The main research objectives of this thesis were to: 1) use GIS technology to develop new analytical tools for the archaeologist to study a given site; 2) analyze multiple archaeological sites using these tools; and 3) formulate new and/or support existing hypotheses about these sites using the information obtained from the GIS based analyses. These objectives will be met by completing the following: 1) examining documented GIS research in archaeology; 2) conducting preliminary GIS analyses of Fincastle Kill Site and Tel Beth-Shemesh using existing data; 3) carrying out field work at the archaeological sites of Fincastle Kill Site and Tel Beth-Shemesh to obtain data for use in new GIS analyses; 4) developing new GIS analytical tools for both sites; 5) applying these specific analyses to the sites; and 6) evaluating the results of the analyses.

It should be noted that this work does not answer any profound questions about the occupants of either archaeological site, but it does use GIS to visualize, analyze and develop hypotheses about both sites by pushing the boundaries of present GIS use in the archaeology. Based on the literature available, the limitations of current GIS use in archaeology were identified and analyzed. Research objectives were developed based on the outcome of the literature and far surpass contemporary work.

### 1.3 Thesis Overview

In Chapter 2 of this thesis the literature is evaluated and a number of significant papers that discuss GIS use in archaeology are assessed. The chapter is broken down into sections that focus on different modes of GIS use in archaeological science. The two main types of papers that are reviewed focus on: 1) two dimensional GIS applications in archaeological research; and 2) three dimensional GIS applications in archaeological research.

Due to the very different nature of both sites, two completely different methodological approaches were required. Therefore, two separate Chapters (3 and 4) discuss the Fincastle Kill Site and Tel Beth-Shemesh rather than following a traditional thesis approach where the methodology chapter would be followed by a discussion of results. The methodology, results and discussion of these results are included in both Chapters 3 and 4 for each site. The fundamental ways in which field excavation techniques need to be adapted in order to embrace this new technology are also presented in each of these chapters.

Some of the sections of these chapters discuss quantitative based approaches to site analysis while other portions identify qualitative research methods. In both cases, the analytical methods used in this thesis push the combination of archaeology and GIS in new directions that up until now have not been explored in written archaeological research.

Generally, Chapter 3 and 4 focus on: 1) analysis of hunting techniques using viewshed study; 2) two and three-dimensional spatial density analysis of faunal and lithic remains; and 3) site excavation and feature validation using visualization models. Of the

three analyses described, the first two are both used to study the Fincastle Kill Site while the latter is predominately applied to Tel Beth-Shemesh.

In Chapter 3 (Fincastle Kill Site) GIS is used to create 2 types of analysis models. First, a viewshed model is used to support a hypothesis about a particular bison hunting style that may have been used. Secondly, two and three dimensional surface interpolation models are then implemented to statistically identify areas of the site where increased butchering activity likely took place.

In Chapter 4 (Tel Beth-Shemesh) field data is used to build digital models of two of the excavation areas of the site (Area F and Area D). The dynamic nature and visualization capabilities of the model are predominately explored. The chapter discusses the creation of the models from the field excavation stages up to data digitization and integration into the GIS. The visualization capabilities of the Area F model are used to validate the recorded 2003 and 2004 field data. The model is then used to inspect and verify the chronological sequence in the recorded field data.

In Chapter 5 (discussion) there is an evaluation of the long-term benefits of using GIS in archaeology. The chapter also addresses many questions surrounding the use of GIS in archaeology. The chapter illustrates that although the sites are situated in very different locations, and are associated with very different cultures, the described research methodology may be applicable to not only both sites, but possibly to many other sites located around the world.

Finally, Chapter 6 of the thesis addresses the need for the archaeological sciences to better embrace technological advances, especially those in the world of computer aided analysis. By coupling the latest research and technology in GIS applications with

fundamental archaeological research methods, this research aims to break new ground for the archaeologist who wants to establish a more comprehensive site analysis.

## Chapter 2

### Literature Review

#### 2.1 Introduction

There have been several articles published concerning GIS applications in archaeological research, however, based on the available literature, the degree to which different GIS applications have been used in the archaeological sciences remains quite minimal. This chapter evaluates a number of different papers that use GIS as the basis of their archaeological research. The chapter itself is broken down by the mode of GIS analysis that was used in each of the papers.

#### 2.2 GIS in the Archaeological Sciences, Mapping and Concepts of Data Sharing and Methodology

GIS, originally developed in the 1960's, was used in archaeological research as early as the mid 1980's (Harris 1986). It was originally used as a recording, storage and analysis tool for archaeological data. Although research in the area of GIS, and its applications to archaeology, has advanced significantly since the publication of Harris' work, he outlined the fundamental benefits GIS can bring to the discipline. Harris acknowledged two very important themes that transcend most GIS applications in archaeology: 1) archaeology has a strong bond with the traditional geographical sciences because archaeological sites and the remains that make up a site are all situated in distinct geographical space; and 2) there is a need to move from traditional archaeological data recording methods of hard copy data storage to soft copy digital data storage. Harris

stressed the importance of being able to store archaeological data in a digital format so it can be updated, edited, manipulated and shared. He also commented on the important reasons for storing and displaying archaeological data in a GIS format. Such a format allows one to overlay different data sets to examine their inter-relationships, and enables archaeological data to be stored based on its geographic location. This information can also be overlaid or linked to other data, such as digital topographic layers, for further analysis.

Harris (*ibid*) used Brighton, England, as a research area to demonstrate these particular uses of GIS. The main goal of his study was to investigate the spatial location of known archaeological sites in this area (130km<sup>2</sup>), and to provide a GIS database that could be accessed by third party groups such as the Brighton Museum. The archaeological data were stored in a raster (pixel) format at 100m resolution and also included soil type, geology, altitude, slope and aspect. The archaeological sites were classified based on a typological system. Therefore, the sites were also grouped based on similar characteristics of the overall site or the archaeological remains themselves.

Within this study Harris identified four major benefits to storing the archaeological data in a GIS. Firstly, archaeological data can be linked and integrated in the GIS based on multiple spatial referencing schemes. Therefore, the information can be retrieved based on different types of attributes, such as the site's time period or its spatial location. In this highly accessible form, data retrieval and analysis can become easier for first (producers of the data) and third party (users of the products derived from the data who were not originally associated with the production of that data) GIS users. Moreover, the data can then be linked to other existing data sets to add information for

further analysis. Visual presentation of spatial data and updates can also be completed “on-the-fly”. Secondly, GIS can simplify the ability to carry out advanced spatial and temporal analyses of archaeological sites because the data can be easily examined statistically or graphically. Thirdly, GIS has flexible graphing and mapping procedures. This feature allows a wide range of maps or other visual mediums to be produced to display archaeological phenomena. These maps can be used for a wide range of applications from working field maps to maps for public distribution and publication. And fourth, data retrieval within the GIS is quick and efficient and can be used as the basis of an enquiry-based system for makeshift requests for information. Essentially, if information regarding a site or many sites is requested from a GIS database, that information can be instantly shared or analyzed. In this sense GIS can be used as the primary decision making tool in the management of the historical environment.

Another early paper that discussed GIS applications and their benefits in archaeological research was that of Wansleebeen (1988). This paper listed numerous GIS applications in archaeological research, including site location analysis, site pattern predictions and site pattern reconstruction. Despite the fact that outdated material existed in this paper, there was still an emphasis on some of the main benefits of GIS and its use in archaeological research. For example, Wansleebeen discussed the ability to overlay and utilize multiple data sets for analysis. Moreover, he explained how statistical methods can be used for archaeological site prediction and the analysis of the spatial relationships between known sites. The methods of GIS analysis discussed in this paper may seem rudimentary to the contemporary archaeologist who uses GIS. However, they remain some of the most widely used GIS applications for archaeologists.

As Harris (1986) pointed out, a considerable amount of data can be integrated into a GIS for the purpose of archaeological analysis. By the 1990s, advancements in computer storage capacity and processor speeds enabled archaeologists to integrate a number of archaeological and geographical variables to study entire regions.

Hunt (1992) used GIS to analyze site catchment to understand settlement patterns. He noted that GIS enables the researcher to overlay several coverages, allowing multiple variables to be used simultaneously. Moreover, due to the intensive data capabilities of the GIS the analyst can maintain what Hunt calls the 'natural' or 'original' thematic categories of data within the study area. Thus, the analysis can be carried out on an objective rather than a subjective basis. For example, earlier studies would have employed subjective soil categories such as 'good', 'better' and 'best'. With the data capabilities of the GIS, archaeologists can use a distinct soil classification layer (true pedology) as an input variable. These are data that would have likely been collected in the field using soil analyses. Hunt implied that earlier research would have limited analysts to using less complex variables as inputs to a model. According to Hunt, another benefit of GIS is the ability to modify the shape of the catchment area. He explained that in previous site catchment analyses, studies primarily employed circular shapes to outline catchment areas of sites, but triangles, squares, and hexagons have also been used. All these shapes are symmetrical, meaning that the site is bounded equi-distantly with the archaeological site positioned in the center of the shape that forms the catchment boundary. By using GIS, archaeologists can more effectively carry out site catchment analyses because they are not limited to a set shape, but can create instead a polygon that provides a better 'fit' to the actual catchment area.

Guillot and Leroy (1995) have not only used GIS for analysis, but to also store and share archaeological data. By using GIS software they were able to compile data from 180,000 archaeological sites throughout France. These data provided archaeologists and regional planners the means to quickly create maps using spatial operations such as data overlay, buffering (i.e. creating a 5km buffer region around an archaeological site) and intersecting (integrating two spatial data sets while only retaining those features that are common to the spatial extent of both data sets). According to Guillot and Leroy (*ibid*) these particular maps have proven useful for urban planning and the management of archaeological and historical sites. Based on those data, they also used GIS to study the Picardie region of Northern France. By overlaying archaeological and geographical data they determined that certain archaeological sites were situated in particular areas where current geomorphic processes could prove to be detrimental to their preservation. Furthermore, regional planners are able to use these types of data outputs to better plan development in archaeologically sensitive areas.

More recently, Ebert (2004) revisits many of the concepts mentioned above and discusses these, along with new theories, from a current perspective. Ebert notes that the three major uses of GIS in archaeological sciences as seen in the literature are data visualization, data management and data analysis. Ebert also delineates that the three most prominent modes of GIS study in archaeology (all of which are discussed below in other academic publications), are site location modeling, GIS procedure related studies and studies, relating to landscape archaeology. The paper then describes the two main data types that are used in a typical GIS, both of which are used in this thesis. These data types are point data (the spot location of an artifact) and areal data (i.e. polygon or raster

data used to represent a surface or region). Ebert notes that point data can be used to analyze trends of the distribution of a particular variable across a given area, while areal data sets can be used for predictive modeling, catchment analysis, watershed analysis and simulation, all of which are important research applications for the archaeologist. He also points out that GIS can be used for two and three dimensional applications, and the three dimensional capabilities of a GIS are a valuable resource, especially to the archaeologist. However, a considerable number of 3D applications are not truly 3D in nature. The paper refers to these as 2.5 dimensional, and this makes representing archaeological elements such as stratigraphy and cultural levels very difficult. This is something that this thesis aims to address.

Ebert's paper also focuses on illustrating the minimal GIS use by Canadian archaeologists. According to Ebert (2004) there have only been two major academic archaeological GIS projects in Canada. Predominately, archaeology GIS projects have been carried out by cultural resource management (CRM) groups. Because much of the information obtained in these CRM projects is proprietary, these groups are less likely to publish the results of their study. There has also been very little published by academic researchers. Most works using GIS are theses and dissertations. Ebert (2004) suggests that the reason for the seemingly limited academic interest in GIS stems from a lack of interest or support for GIS instruction in archaeology programs at the post secondary level. A review of the published literature confirms Ebert's conclusion that archaeologists working in the United States, Europe and other regions are incorporating GIS into their projects on a more frequent basis.

### 2.3 Employing Three Dimensions with Digital Elevation Models and Terrain Variables in Archaeological Analyses

In an example of incorporating a number of variables, Madry and Rakos (1996) used GIS to study “line of sight” and “cost surface” analysis in the Arroux River Valley, Burgundy, France. That study used digital terrain data to analyze and model the interaction of past human cultures and the natural environment. By linking these they were able to analyze ancient behavioral patterns, such as travel networks, based on environmental factors. It was originally believed that the road networks were created based on their proximity to hill forts because they would provide protection to the travelers by maintaining a constant visibility over travel routes. Using digital elevation models, Madry and Rakos (*ibid*) tested four separate hypotheses that the location of the roads was determined solely by:

- 1) the visibility of the roadway from the maximum number of hill forts in the area;
- 2) the location of the ridge crest (the highest point along the ridge);
- 3) the path of least change in elevation near the ridge line (the dividing line along the crest of the ridge);
- 4) some combination of the cultural and environmental factors listed in hypotheses 1 – 3.

The study began with a “line-of-sight” analysis being run on the digital elevation model to test these hypotheses. A line of sight study utilizes the digital elevation model to determine the amount or particular area(s) of a given region that can be seen from one or many points within that region. In most cases the line of sight analyses answers the question “what can be seen from here?” Based on preliminary results it was shown that a considerable amount of the study area fell into regions that were visible from the ancient hill fort locations. Because of the strong correlation between the road and the hill

fort locations the authors decided that further analysis be conducted looking at other factors, such as optimum travel routes. A “cost-surface analysis” was then carried out to evaluate travel routes based on optimum corridors. This type of analysis computes travel routes of least impedance based on selected criteria. In this particular study, Madry and Rakos (*ibid*) selected three variables: (i) highest elevation; (ii) maintaining lowest slope; and (iii) remaining in view of the hill forts. They first considered each variable separately, and found that each test produced different results. Based on slope, the cost-surface analysis computed far too many possible travel routes. The corridors that were computed based on their ability to remain in view of the hill forts were ambiguous. Therefore, the authors ran tests that combined these variables to compute optimum corridors. They found that multiple variables produced the best results. Madry and Rakos determined that the travel routes were likely designed based on a combination of least change in elevation and low slope with a preference to remain within sight of the hill forts. Not surprisingly, their computed paths closely followed the known ancient travel routes. They also noted that similar tests were conducted for other regions in the study area, and yielded comparable results.

Llobera (2001) used GIS in a similar way as Madry and Rakos’ (1996) study. Llobera’s research explored topographic prominence and its relationship to ancient movement patterns. In particular, he concentrated on using topographic data to analyze landscape affordances. Llobera’s (2001) research was focused in Yorkshire, England, and took into account Late Neolithic-Early Bronze Age (3000 – 1500 B.C.) round barrows (burial features), Late Bronze Age linear ditches and Iron Age square barrows as landscape features. Topographic prominence was calculated at radius values of 30m,

90m, 150m, 330m, and 510m, and it was found that there were high correlations between the concentrations of particular burrows and ditches and differing topographic regions. As the radius values were increased, these correlations became more apparent. The study identified that Bronze Age round barrows were predominately located in prominent topographic regions (areas with higher terrain relief and more visible), while Late Bronze Age linear ditches were mostly located in less prominent topographic regions (low lying areas and areas with less terrain relief). This was possibly because the Early Bronze Age people wanted to see locations of burial features from a long distance. Alternatively, maintaining larger features such as ditches could only be done in regions of low topographic prominence.

Llobera (2001) then applied these results to a larger region in hopes of discerning the overall behavior of the location of the landscape features in relation to topographic prominence. A mean topographic prominence map for the entire study area was calculated based on smaller regional topographic prominence maps created in the first section of the study. In this large area approach, Llobera found that Early Bronze Age barrows typically remained in regions of high topographic prominence even when taking into account a larger search radius. Very few of these barrows were located in areas of low topographic prominence (i.e. only a small number of the barrows could be detected until an individual was in close proximity to them). Higher variation was found regarding the relationship of Late Bronze Age linear ditches and topography. A number of these ditches maintained high prominence throughout the landscape, but a large percentage were situated in regions of moderate topographic prominence. Rather than an obvious connection of how topographic prominence was seen in the first section of the

study, the patterns of the Late Bronze Age linear ditches were then compared with the Late Neolithic – Early Bronze Age round barrows. The results from this comparison revealed what could be a territorial system based upon these landscape features.

Llobera (2001) noted that in this particular study GIS was an invaluable tool that revealed information that could not have been obtained through traditional archaeological approaches. In this case, Llobera used a GIS to analyze the topography and the archaeology of an entire region, something that would have taken years and may not have even been as effective using traditional archaeological techniques.

Wheatley (1995) utilized GIS as a tool for topographic three dimensional analyses. In this case, line of site analysis was used to study the possible intervisibility between Neolithic long barrows in Southern England. The locations of 27 known sites were scanned from pre-existing hard copy maps and digitized into a geographic information system. Digital elevation models were interpolated based on digital survey data recorded at 10m intervals, giving the 20km<sup>2</sup> study region a DEM with 80m pixel resolution. A “line of site” analysis was then calculated from each long barrow. Areas of the study region that could be seen from each long barrow were identified and vice versa. Further data were then derived from this initial analysis to test the hypothesis that the long barrows in this region were built with no regard for the ability to view one another from their location. By displaying the new “line of site data” it was found that in particular areas the long barrows tended to occur in locations where a significant amount of other barrows could be seen. In other locations, however, no relationships between line of site and location could be established. In these cases a more random distribution of sites emerged. Wheatley used these data to theorize that the intervisibility of the long

barrows may not necessarily be a result of the want or need for intervisibility, but rather a simple choice to have the long barrows constructed on high ground.

A similar study that employed terrain variables, such as elevation, slope and aspect, was conducted by Kvamme (1992). Kvamme examined the relationship between topographic prominence and location of Hohokam rock piles over a small 400m x 400m plot of land in southern Arizona. Initial inspection of the study area showed that a majority of the rock piles were located near ridge tops and on gentle slopes with North facing aspects. Kvamme utilized pre-existing topographic data to build a DEM for the study area. From this DEM he was able to generate separate information layers consisting of slope and aspect values. When the rock piles were mapped onto the DEM those hypotheses were supported. Aspect data derived from the DEM also supported the hypotheses that the rock piles have a tendency to be positioned in a north-facing manner. However, further slope analysis showed that a significant number of the rock piles occurred on steeper slopes than originally thought.

Kvamme (*ibid*) also uses a ridge drainage index to analyze the topographic prominence of the rock piles. He found that these archaeological features were likely used to grow Agave plants and may have been used as features to gather and hold surface runoff. The ridge drainage index revealed that a large percentage of rock piles were located in regions more ridge-like in character, with rock piles typically located slightly below these ridges. His findings supported the hypothesis that the rock piles were used to collect surface runoff since this position on sloped areas below ridges allowed for water to run properly to collection basins. This particular article is important in showing how pre-existing data can be used in a new project, and showed the importance of utilizing

three dimensional models as a basis for exploring geographic relationships with the archaeological remains.

A different application of GIS, but still combining topographical and archaeological data, was the work of Romano and Schoenbrun (1993) and Romano and Tolba (1994; 1996). They used GIS as a tool to study the ancient Roman city of Corinth. Their research at Corinth employed field survey equipment to acquire topographic measurements of the study area. These measurements focused on the location of archaeological remains such as city roads, walls and monuments. Once recorded in the field, the researchers transferred the information to a digital format and compiled it in a GIS to create a map of the city. The project also utilized pre-existing data, such as topographic maps and aerial photographs from the Greek Geodetic service. This was done to create a more robust database of the archaeological site. Romano and Tolba (1994) integrated digital remotely sensed images from SPOT and LANDSAT satellites in order to supplement the pre-existing and newly acquired topographic data. All integrated topographic data were then used to create a three-dimensional surface of the study area. In addition to the topographic surface map, dynamic databases were constructed throughout the projects entirety. These databases included information such as the name of the building or structure, its date of construction and bibliographic references. They were linked with the GIS and served as attribute data for the topographic maps. These maps and integrated data were used to study the spatial organization of the site and to predict areas for which to investigate further. Areas of topographic highs or lows for example may have contained buried archaeological features. This was an important factor as it enabled some archaeologists to streamline fieldwork by reducing time spent

exploring new areas to excavate. The integrated data also served as a reference tool for the archaeologists in the field.

This research project demonstrated some additional applications of GIS research in archaeology. In this case, GIS was used to store field data in a digital format, giving the analysts the ability to integrate and manipulate the stored data as they worked in the field. As new field data were acquired they could be stored directly into the GIS together with pre-existing data. Furthermore, researchers were able to integrate and use older field data with newer data, a process that is fundamental to this thesis work as well. The work of Romano and Tolba (1996) is one of a few that aims at recording and modeling larger scale field data of archaeological remains such as buildings and roadways. However, their research only took three dimensional measurements of the location and orientation of diagnostic elements of the structures into account, and did not include main features, artifacts or other elements. As seen by the void in the available literature, few archaeological projects have used GIS to fully map and model archaeological remains.

GIS integrates statistics, mathematics and visual tools, such as mapping and 3D visualization to carry out such studies making them all available to a single person or group of users. As explained above, GIS allows researchers to incorporate a significant amount of variables limited only by the power of the computer and its storage capacity. These variables can be used together, to carry out analyses that can be small or very large in scope. Llobera's (2001), Madry and Rakos' (1996), Romano and Tolba's (1996) and Kvamme's (1992) studies are prime examples of this.

## 2.4 High Detail Data Capture and Analysis

Alternatively, research focusing on modeling individual artifacts has been conducted by Andretto *et al.* (2003). Using computers with special modeling software they designed and digitally rendered highly detailed models of archaeological remains. Although they did not employ GIS in their methods their research is worth mentioning because it is one of the few projects that built detailed models of distinct artifacts. Such models make it possible for museums to incorporate interactive displays where visitors can manipulate, look at, and interact with digital versions of artifacts that are normally locked behind glass doors or in storage.

Gerber (2000) is one of the few archaeologists who attempts to fully model archaeological remains. Gerber's research used algorithmic complexity as the basis for performing a "predictive site reconstruction" of the mainly mudbrick structures at Tel al-Hamidiya. Based on the orientation of excavated mudbricks it is possible to predict and identify where unexcavated remains or destroyed mudbrick structures existed. Gerber was able to achieve significant results using this model. His research methods are important for many reasons. When archaeologists utilize predictive models they have the ability to reduce time and cost restraints. Essentially, the archaeologist will have a better idea of the location of specific remains at the site, making excavations more efficient. However, due to the nature of such predictive models, they can only be applied in very particular circumstances, such as mudbrick or stone architecture. Thus, this type of application is only pertinent to archaeological sites that contain specific remains.

As noted above, a considerable amount of the archaeological research that has used GIS as an analysis tool focused on site location prediction. Brandt *et al.* (1992)

performed archaeological site location modeling in the Netherlands using a given set of variables in a GIS. The variables used in the model included soil type and geomorphology of the study region, unit surface area, ecological border distance, proximity to water and proximity to water or ecological border. All the data that were used to build the model were derived from pre-existing maps. Areas that were known to contain cemeteries, burial grounds or archaeological remains were exempt from the analysis because these sites were already known and therefore could have induced error into the prediction model. All data were input into a raster-based system and applied using a weighted model. The weight of each variable was determined on a judgmental basis, and ranged from 'most favorable' to 'poor'. Based on preliminary results the model could predict the location of 74% of the sites. Fifty-six of the seventy-six sites occurred in the "highest expectation zones".

## 2.5 Archaeological Site Location Modeling

Similar to the study above, Perkins (2000) used GIS to analyze the relationship between site location and landscape in Albegna Valley, Tuscany. As model inputs, he applied altitude, slope, aspect and geology as the main variables used to discern what particular location types were associated with specific settlements and how these relationships changed through time. By using this approach Perkins identified distinct changes in site location landscape relationships over time. He noted that in regards to the variables used in the model there was little or no relationship between settlement patterns and landscape during the 7<sup>th</sup> century B.C. From the 6<sup>th</sup> to 3<sup>rd</sup> centuries B.C., site location landscape relationships began to emerge, and during the 2<sup>nd</sup> century B.C., different site

location landscape relationships were recognized. It should be noted that Perkins' model employed specific variables to identify site location to landscape relationships. Although his study identified little or no site location landscape relationships during certain time periods, this was when only taking into account these particular variables. It is likely that site location landscape relationships occurred based on other variables that were not present in this model. As seen in the examples noted above, GIS is also able to combine an extensive amount of archaeological and geographical data for a number of studies, allowing analysis to go well beyond the data/information scope of earlier applications that did not employ GIS.

Typically, the more comprehensive a study is, the better understanding of the site the archaeologist is likely to have. Understanding the paleoenvironment for example allows a better comprehension of the relationship between ancient landscape and the archaeological record, which is a fundamental component of robust archaeological research.

Burton and Shell (2000) employed GIS to study the distribution of archaeological sites in relation to the paleoenvironment. Based on an 8.3km<sup>2</sup> sand and gravel extraction site, data from approximately 1100 boreholes were used to digitally model the subterranean soil and sediment horizons in order to model the paleoenvironment of the research area. Their goal was to use DEMs to analyze and display successive underground layers (strata). These strata consisted of peat deposits, alluvium, sand, gravel, clay, and soil horizons. Of the available strata/horizons, Burton and Shell selected the present day surface, the upper surface of the main alluvium deposit, areas of peat, the top of the main gravel layer and the top of the main basal clay layer as surfaces

to model. Upon inspection of these newly created continuous surfaces (raster based surfaces in the GIS) they determined probable areas of archaeological significance. Burton and Shell were unable to use statistical probabilities to predict site location due to a relatively small study area, which was also a rather homogeneous landscape. However, they were able to visually examine the surface models for general topographic trends, where the likelihood of archaeological remains was more significant. The visually deterministic methods were based on comparing the modeled landscape for each significant stratum to known settlement tendencies. Although statistical analyses were not applied, they were able to implement a qualitative approach that yielded results that helped to determine the archaeological significance of particular locations within the study region. Burton and Shell's research is an example of three important features of GIS. Firstly, modern GIS software is generally a statistically robust group of programs, and therefore archaeologists can use it as a statistical analyst to create probability maps and other visual aids that represent statistical data in a spatial context. However, in some cases statistical methods cannot be utilized. In these cases, GIS allow for qualitative type studies, such as visual analysis. These types of analyses can potentially yield results as important as those produced using statistical methods. Secondly, modern GIS software, such as ArcGIS, has high-quality visualization to display spatial data in a graphical context in two or three dimensions. And thirdly, it shows that GIS users can integrate pre-existing data into contemporary studies.

## 2.6 Summary

Based on the literature review, one can see that there has been a relatively small number of studies published that have applied GIS in archaeological research. Moreover, the degree to which GIS was used, differed from study to study. Therefore, none of the approaches mentioned have been well developed for the research performed in this thesis. Archaeologists have utilized GIS primarily as follows: 1) mapping existing sites; 2) site location prediction; 3) archaeological data storage; 4) studying the relationship between the archaeological site/remains and the landscape; and 5) studying the perceptions of past peoples within the landscape. Very few GIS applications in archaeology have gone beyond these types of uses. The available literature suggests that very few scholars have begun to explore the full potential of GIS in archaeological research or have not yet realized the possibilities that GIS has to offer the analyst. This study aims to go beyond the scope of the research cited above, and to break new ground for the possible uses of GIS in archaeological analyses.

## Chapter 3

### The Fincastle Kill Site (DIOx 5)

#### 3.1 Introduction

This chapter outlines and discusses the research conducted on the Fincastle Kill Site (DIOx 5). Field methodology and laboratory analyses used for the GIS applications performed in this part of the thesis are explained. Section 3.2 gives a site description and briefly examines the archaeological significance of the site. Sections 3.3 and 3.4 discuss the preliminary research of the site, and document the field protocol and methodology used to gather important GIS data during excavation. Sections 3.5 - 3.8 discuss the process of building the GIS database and the different analyses that it was used for.

This chapter has two main goals: 1) to assess hypothesized bison hunting techniques used at the site; and 2) to delineate and spatially correlate areas of the excavated site that may have high and low concentrations of archaeological remains. The first goal was accomplished by using a viewshed model (Section 3.6), and the second goal was achieved by using two and three dimensional interpolation models (Sections 3.7 – 3.8). The broader theme of this chapter however, is to demonstrate GIS in the context of archaeological research for new types of analyses that would otherwise be extremely difficult using conventional research tools. Throughout this chapter, many of the GIS methods and analyses were used in conjunction with traditional archaeological research techniques to yield innovative approaches to understanding the archaeology of the Fincastle Kill Site.

### 3.2 Site Description and Archaeological Significance

The Fincastle Kill Site, also known as site DIOx 5, which is the name given to it using the Borden code geographical grid reference system, is located north-east of Taber, Alberta, Canada, near the town of Purple Springs (Figure 3.1). The site is located in the Fincastle Grazing Reserve, found near Fincastle Marsh. The landscape of the site and the surrounding area is typical of Southern Alberta: tall prairie grasses (Blue Gramma and various grains), cacti and other plants that thrive on little moisture sit on top of rolling fields. The climate is semi-arid and sees minimal precipitation throughout most of the year. The site experiences strong prevailing winds that predominately move from the west. The soil and sediment is normally dry. The sandy soil and sediments, wind and vegetation have played major roles in the development of the landscape. Presently, much of the area around the site is affected by aeolian processes, characterized by the sand dunes that have migrated along an eastern route. The Fincastle Kill Site sits within one of these dunes.

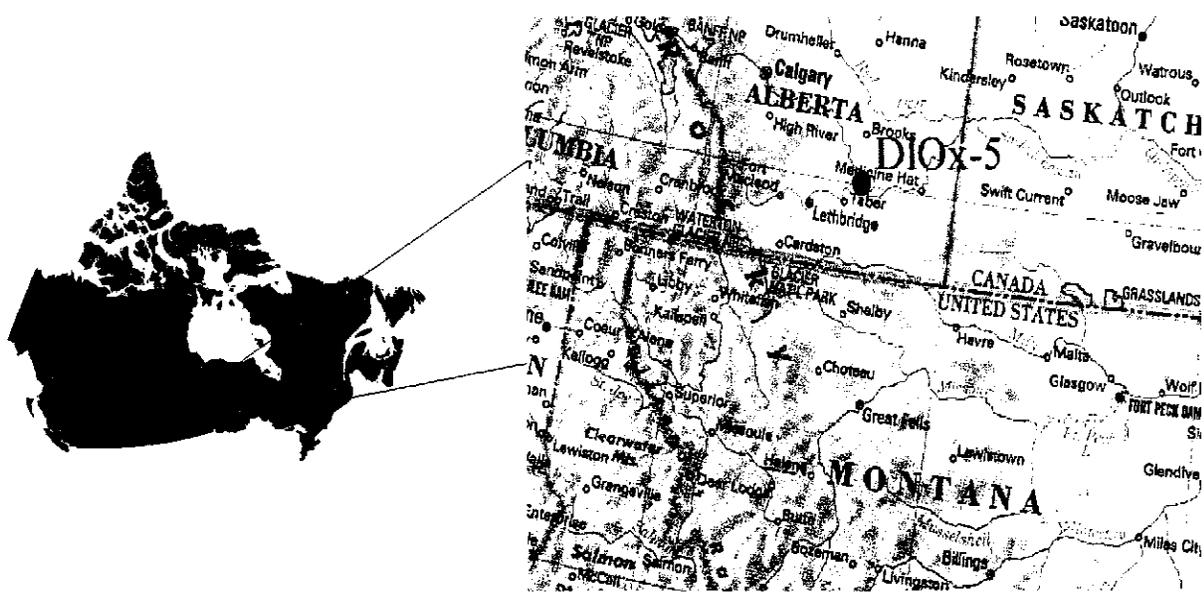


Figure 3.1: Location Map of the Fincastle Kill Site (DIOx 5).

The archaeological site as defined in 2004 is approximately 120m long from north to south, and 250m wide from east to west. The dune itself ranges from 0.5m high at its western side to approximately 4m high at its eastern edge. Excavations in the first half of May focused on the western area of the site, while excavations in the second half of the month and during August moved to the eastern side (Figure 3.3). The archaeological remains that were found at the site include faunal remains (predominately bison bones), fire broken rock (FBR), projectile points, and lithic debitage.

Based on the archaeological evidence, it is likely that the site was used for the hunting and butchering of bison. Using a bison metacarpal and vertebra that were excavated at the Fincastle Kill Site, the site was carbon dated to 2540 +/- 50 years before present. The archaeological remains, and more specifically the projectile points, lead us to believe that the site may be connected with the Sonota group, a North American plains culture that was heavily dependent on bison hunting (Walde *et al.* 1995). However, known dates for the Sonota culture typically place it between 1900 and 1000 years before present, thus potentially making the Fincastle Kill Site the earliest known archaeological site in the northern plains that is connected to the Sonota culture.

### 3.3 On-Site Preparation

Excavations at the Fincastle Kill Site were carried out during two separate periods in the summer months of 2004. The first excavation phase was conducted as part of a summer field school through the University of Lethbridge and Red Crow College, and ran from May 3 - May 28, 2004. The excavation team included 24 undergraduate students and two graduate students, and was directed by Dr. Shawn Bubel.

The GIS work for this project began in early March of 2004. At this time a 2000 vintage 0.5m resolution digital aerial photograph of the archaeological site was acquired from Valtus Imagery Inc., an Alberta-wide company that procures and provides high resolution aerial images. The digital image was orthorectified and georeferenced to UTM zone 12, using NAD 27 as the projection plane as this is the most common projection used for this geographic area (Figure 3.2). Orthorectification is typically carried out on most air-photos and digital imagery to negate geometric distortions created due to off-nadir viewing (not taking the air-photo looking straight down at the ground), thus making it possible to use the imagery as a basis for conducting proper ground measurements. These orthorectified images are commonly referred to as orthophotos. Most often digital air-photos are also georeferenced so they can be integrated into a GIS and so their true location on the Earth's surface is known. The orthophoto used had a geometric accuracy of less than 0.5m error (one pixel). An accurate ortho-image is also important for conducting ground measurements with GIS software.

Ground work conducted during earlier visits to the site identified base points (BP) that could be recognized on the ground and on the digital image. This ground work also identified general areas of the dune where the excavations would be carried out. These

base points were used as datums to maintain consistent measurements during the excavation process. Five BPs were established within the dune area (Figure 3.3).

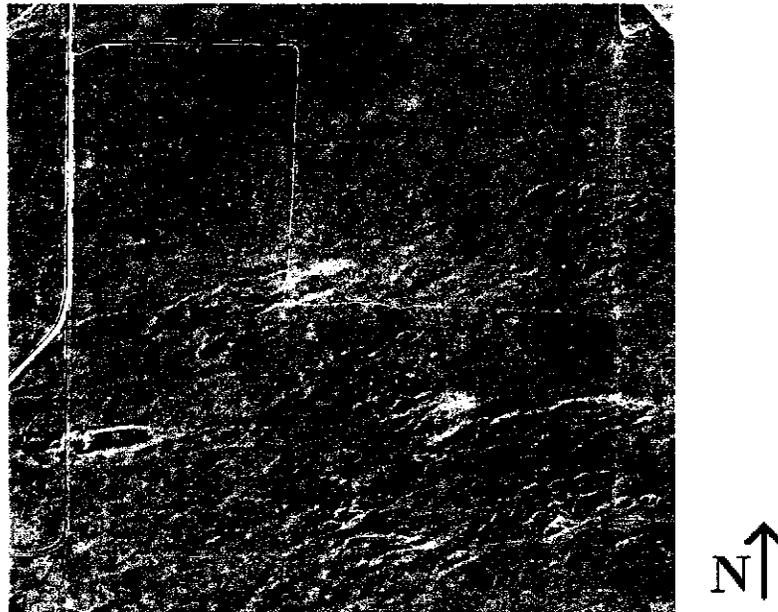


Figure 3.2: 0.5m pixel 2km x 2km coverage digital air photo projected to universal transverse mercator (UTM) zone 12, 1927 North American Datum (NAD 27) used for georeferencing.

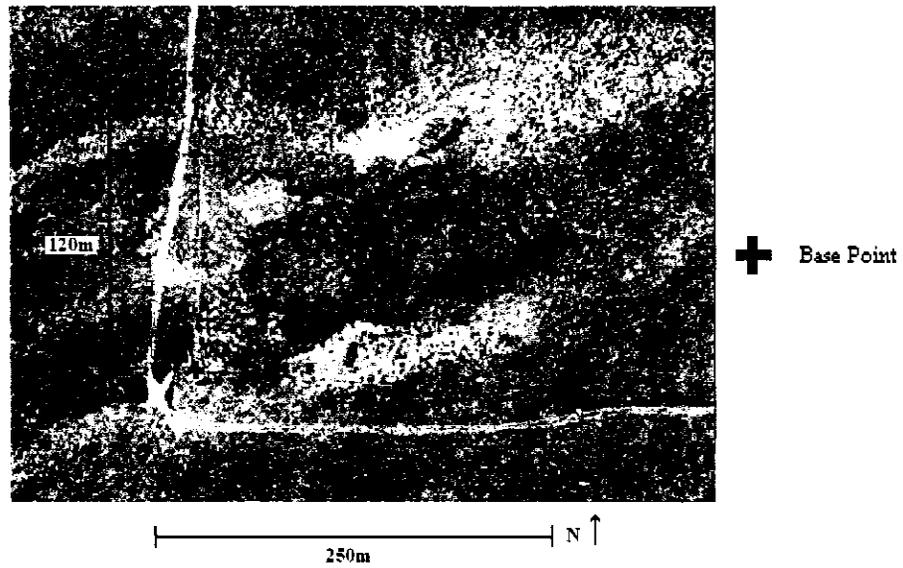
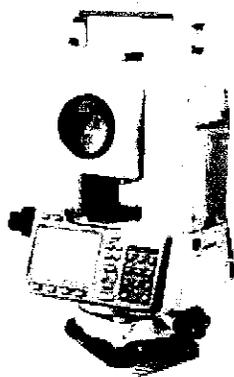


Figure 3.3: A closer view of the site showing the location of base points (BP's) on the dune area.

Using ArcGIS 8, a 120m x 260m grid consisting of 1m<sup>2</sup> cells was overlaid on the digital image and used as the basis for the ground excavation grid. The *Fishnet* extension available for ArcGIS 8 was used to create the grid. The *Fishnet* extension is a simple tool that creates a symmetrical grid of vector based lines at a specified distance. For example, in the case of the Fincastle Kill Site, 1m was used as the output grid size. The southwest corner of the grid was aligned to the southwestern base point (BP 1).

The excavation area was set up following a checkerboard excavation method made of 1m<sup>2</sup> excavation units aligned on the ground in accordance to the digital reference grid (Figure 3.5). This created a system where the actual field excavation units could be properly georeferenced in the GIS data base. A Sokkia© Total Station™ that uses laser ranging was used to accurately measure out and place the units. By using the fixed BPs, the Total Station™ user was able to triangulate their location on the site and then accurately measure out and position each excavation unit within the checkerboard. This technique maintains a consistent position of the checkerboard pattern with each grid cell positioned in a parallel north-south manner.



**Figure 3.4: Example of Sokkia Total Station used for surveying and measuring the location of archaeological remains.**



**Figure 3.5: Checkerboard pattern in East Block of excavation area.**

Once the excavation units were laid out the relative elevation (in relation to the BP's) of each unit datum was measured. The datum point used for each unit was the southwest corner of the excavation square. This was also accomplished using the Total Station™ equipment. Once the units were laid out, excavation began. Although GIS was used to lay an excavation grid over the entire archaeological site, only certain areas were selected for excavation. As noted above, the areas selected for excavation were based on initial ground work and test pits that were dug in random areas of the site.

### 3.4 Field Methods

Manual excavation was carried out using Marshalltown® 45/5™ and 45/6™ hand trowels. Small digging equipment, such as the hand trowels, were chosen over larger equipment, such as shovels, to maintain a higher level of control over the amount of sediment removed. Moreover, using trowels minimized accidental displacement of artifacts while excavating. Other equipment used included 5m long metric measuring tapes, metal plum bobs, bubble line levels, paint brushes and other small digging equipment such as wooden skewers, serrated knives and dental tools.

Each unit was excavated by a team of two individuals. The excavation units were dug in 5cm arbitrary levels with the first level being measured at the same height as the string line, which is essentially the ground surface of the unit. In some cases the ground surface was above the string line because of undulations in the terrain of the site. In circumstances such as these, the sediment that existed above the starting level (the string line) was counted as part of the initial layer. In such cases, however, the amount of sediment above the string line was minimal. As the sediment matrix surrounding the archaeological remains was removed the location of the exposed artifacts, ecofacts or features was measured and recorded. This was accomplished by vertically positioning the plum bob above the remain to measure its northing and easting location. 5m measuring tapes were used to determine the distance from string lines that were placed around the sides of the excavation unit (Figure 3.6). The z measurement (vertical depth) was recorded by measuring the length of the plum bob string from the line level drawn straight across from the south-west datum pin (after it had been removed from the unit). As noted above, the south-west corner of the unit was used as the base point unless this

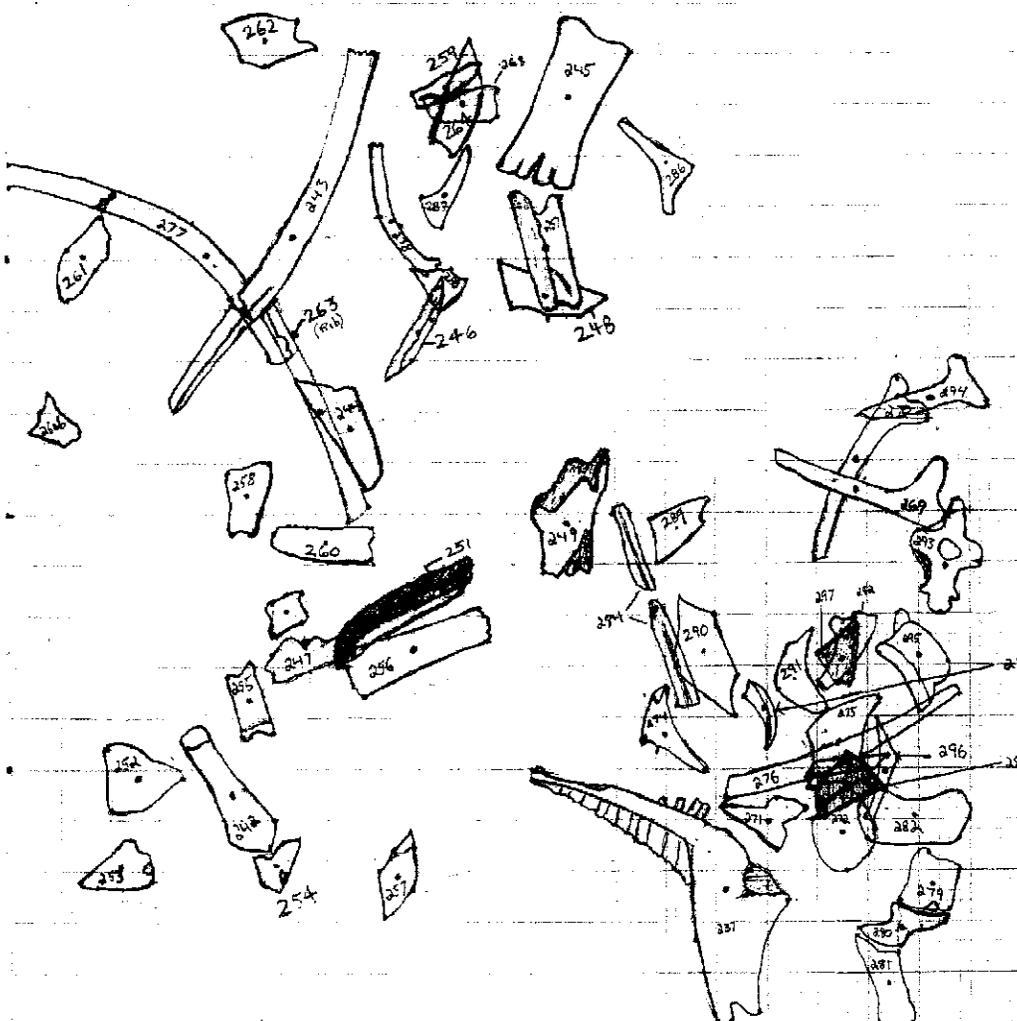
corner collapsed (due to the excavation of adjacent units). If this occurred another corner could be used as a datum, once it was measured from the fixed base points of the site. The Total Station™ was used as the main device to measure the exact height of each unit datum relative to the base points. Therefore, the z measurement of all archaeological remains that were recorded could be directly compared.



**Figure 3.6: Example of field methods (measuring the spatial position of an artifact).**

For example, the student in Figure 3.6 is measuring the Northing position of the archaeological remain they have uncovered. The tape measure is positioned on the southern edge of their excavation square attached to one of the string lines bordering the south edge of the unit. The measured values were then recorded and plotted at a 1:5 scale on all-weather mm graph paper (Figure 3.7). These graphs are referred to as level graphs. Therefore, each graph represents a 5cm thick level. In some units certain levels

contained far more remains than could possibly be graphed on a single sheet of paper. In these situations multiple graph sheets were used for a single layer. Alternatively, some levels did not contain any archaeological remains, and therefore no graph sheet was used.



**Figure 3.7: Example of level graph with graphed archaeological remains. Numbers refer to catalogue code used to record archaeological remains.**

The plotting of archaeological remains was done following a strict rubric. Faunal remains were mapped only if: 1) the element was identifiable; or 2) the bone was larger than 5cm. All knapped lithic artifacts, including projectile points and debitage were mapped. Other lithic remains that were identified as artifacts, such as fire broken rock (FBR) larger than 2cm were also mapped on the level graph. Each different

archaeological remain was drawn a particular way to easily identify it. For example, the faunal remains and fire broken rock were drawn using clear polygons and polygons with hatching respectively. These polygons were drawn in the exact shape of the elements that they represented. Debitage was displayed using an x, while projectile points were drawn using polygons representing their exact shape. Catalogue numbers were also written next to each mapped archaeological remain for referencing purposes.

Other field data that were acquired included measurements and graphs of soil/sediment profiles, level sheets recording the general matrix of each level (this included the elevation below datum of each level, the particle size of the soil/sediment and Munsell soil colour), with repeat information and other notes of interest recorded in the field notebooks.

Surface elevation data measured with the Total Station™ were also acquired and used to produce a DEM of the site, including the dune ridge area. The DEM was created at a 3m pixel resolution, achieved by measuring the locations of individuals holding stadia rods with reflective prisms traveling across the site stopping at approximately 3m intervals. Areas with significant slope change were measured at closer intervals. It was decided that a 3m pixel would generate enough detail in a DEM of the dune area, and would be a resolution high enough for analytical use.

### 3.5 Laboratory Methods

Once the excavation of a level was complete the graph was brought to the laboratory for GIS data systems integration. Work in the laboratory began with digitizing the entire set of graph sheets. To digitally store the visual information from the graph sheets in an acceptable GIS format, Adobe Photoshop 6<sup>©</sup> was used to scan the level

sheets at a 200dpi (dots per inch) resolution. This resolution was required to create digital scans of the level sheets where the information on them (the graphed archaeological remains) could easily be seen and distinguished. The scanned images were then stored as high resolution .TIFF (Tagged Image File Format) files, because .TIFF format pictures do not degrade in resolution when viewed at different scales. This is known as a loss-less format. This is a very important factor for some of the processes described in this section. As well, .TIFF is a file type that is recognizable by ArcView GIS 3.2, which is the main software used for the digital integration of the field data.

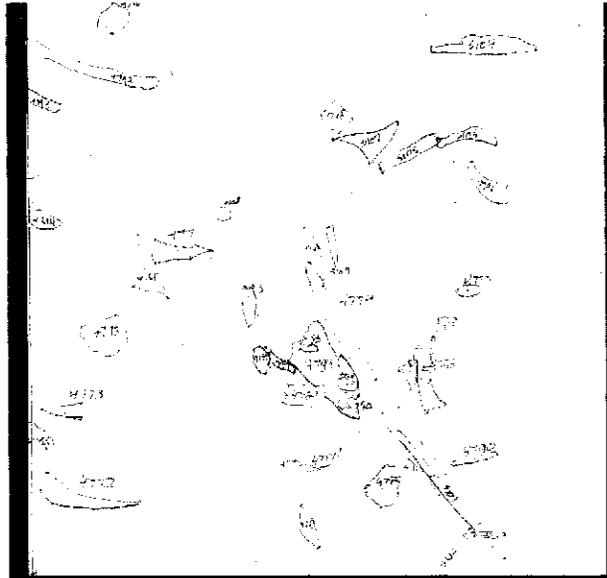
To accurately georeference the archaeological remains from the graph sheets, the original file containing all geographic information ('world file' .TFW) that was used for the digital aerial photograph (Figure 3.2) was used to reference the digitized graph sheets. A world file is a simple text file that contains the geo-positioning information of the digital image it corresponds to. This information is then read and used to position the image by the GIS program when the image is first opened or imported into the GIS. For this exercise however, the information contained in the world file was slightly altered in order to compensate for the considerably smaller area of coverage (2000m x 2000m digital aerial photograph vs. the 1m x 1m excavation unit). Therefore, the northing and easting values contained in the .TFW file needed to be adjusted (approx. 1.9km change) to compensate for the different sizes of coverage areas. In each case, northing and easting information was provided to correctly position the bottom left corner and upper right corner of the .TIFF image. Because of the nature of the digital aerial photograph and the excavation units (both are squares) only a simple adjustment of the referencing values in the world file was needed.

As each subsequent unit was digitized and the location shifted, the world file was updated to provide the correct location of the bottom left and upper right corners of the graph sheets. A single world file was used because the geographic positioning information for multiple graph sheets from the same excavation unit were all from the same location. Again, due to the symmetry of the represented ground area on the digitized graph sheets (1m x 1m), once the .TIFF file was properly georeferenced, the hand graphed remains on the graph sheets were also in their correct positions in the GIS. In this case, the image did not need to be stretched or skewed to fit the applied reference scheme. This is important since any stretch or skew of the image would render the location of the archaeological remains incorrect, thus leading to possible misinterpretations of the site. When this was complete, the excavation units were georeferenced to the recorded northing and easting position of their southwest datum on the digital ground excavation grid, as explained in Section 3.3.

After completing the georeferencing procedure, the hand drawn archaeological remains represented on the .TIFF images were digitized into Arc View GIS 3.2 readable data files. This process was accomplished by using the available tools within the GIS to digitally hand trace over the digital graph sheets, thus creating a new overlay file composed of polygons. Figure 3.8 shows a digital graph sheet with the digitized faunal remains layered on top. Polygons, rather than line segments, were used to render the new data since: 1) the faunal remains would be better represented visually as polygons rather than line segments; and 2) polygons are a more dynamic data type to work with in latter stages of the analysis that involve three dimensional visualization (Figure 3.8).

Hand digitization of the archaeological remains required a considerable amount of time due to the large number of measured remains drawn on the graph sheets (approximately 5000 items). While data integration continued in the GIS, research assistants manually catalogued the excavated remains, beginning with the lithic debitage and projectile points. As these artifacts were processed in the laboratory, their measured attributes, including material type, material colour, size, length, width, weight, thickness and other identifiable characteristics, were recorded and entered into a digital Microsoft® Excel™ data base. This information was then added and associated with the GIS polygon files using the catalogue number as the common data base field. The fact that the attributes of each item were entered directly into a digital database saved a considerable amount of time because there was no need to transfer the attribute data from a hard copy format, to a digital format, and then to a GIS.

Once all faunal remains were digitized, all other remains, such as fire broken rock (FBR), projectile points and debitage, were digitized. To capture the dimensional characteristics of the FBR and projectile points, polygons were again used in the digitization procedure. Since these were small, an “x” was deemed the most suitable way to mark the spatial location of debitage that was recorded on the graph sheets. As a result, more detailed information regarding the shape characteristics of the debitage did not exist. Thus, the locations of debitage were recorded using points in the GIS, instead of polygons. FBR, projectile points and debitage were digitized after the faunal remains because of the relatively small overall percentage (<5%) of artifacts that they represented from the entire collection.



a



b

**Figure 3.8: Digitized graph sheet (a) with digitized faunal remains overlaid on top (b).**

The GIS digitization process thus far has involved 2 dimensions (northing and easting geographic locations) regarding the remains from the 5cm excavated levels. However, this does not include a thickness measurement for these remains. While this research was being carried out, only a small number of faunal remains were examined

and analyzed for dimensional measurements. Therefore, only a few polygons had available dimensions that could be used as attribute data for three dimensional modeling. To solve this dilemma, average dimensions were calculated for each type of faunal remain that was digitally represented. For example, each femur was assigned a thickness of 8cm, a measurement based on the average documented thickness of excavated femurs at the Fincastle Kill Site. Thus, each element (femur, rib scapula, etc.) would have equal thicknesses when displayed in a three dimensional view. Once the faunal remains are processed in the laboratory, their true thickness measurements can then be added to the GIS data base.

In addition to the archaeological remains, the main dune in which the site is located, was modeled. As explained earlier, numerous surface elevation points were taken at equal intervals along transects across the dune with the Total Station (Figure 3.9). Using the ArcGIS 9 3D Analyst application, a 3m grid cell resolution DEM was interpolated using the inverse distance weighting (IDW) method. The DEM created covers the inner eastern section of the parabolic dune and some of the surrounding area. A 3m<sup>2</sup> pixel was chosen as the most suitable interpolation size because it was directly based on the sample intervals that were recorded in the field. Interpolating to a smaller pixel size may have induced error into the digital model, while using a larger pixel would result in an overall loss in data quality.

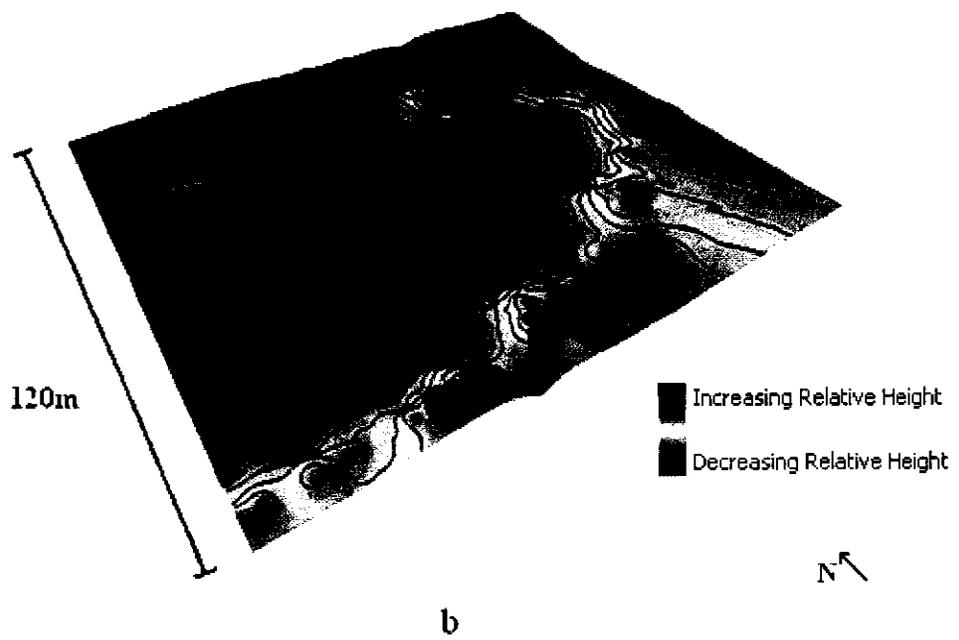
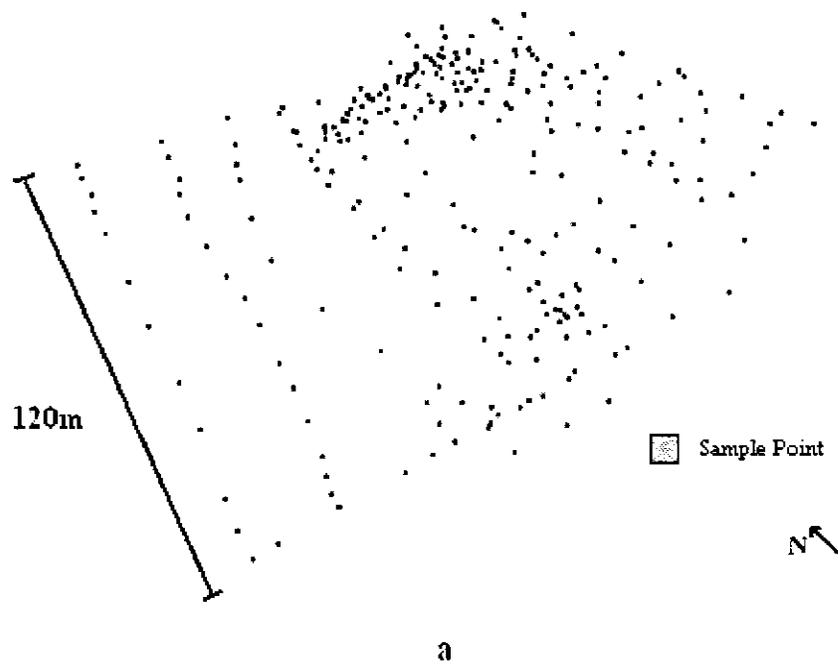


Figure 3.9: Sample points for DEM interpolation (a) and final DEM with .25m contours (b).

Again, using the same program, a shapefile consisting of .25m contour intervals was created to capture the surface relief of the dune. The DEM was then given a vertical exaggeration to better display the subtle changes in the undulating dune surface. This vertical exaggeration is needed to effectively visualize the dune because the greatest range in elevation is approximately 4m.

### 3.6 Viewshed Analysis

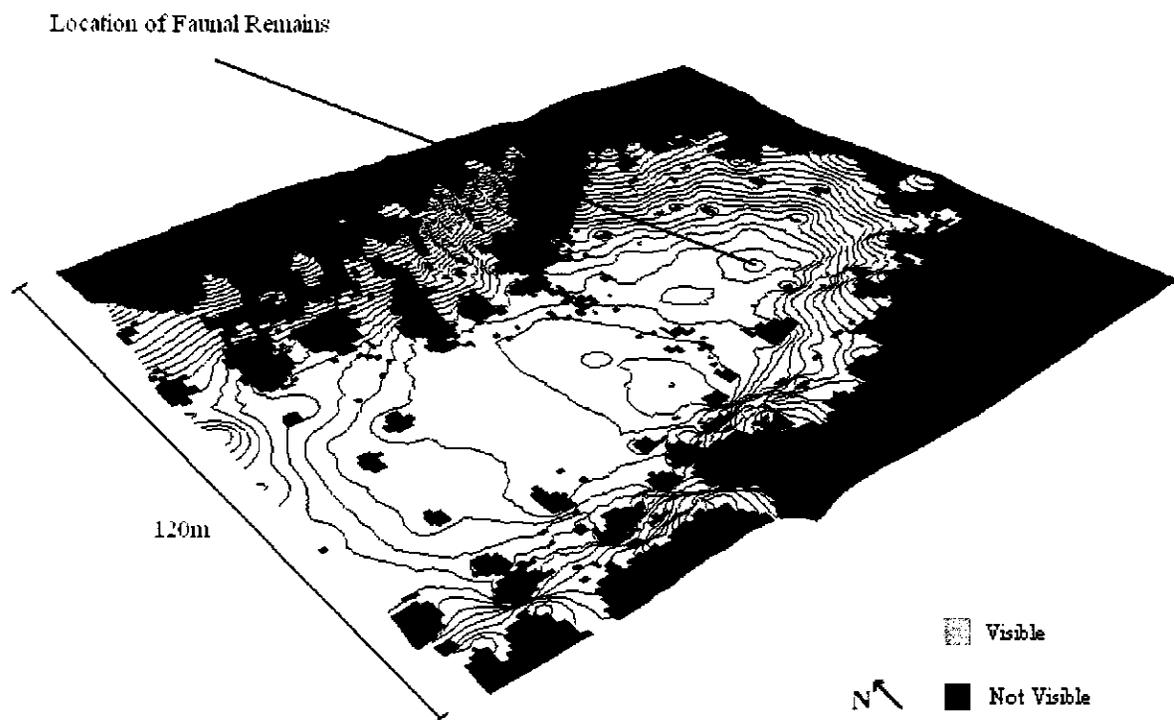
Many North American plains cultural groups used sand dunes as a tool for hunting bison similar to what was done at the Fincastle Kill Site. In most instances the people would drive the animals upwards into a parabolic or barchan dune at which point the bison would become immobilized due to the slope of the dune, the length of the incline and the depth of the sand. The running bison would become slowed and tired, eventually unable to evade the hunters. A well known example of this is the Casper Bison Kill site located in Casper, Wyoming (Frison 1974). In some cases the hunters built a barricade, often corral-like, along the crest of the dune if circumstances, such as a low dune crest required it.

At the Fincastle Kill Site, however, researchers hypothesize a slightly different hunting technique. Using this hypothesized technique it is likely hunters may have hidden on the outer edge, along the top of the dune waiting to ambush the bison when they came to the center of the dune where they used it as a watering hole. This hypothesis was developed because the dune is small in size and no postholes were found to suggest a corral structure was built to keep running bison contained in it. Furthermore, lacustrine deposits were found that are contemporary with the excavated archaeological

remains. This was known based on geoarchaeological analysis (soil and sediment profile analysis) conducted at the site during the time of excavation.

Viewshed analysis in ArcView GIS 9 was used to determine if this hypothesis would have been an effective way to hunt bison at this site. Using the DEM of the Fincastle Kill Site (see Section 3.4), a single point was digitized in the center of the bone bed, a location where the bison were likely watering and killed. From this point, a viewshed surface was created (Figure 3.10). The result is a new raster layer representing what can and cannot be seen from the given point (the central location of the excavated faunal remains).

To compensate for the standing height of the bison and the hunters, the viewshed point was given an artificial elevation of 3m above the dune surface. This elevation compensates for both the crouching height of the hunters (1m) and the approximate head height of the bison (2m). The analysis did not compensate for shrubbery that may have been located along the upper ridge of the dune, therefore it represents a “worst case” scenario for the hunters. Currently, the most prominent plant life at the Fincastle Kill Site is indigenous wild flowers, sage bushes and prairie grasses, all with approximate heights of less than 0.75m. If this vegetation existed at the time the site was used, which is likely the case, the hunters may have used the vegetation to hide behind, giving them extra cover. The heights of the vegetation can be accounted for by adjusting the elevation of the view point. However, as explained above, it was decided to give the bison advantage in order to calculate the minimum amount of area that could not be seen from a bison’s vantage point.

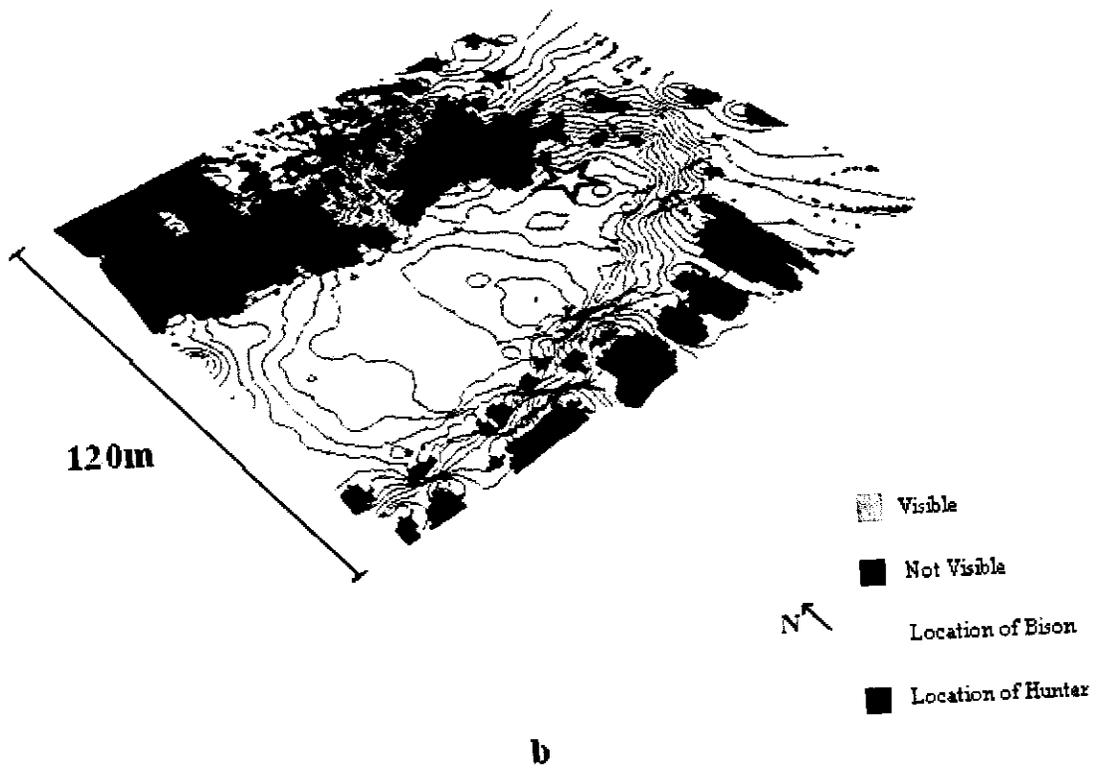
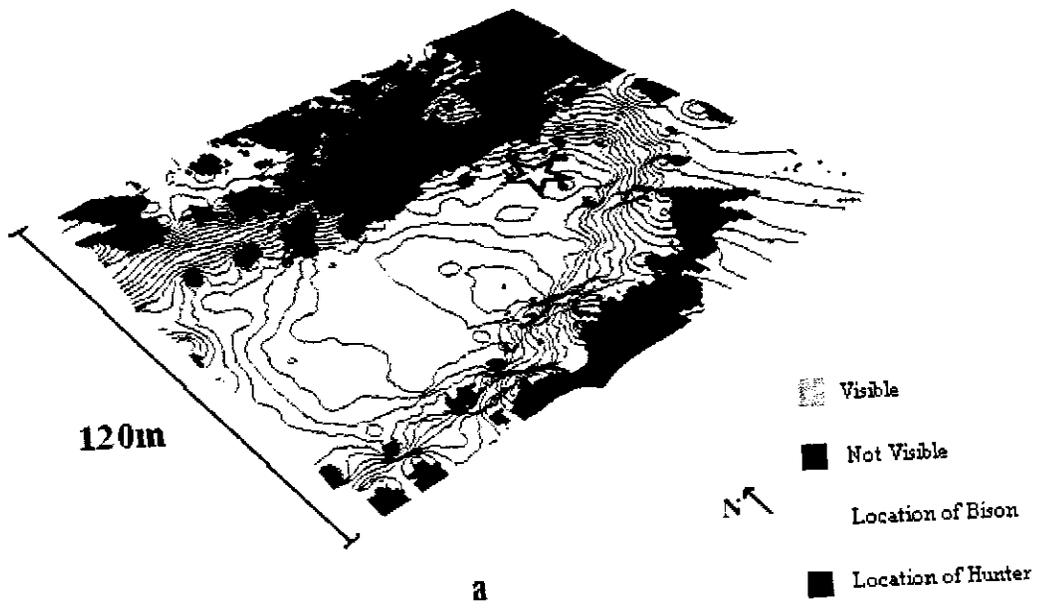


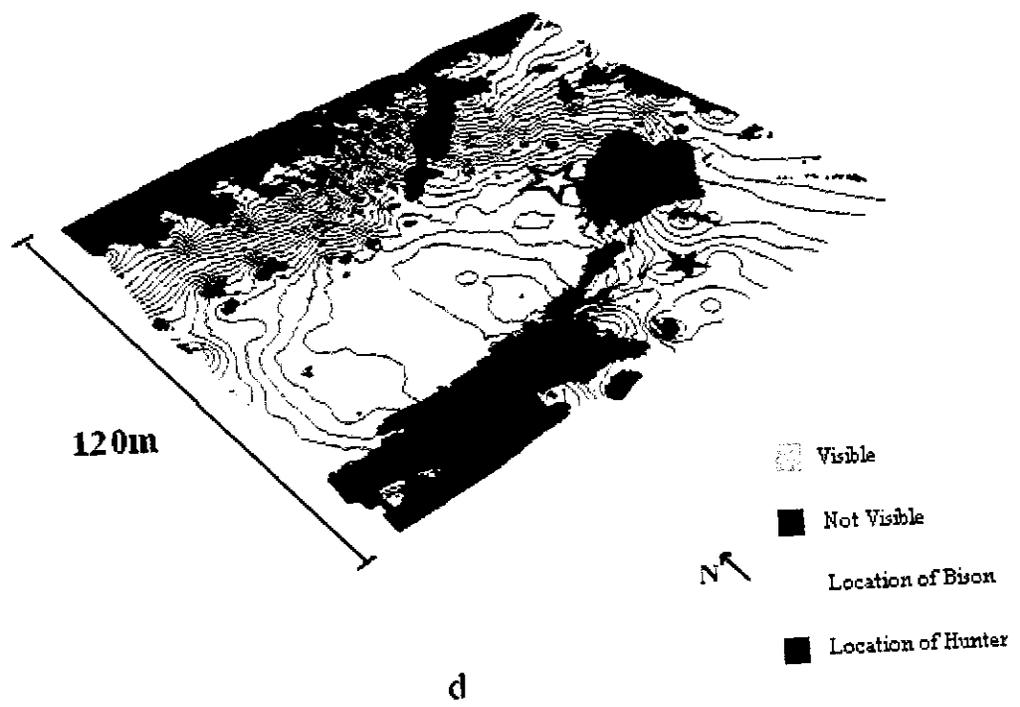
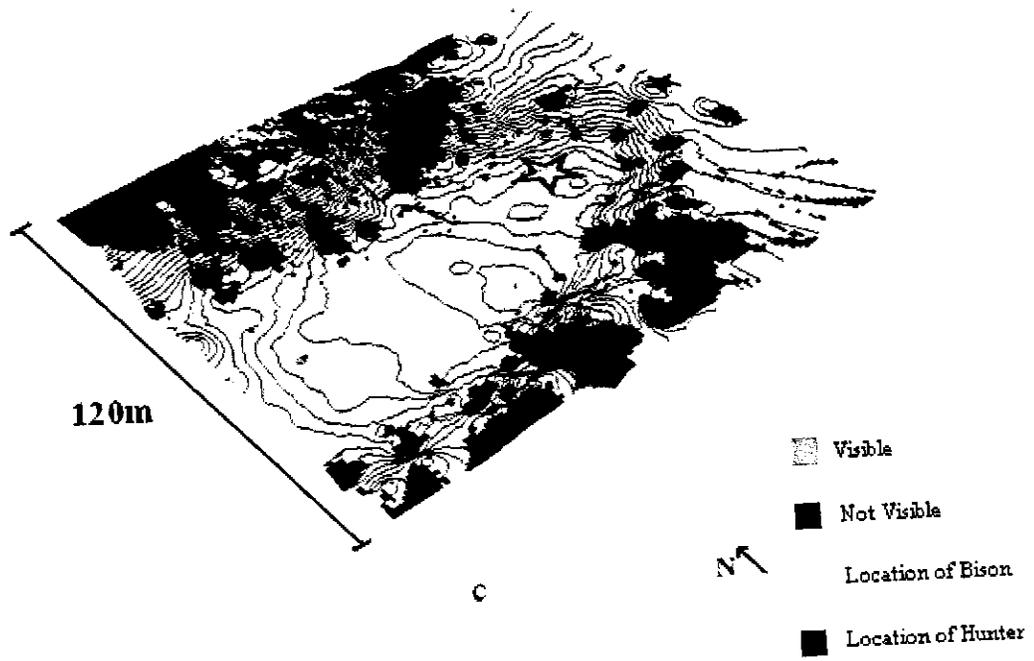
**Figure 3.10: Viewshed surface.** The areas that the bison were able to see are shown in green. Areas not visible are shown in red. This viewshed was created from a central region of faunal remains using a 3m elevation for the viewshed.

The viewshed created using the DEM assumed that the present position of the dune was the same at the time it was used. Although this may or may not have been the case, the analysis was conducted to test the effectiveness of this hunting strategy. Should future geoarchaeological work find a different environment (i.e. new dune location, dune height or morphology) a new viewshed can be created based on the reconstructed paleoenvironment. At present, the viewshed illustrates that the majority of the dune surface located behind the main ridgeline is not visible when viewing from where the faunal remains are located. This position is likely where the bison were situated before

they were killed. According to the viewshed analysis, the hunters could have positioned themselves where no ridgeline exists. In this situation, hunters could have held positions almost entirely surrounding the bison within the dune, making an ambush highly effective.

Alternatively, Figure 3.11 demonstrates a number of viewsheds from the hypothesized hunter's view point. Five possible hunter locations were selected along the dune ridge. These points, located within the red zone (the region of the dune that the bison can not see from their perspective) of the primary viewshed analysis were digitized. Multiple viewshed layers were created using each of the 5 hunter positions. Finally, a viewshed surface was created using all five hunter positions simultaneously. This last surface took into account the combined view points of all 5 hunters at one given time.





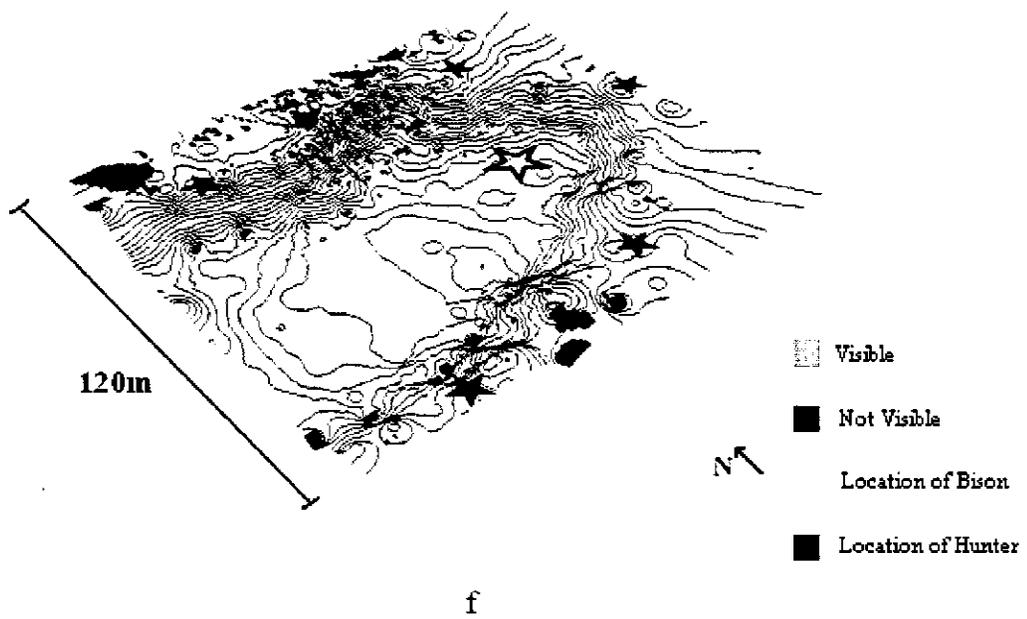
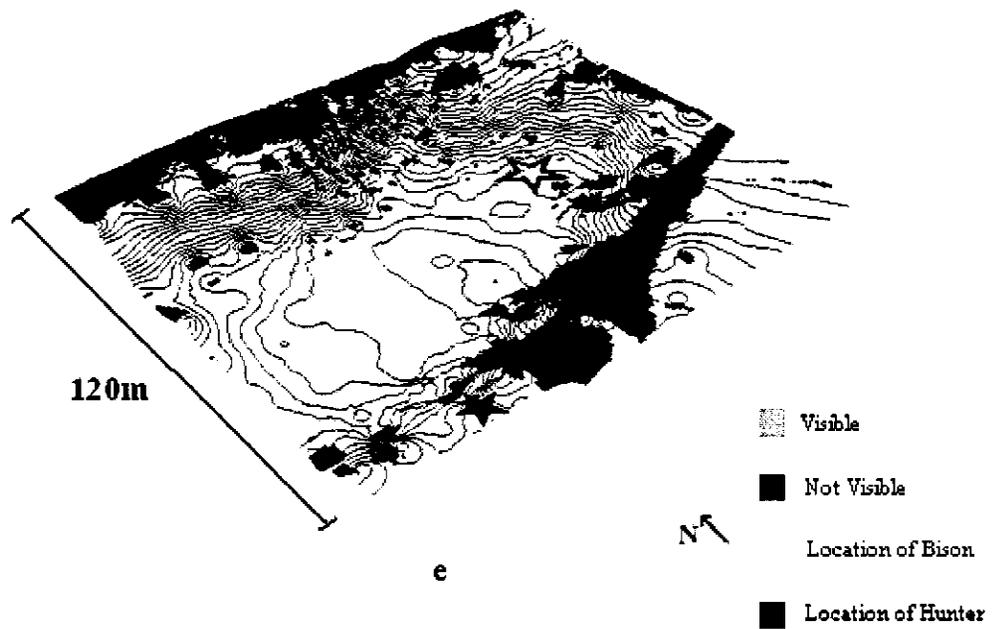
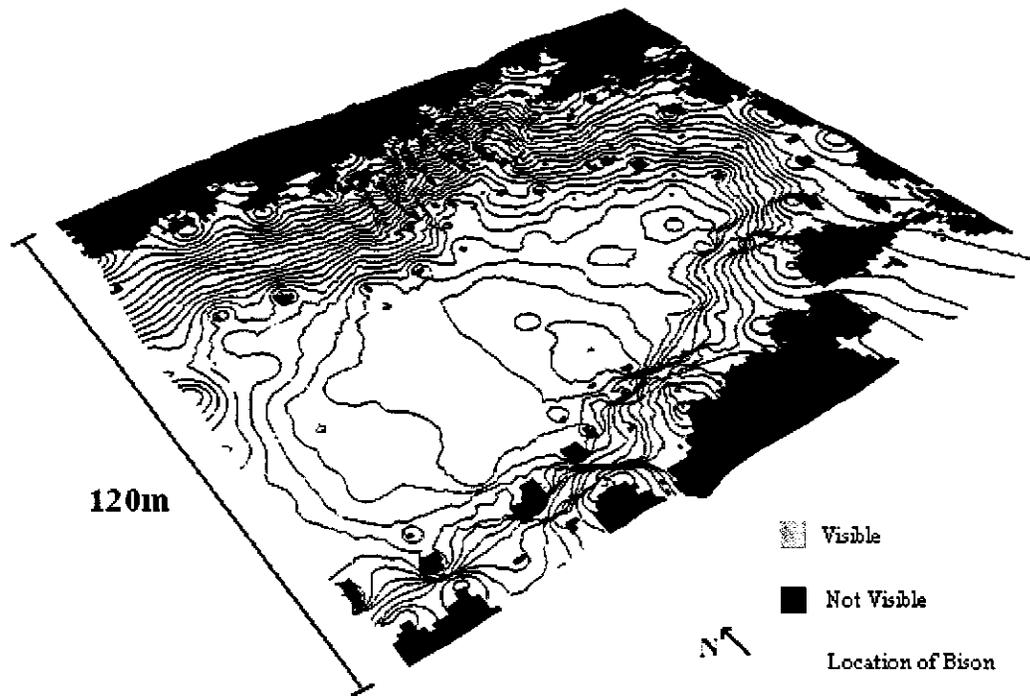


Figure 3.11: Figures a - e show a comparison of viewsheds created from each different hunters' (blue stars) view position of the bison (yellow star). Viewshed f represents all five hunter positions simultaneously.

When comparing each of the individual viewshed layers one can see that depending on which hunter position was used, there were certain regions of the dune that were not visible. However, regardless of which point is used as the input for the hunter's location, the bison are always visible. When using all hunter points in conjunction with one another, almost the entire dune region, including the location of the bison, is visible.

The bison would have needed to travel from the outside to the inside of the dune to access the area where the watering hole existed. Therefore, the bison likely traveled in a west to east direction when entering the dune. Based on the geoarchaeological evidence (soil/sediment profile analysis), the entrance to the parabolic dune was most likely from the west, within the arms of the dune extending in this direction. With this in mind, a viewshed analysis was created to analyze the path that the bison would have likely taken to get to this location. A point file was created along this path and was used to represent a herd of bison traveling in an eastward direction through the inner region of the dune. A viewshed analysis was then conducted using this new point file. The same parameters that were used for the primary viewshed analysis were again used as inputs into this viewshed model. These results showed that considerably more area of the dune was visible from the bison's viewpoint when using the new points as the input file (Figure 3.12). However, there were still regions of the dune where hunters would be able to hide and remain undetected. Even when using the original hunter positions from the primary viewshed analysis, only two locations (Location 1 and 5 in Figure 3.11) had to be adjusted to fit in the area that could not be seen using the new viewshed model. It should be noted, however, that the points representing the bison path may not necessarily be representative of the bison herd because it is not known if the herd traveled through

the dune as a condensed or more dispersed unit. Either way, the points used for the viewshed analysis favor the bison giving them more visible area by using dispersed points as the inputs for the viewshed surface. This was done to give the bison the utmost advantage in this test.



**Figure 3.12: Viewshed surface.** The areas the bison were able to see are shown in green. The areas they are unable to see are in red. This viewshed surface was created using points along the “bison path” using a 3m elevation for the viewshed point. Surface is shown with 0.25m contours.

To determine the true hunting technique used at the Fincastle Kill Site would require research inputs that go well beyond GIS use and the viewshed analysis presented above. There are many ways that the dune could have been utilized as a hunting device that have not been explored in this application. For example, a fence could have been erected around the crest of the dune to trap bison herded into the enclosed area by hunters. Although no fence post holes have been found at the Fincastle Kill site, it remains a hypothesis. Another possibility may involve the use of the site in the winter. If the snow pack was deep enough, the bison may have become slowed in the drifts when driven into the site by hunters. Analysis of the bison faunal remains will eventually yield seasonality information, but this has yet to be completed.

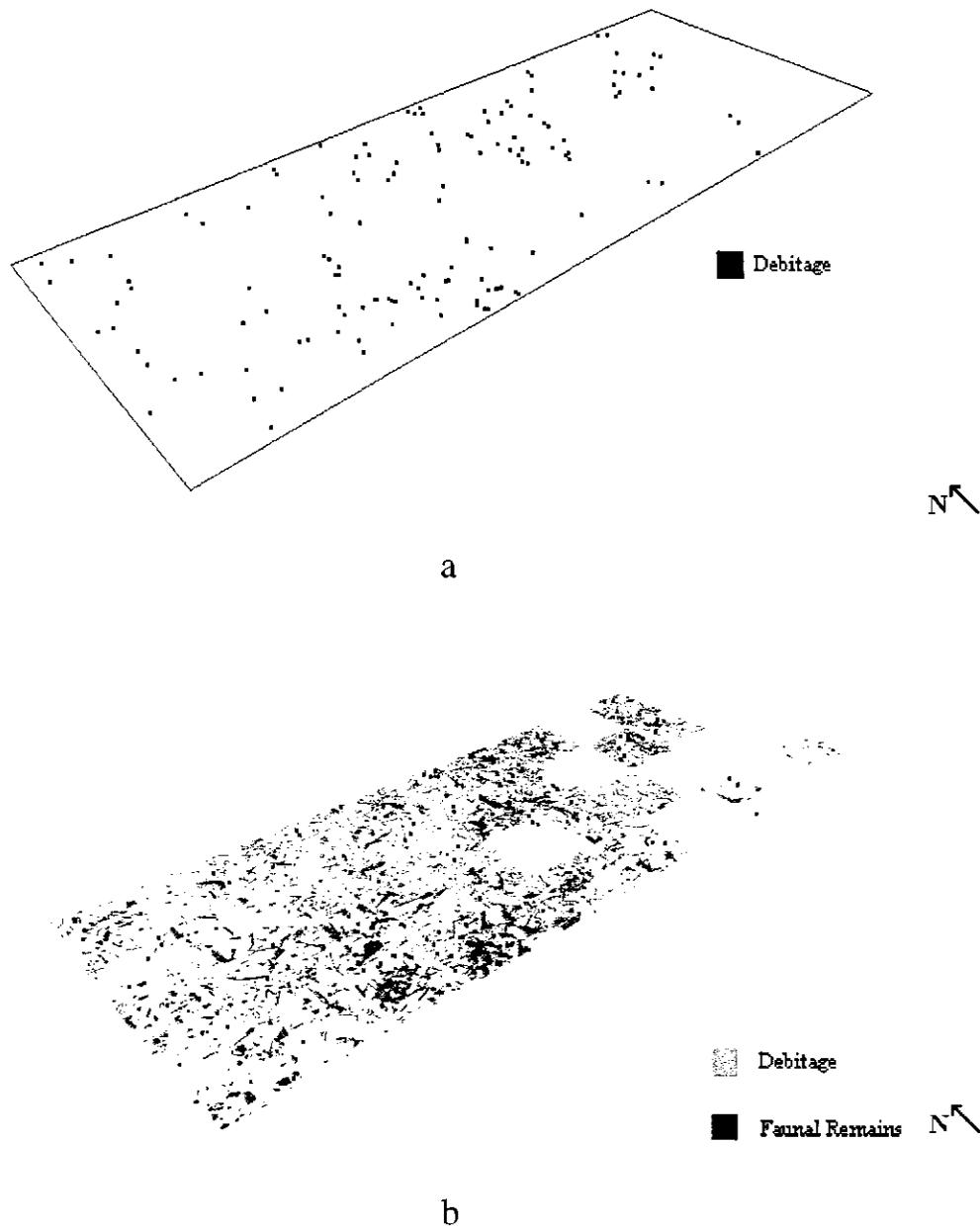
Furthermore, the model has not taken into account some of the most important factors that would otherwise quickly disprove the ambush hunting theory suggested. It is known that bison use scent as a method of predator detection. Although this was not accounted for in this viewshed, the model does allow for certain inputs to be used that would replicate this phenomenon. As well, the model did not account for the bison's ability to look up and down which ultimately affects the amount of visible surface area that the viewshed model delineates. Again, there are ways in which the model can account for this factor. However, it was only important in this section to demonstrate the ability to use GIS to test a given archaeological theory. It was not used as a tool to prove or disprove this theory.

### 3.7 Two Dimensional Spatial Density Analysis Using Surface Interpolation Models

During the excavation of an archaeological site, correlations between the location of artifacts, and groups of artifacts can become visually apparent to the archaeologist. Researches have been able to map out these clusters of artifacts to study the significance of their spatial correlations. The literature shows that until recently these maps have been prepared manually as hard copies. Using GIS to study these spatial correlations allows the archaeologist to: 1) interactively map and visualize the archaeological data; and 2) use mathematical models to statistically analyze these spatial correlations. Sections 3.7 – 3.8 use GIS to perform spatial interpolations to determine if spatial correlations between the archaeological remains of the Fincastle Kill Site exist.

As mentioned above, debitage was recorded and digitized together with the other archaeological remains excavated from the site. During the excavation process the debitage was either found *in situ* or when screening the excavated matrix from the unit. For this analysis only the debitage found *in situ* was used. This was because their provenience in both the horizontal and vertical dimensions were used for the study. Of the 600+ lithic flakes catalogued from the Fincastle Kill Site, 134 were found *in situ*. The large number of flakes recovered in the sieve rather than *in situ* is because most were smaller than 1cm making it difficult to locate them when trowelling in the excavation unit. Moreover, a considerable amount of the debitage was Knife River Flint. This particular rock is very similar in colour to the local soil and sediment making it difficult for excavators to differentiate.

The lithic data were integrated into the GIS using the same technique applied for the faunal data. Points were digitized based on the location of the remains on the georeferenced .TIFF images of the level graphs. However, rather than digitizing polygons, points were digitized and used to represent the lithic debitage (Figure 3.13).



**Figure 3.13: Location of flakes with an 11m x 4m excavation section (East Block) of the Fincastle Kill Site (a) overlaid with digitized faunal remains (b).**

Using surface interpolation methods (inverse distance weighting), a raster layer was constructed that represented the concentration of flakes found in this particular region of the site. Inverse distance weighting is an interpolation function that creates a “neighborhood” around each given point used as the input in the analysis. Then a weighted average is taken of the values within this neighborhood (i.e. the other points within a specified distance from the point of interest). The interpolation is called inverse distance weighting because the “weight” of each point (flake) decreases as a function of increasing distance from the point of interest. The interpolation method uses these weights to define high and low concentrations of a particular variable within the specified study area.

To create the raster surface, ArcGIS 9 spatial analyst extension was used. Within this module ‘density analysis’ was selected as the main function to build the surface model. Kernel density was used as the main interpolation method. This method creates a surface based on neighboring values. Areas with a higher concentration of lithic remains (debitage) in one area will be weighted more strongly compared to the same size area with less or more dispersed debitage. Kernel density was chosen because of the small size of the study area and the method’s ability to create an interpolated surface that would distinguish areas of high and low density to a better degree than what could have been produced using a ‘simple’ density analysis.

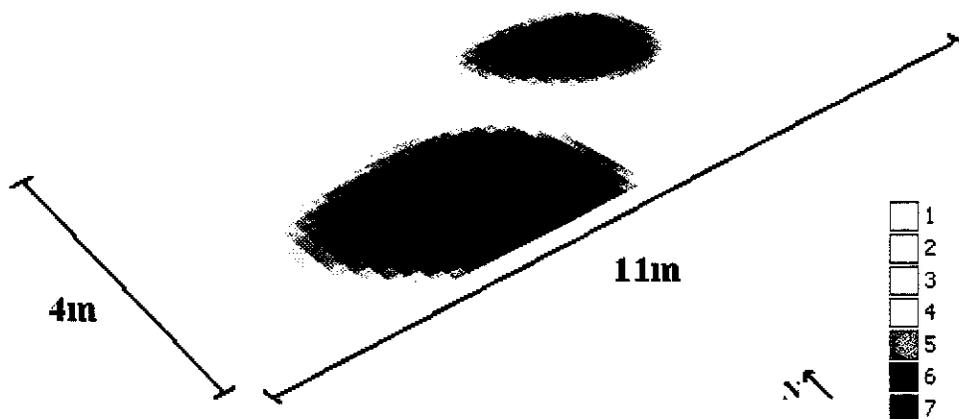
As inputs for the interpolation calculation a search radius of 2m was used for each point. The 2m search radius was chosen due to the small study area, and the fact that the debitage is found in a much more dispersed manner than the faunal remains. The 2m search radius was able to account for this. Therefore, only flakes falling within 2m of

one another would be weighted together. The surface model uses 0.10m<sup>2</sup> pixels to represent the density analysis. This pixel size was chosen so that there would be a resolution high enough to represent the small 11m x 4m study area. Larger pixels would not have been very representative of this. The 0.10m pixel size was also chosen because of the large number of archaeological remains that occur in a given area. It is apparent that high concentrations of faunal remains do occur in areas <0.10m<sup>2</sup> in this excavation site, thus, a 0.10m<sup>2</sup> pixel is a good representation of this phenomena. Although the debitage occurs at much lower concentrations at this pixel size, it was important to use the same resolution grid to directly compare the results of the interpolation.

It is apparent in Figure 3.14 that there are two main regions of high lithic density (red colour >7 flakes per 2m<sup>2</sup>) both located in the central region of the excavation grid centering over units 559N\_597E, 559N\_598E (lower region of high lithic density) and units 561N\_600E, and 560N\_600E (upper region of high lithic density). Yellow and green colours on the density analysis surface represent medium (3 - 7 flakes per 2m<sup>2</sup>), and low density (<1 flake per 2m<sup>2</sup>) areas of debitage, respectively. The class sizes were derived based on the current dataset, where the number of debitage found in each unit is considerable smaller compared to faunal remains. As more field data is obtained, the dataset may have to be adjusted. Future areas of the site may yield more than 25 flakes per m<sup>2</sup>, making the present maximum of 7 a 'low' value. The classes can be modified to more accurately represent the current dataset used for the analysis.

As seen in figure 3.13, there were areas within the East Block that were not excavated. These unexcavated areas were used as data inputs in the interpolation model. It is possible that these data gaps could have induced some bias in the results of the

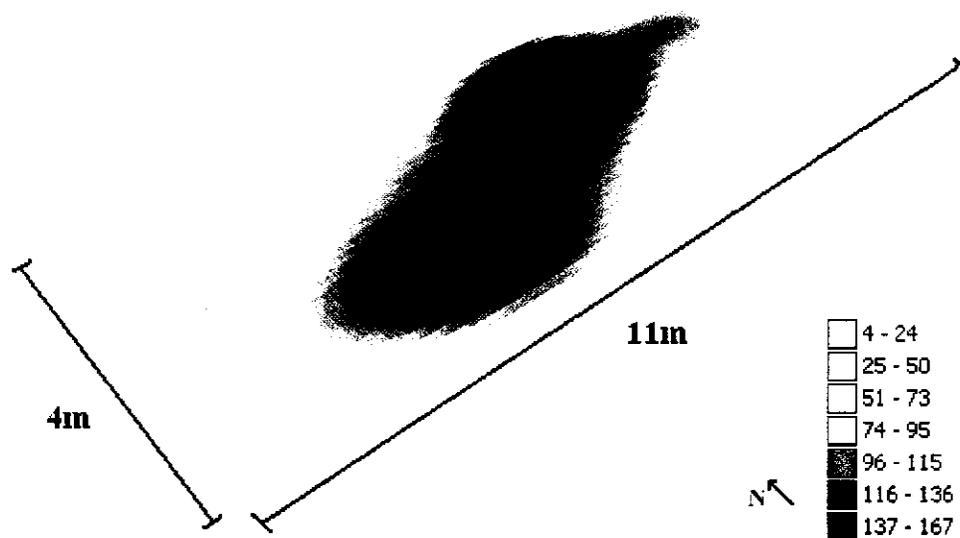
interpolation, which may have, to some extent, artificially created the high and low density regions of the archaeological remains. However, other field data, such as vertical profiles of the adjacent units that were excavated, suggest that the unexcavated units closely resemble the results that have been generated by the interpolation models. Thus, it can be inferred, that the data gaps (the unexcavated units) have created minimal error in the model. Furthermore, over a larger area, the potential problems occurring from a data gap of this extent would likely be minimized. As more data is used in the Fincastle Kill Site interpolation model, the possibility of a data bias such as this will decrease.



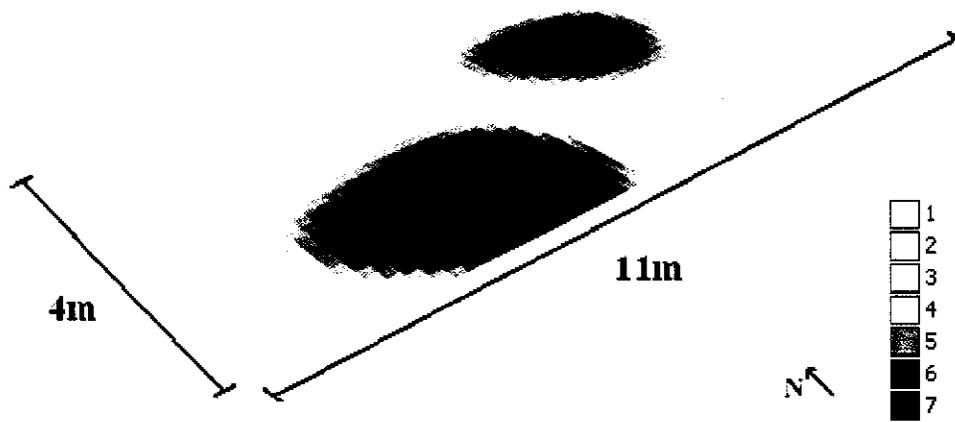
**Figure 3.14: Two dimensional density analysis of lithic debitage using density analysis interpolation (2m search radius, 0.1m pixel). Surface density layer displays regions of high (red), medium (yellow) and low (green) debitage densities. Legend displays number of debitage pieces per m<sup>2</sup>.**

To compute a two dimensional density surface for the faunal remains the polygon layer that was originally used as the data set was converted to a point file. This was done by determining the centroid for each polygon in the data set. In this process, one point is created in the center of each polygon that occurs in the data set. Next, a density surface for the faunal remains was created using the same inputs that were used for the debitage.

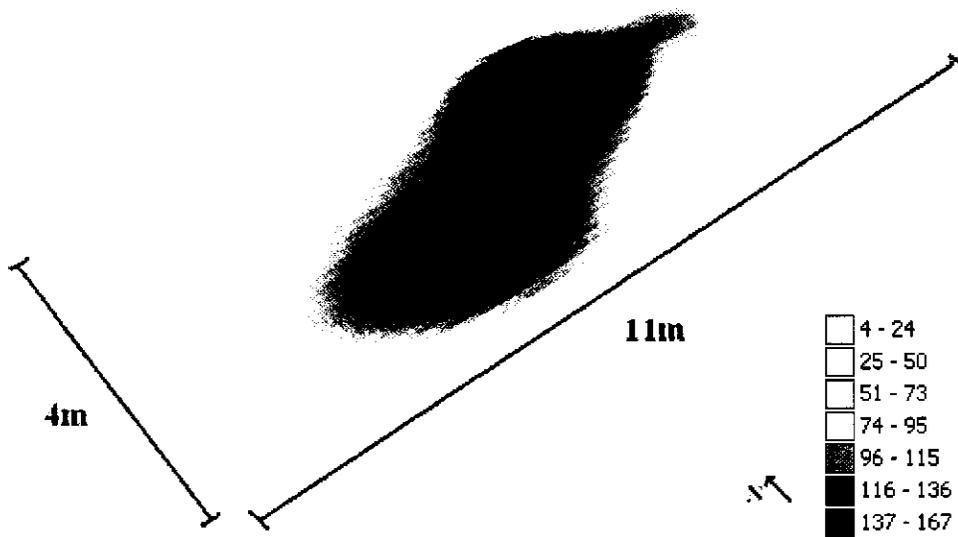
This makes it possible to directly compare the two surfaces since they both use the same inputs for search radius and the same outputs for pixel size. The main difference however is the number of bones found in each unit, and thus the values used for the class sizes. For the faunal remain a high density class is 137 – 167 bones while a high density class of debitage is 6. The visual results of the interpolated surface show that, similar to the lithic density surface, there are also two areas that have a high density of faunal remains. These areas (red in colour) can also be seen in Figure 3.15. In this situation, the colour coding of the interpolated surface is an effective tool as it represents areas of relative high and low densities of these remains. The correlation model takes into account the relative nature of these values. The density surface was then overlaid with the faunal layer to determine if there was any correlation between the amount of debitage and the amount of faunal remains found.



**Figure 3.15: Two dimensional density analysis of the faunal remains (2m search radius, 0.1m pixel). Density surface layer displays regions of high (red), medium (yellow) and low (green) densities. Legend displays number of faunal remains per m<sup>2</sup>.**



a



b

Figure 3.16: Lithic density surface layer (a) and faunal remain density surface layer (b). Legends display number of debitage pieces (a) and number of faunal remains (b) per m<sup>2</sup>

When comparing the layers (Figure 3.16), it is clear that there is a high degree of correspondence between the locations of high lithic and faunal remain densities (i.e. areas with a high density of faunal remains are also areas where high concentrations of debitage occurs). Assuming that the bison were butchered where the faunal remains were located, it seems likely that the areas of high lithic concentration represent locations where butchering was taking place. Here the people butchering the bison may have been retouching their tools to sharpen them. Alternatively, less debitage should be found in areas where less butchering occurred which the density surfaces support. Of course one could argue that these results could be showing excavation bias rather than a cultural connection. It is possible that areas of high density concentrations of *in situ* debitage and faunal remains reflect good excavation techniques, where areas of low concentrations of material are the result of poor excavation attention. This is not likely to be the case for this site due to the detailed excavation methods used. Eventually the sieved material will be added to the GIS model to confirm this.

Finally, the ArcInfo “correlation” command was used to statistically determine the spatial correlation between the lithic and faunal density surfaces. In this analysis, the correlation command uses spatial attributes (x and y coordinates) of the surfaces to assess their spatial correlation. The resulting correlation coefficient of the analysis was 0.651 which means that a positive spatial correlation exists between the debitage and the faunal remains. Correlation coefficients for this type of analysis range from -1 to 1. Values near -1 represent surfaces that are negatively correlated. In this case that would mean that areas with high lithic density would have few faunal remains or vice versa. Values

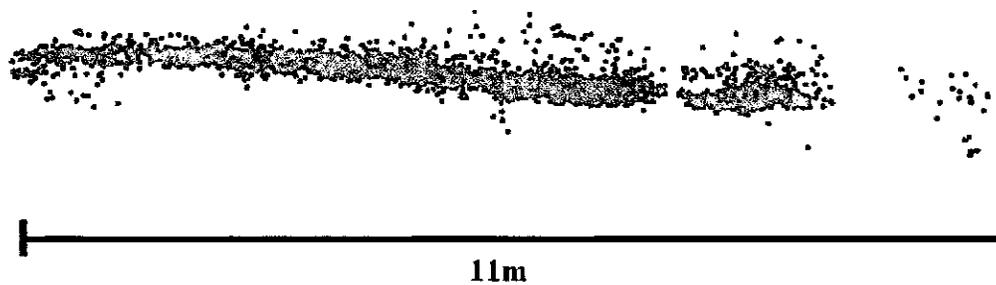
approaching 0 suggest that the surfaces are independent and no spatial correlation exists. Correlation coefficients closer to 1 represent surfaces with a high spatial correlation.

### 3.8 Three Dimensional Spatial Density Analysis Using Surface Interpolation Models

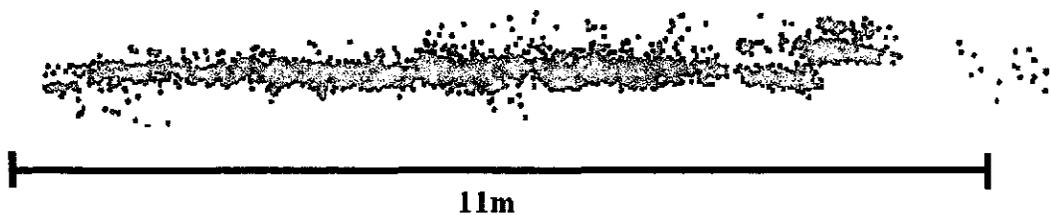
Once the two-dimensional density analysis was completed, the lithic database was separated into 7 equal levels (approximately 5cm each) below the surface. The following levels were used: 1) 497.81 – 497.87; 2) 497.87 – 497.92; 3) 497.92 – 497.97; 4) 497.97 – 498.02; 5) 498.02 – 498.08; 6) 498.08 – 498.20; 7) 498.20 – 499.00. These levels correspond to the false 500m top elevation that was originally given to the excavation area during initial surveying. 500m was an arbitrary height that was chosen and does not have any meaning other than that of a reference point. Because the levels were classified into equal categories, the last two levels (levels 6 and 7) were not the same overall elevation change as levels 1 – 5. The faunal database was also classified using these same levels as shown above. This meant that the position of the debitage and faunal remains could be directly compared and correlated on a level-by-level basis. As with the initial two-dimensional analyses, a density surface was created for each category. In some cases there were no remains in some levels, and, therefore, a density surface was not created.

Furthermore, the East Block excavation area had a slight elevation decrease from west to east. Therefore, the western-most units of the East Block had a slightly higher overall elevation than the eastern units. The overall elevation change from west to east was measured at the time of excavation, and, therefore, it could be compensated for in the

analysis. It was decided that the present day surface did not necessarily represent the horizontal position in which the bone bed originally lay. In which case, calculating the spatial correlation of the debitage and faunal remains based on the present day position would not directly represent the archaeology of the site. Therefore, the debitage and faunal remain levels had to be adjusted to compensate for the west to east elevation change. Although the overall elevation change was known, the mean depth for all recorded debitage and faunal remains was calculated for each unit. This value was then adjusted based on its difference from the maximum mean elevation.



**Figure 3.17: Profile of overall elevation change of unadjusted faunal remains shown using Arc GIS 9 3D Analyst. Faunal remains shown from west (left) to east (right) of the East Block.**

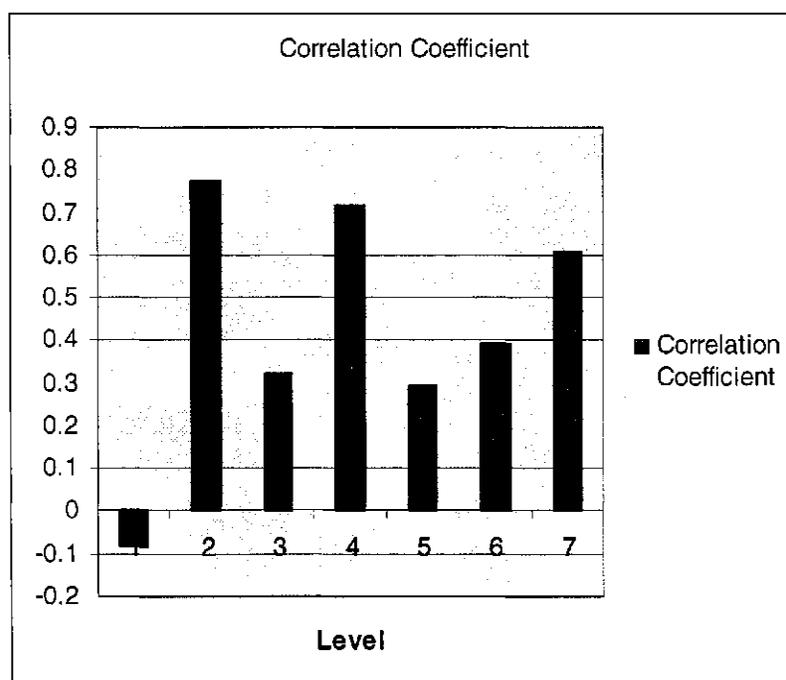


**Figure 3.18: Profile of overall elevation change of adjusted faunal remains shown using Arc GIS 9 3D Analyst. Faunal remains shown from west (left) to east (right) of the East Block.**

As with the two-dimensional analysis, the ArcGIS 9 density analysis tool was used to produce the new interpolations. The same parameters were also used for the

model inputs. Because the remains were grouped into levels, a significantly smaller amount of data was used to interpolate each density surface. However, the model still allowed for the identification of high and low density areas of archaeological remains.

Fourteen total surfaces were created, (7 lithic and 7 faunal). The statistical relationship between the paired surfaces was tested using the ARC Info “correlation” tool. For this study only surfaces representing the same level were correlated with one another. Figure 3.19 displays the spatial correlation values calculated for each of the examined levels.



**Figure 3.19: Spatial correlation values calculated for 3D density analysis of faunal and lithic remains.**

The analysis shows positive spatial correlations in all but one level. In level 1, the lithic remains are far more dispersed than the faunal remains, which may account for the negative correlation.

In conjunction with the two dimensional density analysis, this three dimensional analysis shows that the correlation between a high spatial density of faunal and lithic remains may exist through both space and time. The two and three dimensional density analyses indicate a high correlation at the spatial level while the three dimensional analysis may indicate a high correlation at the temporal level. Currently, it is not known whether the Fincastle Kill Site is a single or multi-component site. However, this or similar types of analyses may help determine what type of site it is.

This research has served to shown that basic spatial relationships between the lithic and faunal remains do in fact exist. However, more in depth research into the nature of the spatial relationships is required. For example, faunal remains will be classified and analyzed by element (femur, metacarpal etc.), and can then be spatially compared with the debitage and the bones themselves. Fire broken rock could also be used in the analysis in order to identify areas of the site that may have been used to process the bison.

The analyses explained in Sections 3.7 and 3.8 assessed a very small portion of the entire archaeological site. Once more of the site is excavated and the remains are processed more extensively, far more data can be used in the analyses. Analyses similar to that of Gerber (2000), which incorporate predictive approaches to the excavation, can also be carried out. Research such as this can effectively streamline the excavation, reducing time, cost and efforts.

### 3.9 Summary

Two types of GIS applications were demonstrated in this chapter: 1) a viewshed model to assess a hypothesized bison hunting technique used at the archaeological site;

and 2) surface interpolation models were created to delineate high and low density areas of faunal and lithic remains.

The viewshed model was shown to be an effective tool for conveying and assessing the hypothesis that the bison hunters used an ambush technique. We have also seen that a hypothesis, that may have not been possible to test using conventional archaeological methods, was investigated using this model. Section 3.6 of this chapter also illustrated how changes to the model inputs could be made, thus allowing the user to apply a number of variables. The dynamic nature of the viewshed model makes it a robust application.

The surface interpolation models successfully delineated and assessed areas of high and low concentrations of faunal remains and lithic debitage. The models were also successful when applied in two and three dimensions. Section 3.7 showed that the two dimensional model can assess the artifact clusters based on spatial organization, while Section 3.8 illustrated that the three dimensional model can potentially assess the artifact clusters based on two elements: 1) spatial organization; and 2) temporal organization.

The significance of the analyses described in Sections 3.6 – 3.8 of this chapter were not necessarily the results that they yielded, but rather that GIS and the GIS models used were an effective analysis tool that produced useful information. An archaeological study could be conducted using this new data alone. However, the goal of this thesis was to develop and demonstrate the importance of these GIS tools.

Due to the congruency of the methods and theory of the GIS used at the Fincastle Kill Site and Tel Beth-Shemesh, further discussion of the methodology, benefits, problems and impacts of the GIS models discussed above follow in Chapter 5.

## Chapter 4

### Tel Beth-Shemesh

#### 4.1 Introduction

In this chapter the research and GIS applications at Tel Beth-Shemesh, Israel are presented. Although Tel Beth-Shemesh and the Fincastle Kill Site differ with respect to the excavation techniques used, the archaeological remains, and the spatial layout of the site, some of the fundamental GIS methods that have been discussed in the previous chapter are used in this case as well. For example, similar data integration and analytical procedures were used. One of the important benefits of GIS applications in archaeology is that it can transcend numerous sites, thus making it a valuable tool for many archaeologists.

Sections 4.2 and 4.3 discuss the field techniques used at Tel Beth-Shemesh, and assess the early experimental GIS modeling and visualization techniques used. Much like the previous chapter, the field work is explained in regards to GIS data integration. Section 4.4 discusses the construction of the Tel Beth-Shemesh GIS model while Sections 4.5 and 4.6 outline and discuss the main goals of the Tel Beth-Shemesh research. These main goals are: 1) to delineate the different occupations of Area F (Section 4.5); and 2) validate the excavated features and visually outline the chronology of Area F (Section 4.6). Both goals are achieved by means of construction and use of the Tel Beth-Shemesh GIS model.

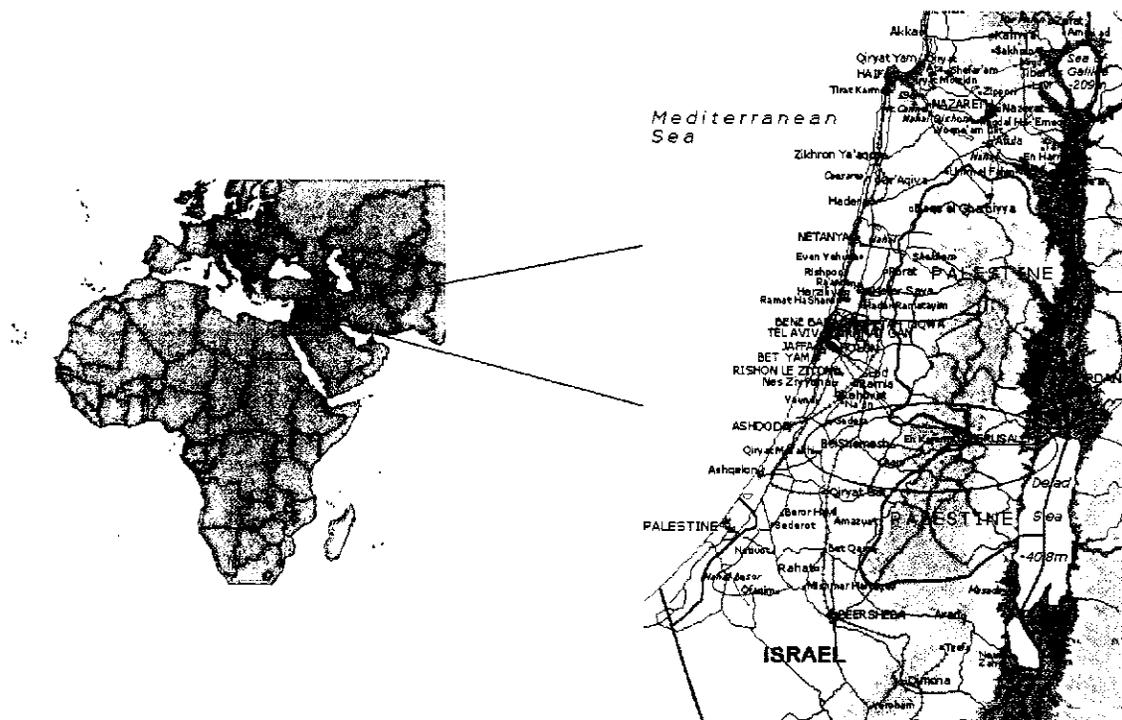
As with Chapter 3 (the Fincastle Kill Site) the Tel Beth-Shemesh chapter has a general theme throughout, that being the goal of using field data from the Tel Beth-

Shemesh excavations to construct and use a GIS model that demonstrates methods of research that have not been carried out using conventional techniques.

## 4.2 Site Description and Archaeological Significance

Tel Beth-Shemesh is located in the outskirts of the modern city Beth-Shemesh, Israel, 20km west of Jerusalem (Figure 4.1). “Tel” is an Arabic word meaning hill or mound, and is used in an archaeological context to refer to an ancient mound made up of anthropogenic deposits. Tel Beth-Shemesh is a multi-occupational site, with archaeological remains dating from 2500BC (Middle Bronze Age) to the Middle Ages (14<sup>th</sup> century AD).

The site is located within the “Shephela” or lowland region of Israel. This region is defined by rolling hills that reach approximately 400m above sea level. The area is much more temperate and humid than the Negev region to the south, but still experiences little moisture. The region is comprised of alluvial valleys containing soil and sediment with large amounts of nutrients that have helped farmers successfully grow numerous fruits and vegetables for thousands of years (Mazar 1992).

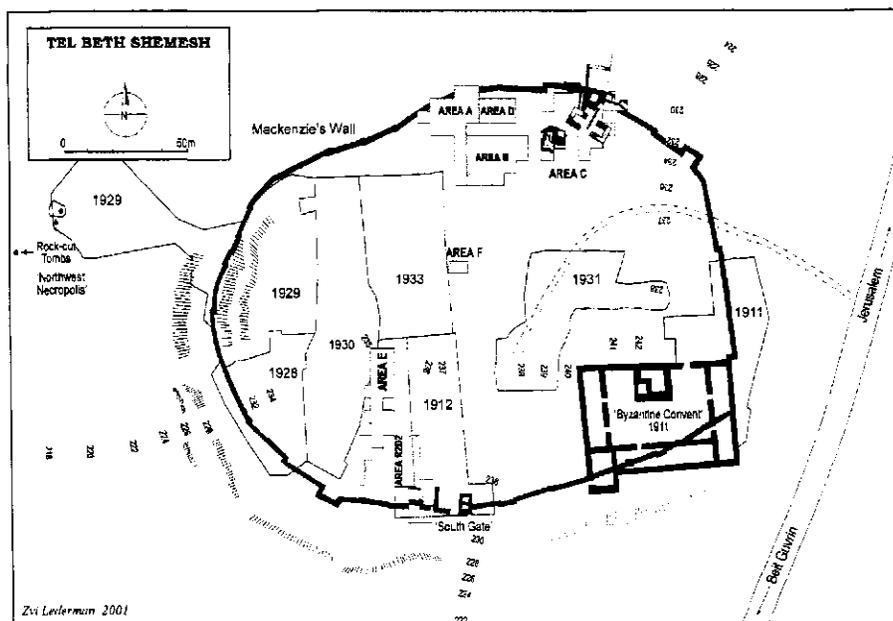


**Figure 4.1: Map displaying location of Beth-Shemesh Israel.**

The 7 acre mound that comprises the site is located at the geographical, political and cultural border between the ancient Canaanites, Philistines and Israelites living in the region from the 13<sup>th</sup> to 7<sup>th</sup> centuries BC. Most biblical archaeologists regard the transition from the Late Bronze (LB, 1500 – 1250 BC) to the Early Iron 1 (Iron I, 1200 – 1000 BC) period to be one of cultural change in Israel. There are two hypotheses regarding this change: 1) the Canaanites who occupied this area during the LB and Early Iron I ages experienced a cultural change within their own community, thus evolving into what we know now as the ancient Israelites; and 2) a new cultural group emerged (the ancient Israelites) who were not indigenous to this area. Current excavations at Tel Beth-Shemesh aim to discover if either hypothesis is correct.

Tel Beth-Shemesh was first excavated in 1911 - 1912 by D. Mackenzie and then in 1928 – 1933 by E. Grant. It was not until 1990 that excavations resumed under the

direction of Dr. Shlomo Bonimovitz and Dr. Zvi Lederman of Tel Aviv University. Since 1990 excavations have been conducted each summer except for 2002. Figure 4.2 shows the different excavation areas completed. The areas shaded are those excavated post 1990.



**Figure 4.2: Map of Tel Beth-Shemesh displaying the areas and dates of the excavations from 1911 – 2003.**

Near Eastern archaeologists have mainly used note books, simple computer databases and hand maps as a means to record field data. In a spatial context, there has been little focus on the precise recording of this data, apart from large architectural features. As evidenced in the literature, Near Eastern archaeological techniques have only recently incorporated GIS as a means to more accurately store, explore and analyze site data. Much of the research regarding GIS use in Near Eastern archaeology is speculative, or still remains in the project phase. Little literature regarding this material has been published, and of the published work, little uses more than rudimentary GIS as an analysis tool. With this in mind, this chapter of the thesis aims to develop and

demonstrate sophisticated GIS tools for the archaeologist to spatially analyze Near Eastern sites. As with Chapter 3, this work of this chapter does not answer significant questions concerning the archaeology of the site, but focuses on developing and demonstrating the GIS tools that can be used to aid the archaeologist in answering these important questions.

### 4.3 Field Preparation

Prior to the summer 2004 excavations at Tel Beth-Shemesh, Israel, GIS planning and testing was done at the University of Lethbridge. Field data recorded from the 2001 and 2003 field seasons were used in this process. These data consisted predominately of feature measurements of floors, walls, silos, pits, and other human constructed components of the Late Bronze (LB), Iron I and Early Iron II periods. The data included horizontal and elevation measurements of these feature types.

These original field measurements were hand recorded using measuring tapes and level devices and graphed to scale on all weather graph paper. The hand graphs were then scanned and digital level files of the site features were created using Macromedia© Freehand™ software. These initial digitization steps were completed in Israel during the 2001 and 2003 field seasons.

During November and December of 2003 the digitization and integration of this field data and Freehand files into Arc View 3.2 GIS software was carried out. To transfer the Freehand files into an Arc View readable format, the files were exported and opened in Arc View as .TIFF images. Once opened in ArcView, the features on the digital level sheets (the .TIFF images) were hand traced and converted into polygon files (Figure 4.3).

It was later realized that the Freehand drawings were not needed to import the data into a GIS format. It was found that the hand drawn graph sheets could be directly scanned and converted to .TIFF files and opened in Arc View GIS 3.2 in a similar fashion to that of the Fincastle Kill Site. However, because the 2001 and 2003 freehand drawings already existed, it was decided that they would be used.



**Figure 4.3: Example of early GIS testing using 2001 and 2003 Tel Beth-Shemesh field data. Individual features unearthed from Area A during previous excavation seasons are shown as differently coloured polygons from oblique view (a) and top down view (b).**

With this completed, the testing of three dimensional display methods began. This was done by assigning arbitrary height and thickness measurements to the features in order to provide three-dimensional characteristics. Arbitrary elevation measurements were also assigned because these particular measurements were not available from previous excavation seasons. These arbitrary measurements were based on relative differences of excavation depths for each displayed feature. Although this was not an accurate reflection of the actual situation, it was done in order to save time in the early stages of modeling. Authentic depths either measured in the field or extrapolated from the depths of other field measurements were used in latter phases of this research. At this point, however, the test models showed that they are effective devices for integrating and analyzing Tel Beth-Shemesh field data in a GIS. Therefore, these methods would be used to display and analyze field data from the upcoming 2004 excavation.

#### 4.4 Field Methods

The summer 2004 excavations at Tel Beth-Shemesh ran from June 13<sup>th</sup> to July 8<sup>th</sup>. The excavation team consisted of 19 students from the University of Lethbridge, 3 field directors and 7 American students. The 2 main excavation directors were Zvi Lederman and Shlomo Bonimovitz from Tel Aviv University.

The 2004 excavations were initially set up in two main areas on the Tel: Area D to the north and Area F located near the center of the site (Figure 4.2). The excavation team was divided into two equally sized groups to work in these areas. The teams switched areas after 2 weeks of excavation to gain experience working in different matrices. Due to the fact that Area F was becoming very deep and Late Bronze strata had

not been reached by the end of the second week, it was decided that all efforts would be concentrated on Area D, where Late Bronze strata had been discovered (the main goal of the 2004 excavation was to reach the LB remains). With 8 excavation days remaining both teams worked in Area D to expose as much of the LB remains as possible.

Daily field work ran from 5am – 1pm Sunday through Thursday. Field excavation took place early in the morning in order to avoid afternoon temperatures that often exceeded 35 degrees Celsius. During the afternoons the team washed pottery sherds, catalogued and analyzed artifacts, and attended lectures. Manual excavation was typically done using a hand pick and trowel. When more precise excavation methods were required, Marshalltown 45/5™ and 45/6™ hand trowels, dental equipment and small hand picks were used. Five meter metric measuring tapes, a Sokkia© Total Station™ and plum bobs were used to measure the spatial locations of significant archaeological remains. In some cases, the excavation units became too deep to easily carry out excavated sediment. Therefore, a pulley system was used to transport the material safely out of the excavation units (Figure 4.4).

All units were excavated following a Wheeler-Box method, using 5m x 5m units with alternating 0.5m and 1m baulks (Figure 4.5). 5m<sup>2</sup> units were chosen because this size allows archaeologists to expose enough architectural features and remains to understand them without significantly decreasing the amount of control in each unit. The 0.5m baulks were used to separate the excavation units, and the 1m baulks were used as separation devices and transport routes to move excavators and/or excavated material. Depending on the context of the excavated sediment, it was run through a ¼ inch sieve to check for archaeological remains that may have been missed. Due to the large amounts

of sediment excavated in a day, not every bucket was sieved. For example, 1 out of every 10 buckets of excavated sediment was sieved from an area containing filled debris. Sediment coming from a sealed pit may require 1 of every 3 buckets to be sieved. This variable system of sieving is standard archaeological practice in the Near East. If several small remains are discovered while excavating or sieving a particular locus, each bucket of sediment may be sieved. Approximately ten percent of all excavated material was sieved in this manner.

The position of all significant archaeological remains was measured. A significant remain included lithics, ground stones, metal objects, whole ceramic vessels, and any atypical objects. Ceramic sherds and bones were not individually measured as several hundred could be discovered in a single locus and typically have no significant detailed context. This method of selective data recording is typical in Near Eastern archaeology because of the number of remains at these sites. The amount of time and effort required to record each individual remain would be enormous and is never actually feasible during the short period (4 – 6 weeks) that a field season typically lasts. Moreover, the time such detailed recording requires would not result in a proportionate improvement to our understanding of the occupants of these sites. Once the artifacts, including the ceramic sherds and bones, were removed from the excavation unit they were bagged and given a number code that associated them with a specific excavated unit and layer.



**Figure 4.4: Pulley system used to transport excavated material in Area F of Tel Beth-Shemesh.**



**Figure 4.5: Two 5m x 5m excavation units from Area F divided by a 0.5m baulk with sandbags on it.**

In addition to measuring the artifacts, the position and thickness of all site features were recorded as well. Thickness was calculated by measuring the top and bottom of the feature, and in multiple locations if the feature was asymmetrical. Its relative 3D position was measured using the Total Station. To measure using this instrument, the position of the Total Station is first calculated in relation to the excavation units. This position was established each day using triangulation calculated from known points. The distance and angle measured from the Total Station to any *in situ* artifact or feature is then measured and its relative position calculated. During the first 3 weeks of the excavation, the instrument was positioned between Area F and Area D in order to record finds in both areas (Figure 4.6). At the beginning of each day the Total Station would be set up and resectioned to calculate its relative position on the Tel. Typically it would remain in the same location through the excavation day because if it were moved, the user would have to recalculate its relative spatial position.



a



b

**Figure 4.6: View to the northeast towards Area D from the Total Station (a) and then to the southwest to Area F (b).**



a



b

**Figure 4.7: Total Station user (a) targeting the prism holder (b) holding the measuring rod over an artifact in Area D.**

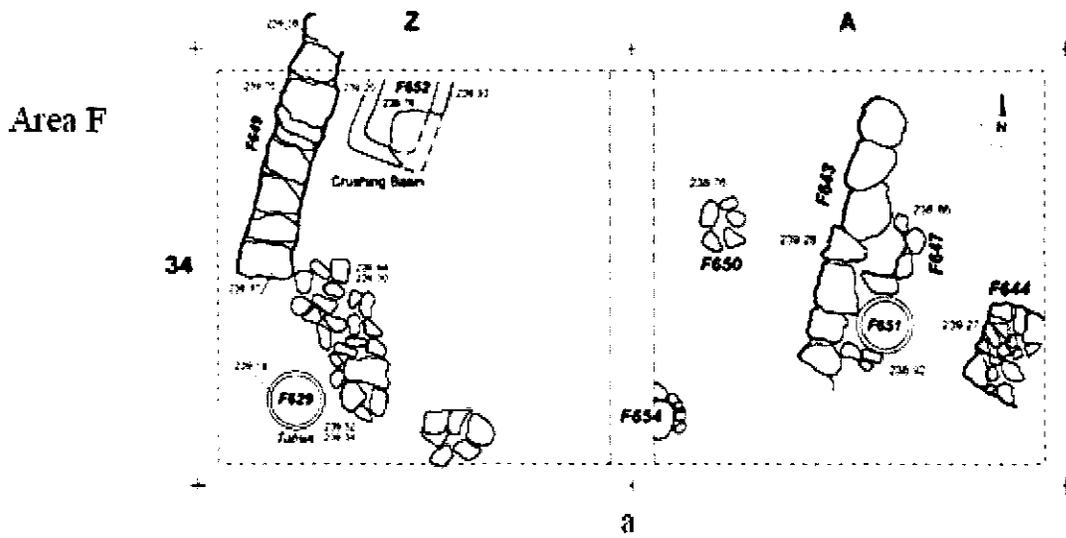
When archaeological remains needed to be recorded the user of the instrument would travel to and from the excavation area while maintaining radio contact with either the field director or another member of the excavation team. As with standard

theodolites, the user would locate the targeting prism reflector that was being held by another individual on the artifact or feature being measured (Figure 4.7). During the last 8 excavation days the instrument was positioned adjacent to Area D since Area F had been closed. This new position saved a considerable amount of time because the Total Station user did not have to travel as far to use it.

When the 3D position of the item was measured the position and reference was stored in a digital format in a hand held data logger. The hand held unit could also be used to store information such as details about the recorded item, the artifact number, and other notes. As in previous field seasons, site features, such as walls and pits, were also hand measured and graphed to scale on all weather paper. Other information recorded on the Total Station included details on pottery sherds removed from each unit. When excavating each layer, the pottery sherds were placed in unique buckets. Once a bucket was full, or the layer finished, it was given a number code detailing the particular layer that it came from. The depth of the layer, or each partial layer, where the pottery bucket came from, was recorded for each individual bucket. The excavated archaeological remains were catalogued on site and then the data stored in the data logger was transferred into a Microsoft Excel database at the field camp in the evenings.

## 4.5 GIS Model Generation

As explained in Section 4.3, experimentation with GIS data integration methods had been completed prior to the start of the summer excavations and a working model was created. During the 2004 field season, recorded feature data were digitized and converted into a GIS format simultaneously to the field excavations. Not only did this procedure serve to test the viability of this particular process, but by doing it at the same time as the excavations, any measurement that had been missed or forgotten could be recorded. Features were excavated, measured and recorded on graph paper in the field, and these graph sheets were then scanned and digital polygon files created in Arc View GIS in the afternoon. Figure 4.8 shows these features and their associated number. F831, F825, and F819, for example, are pits discovered in Area D; F290 and F291 are walls in Area F. Essentially, GIS data were produced as the excavations progressed. Using this model as a base (created before the excavations began) successful results were achieved with the new 2004 data while at the field base camp (Beit-Guvrin Kibbutz).



Area D

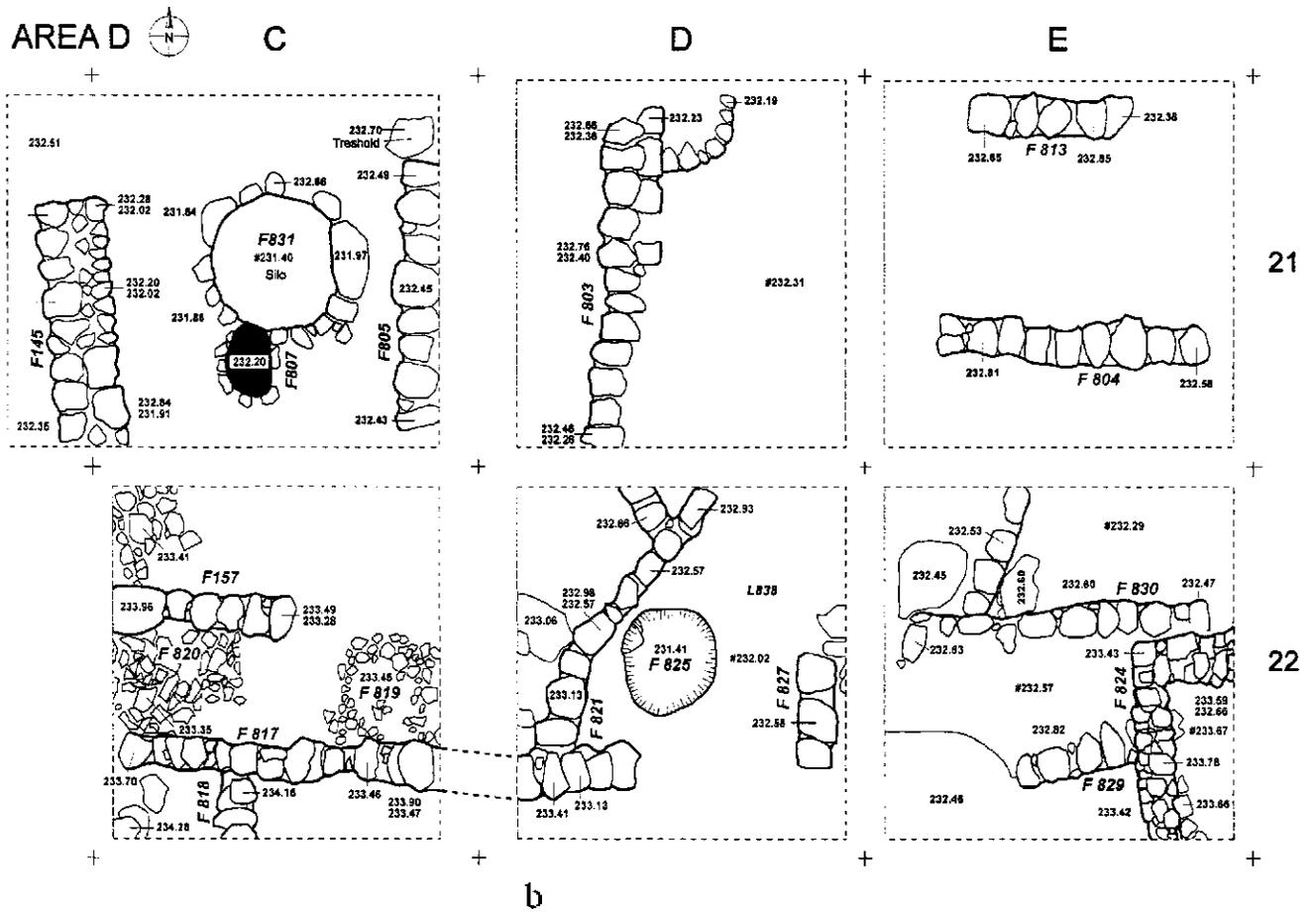


Figure 4.8: Early digitization of Area F features (a) and Area D features (b) in Arc View GIS.

The digitization process required a pseudo-georeferencing of the excavated remains, which was necessary due to the lack of referencing information associated with the digital files. Because all the relative spatial information (feature measurements and excavation unit dimensions) were known prior to the GIS integration, these values were used in the georeferencing process to attain a high degree of accuracy (<1cm error) of true relative spatial positions of the archaeological remains. In projects such as this, relative spatial referencing can only be applied. This is the case with most archaeological sites in the Near East because the acquisition of remotely sensed imagery is unavailable due to cost or the sensitive nature of the area. Moreover, digital imagery such as LANDSAT 7 and SPOT 5 (15m pixel and 2.5m pixel resolution respectively), do not have a high enough spatial accuracy or resolution (the digital imagery) for spatial referencing. For this particular type of study, only relative referencing between the artifacts and features are needed as it is the relationship between these elements that is important.

As mentioned above, early GIS data integration utilized arbitrary values based on field measurements to determine feature thickness as a property of its dimensions. These assigned values were used primarily to test the application time, difficulty and accuracy of the creation of the GIS model, and also served as a visual medium for the excavation team. Using arbitrary values aided to expedite data integration and construction of the feature model in the GIS. True values from field data were later applied to the GIS model upon return to the laboratory at The University of Lethbridge.

Given that the horizontal positions (x and y values) of the features were accurately measured at the time the features were digitized in Israel, only the vertical

position/thickness (z value) needed to be calculated. Because measurements at the top and bottom of the features were taken in the field, the thickness could be determined by calculating the difference between them. In certain cases, the thickness varied along the horizontal plan, which is often the case with walls and floors. In these cases, multiple measurements along the feature were taken. Figure 4.8 shows Area F in the early stages of its digitization. The excavation baulks were also digitized to serve as a visual aid in assessing the overall scale of the model. In early models the features were assigned arbitrary colours. Later, a particular colour scheme was used.



a



b

Figure 4.9: Site features from Area F (11m x 5m) rendered (a) shown again with modeled baulk (b).

Once the site features were digitized and modeled, the positions of the recorded artifacts were input into the GIS. The Microsoft Excel file containing the artifact position information was imported into ArcView GIS in order to create a new three dimensional theme consisting of points. Each point represents a distinct artifact or, in some cases, a field measurement such as a top or bottom layer measurements or the location of a pottery bucket. The spatial position of each was recorded with the Total Station. Because the measured artifacts were referenced in the GIS based on their recorded relative position, and the site features were also recorded using this same scheme, once all the data were digitized they were positioned to accurately represent the spatial arrangement of the *in situ* remains. Figures 4.10 and 4.11 show the digitized features and pottery bucket measurement points from Area F.

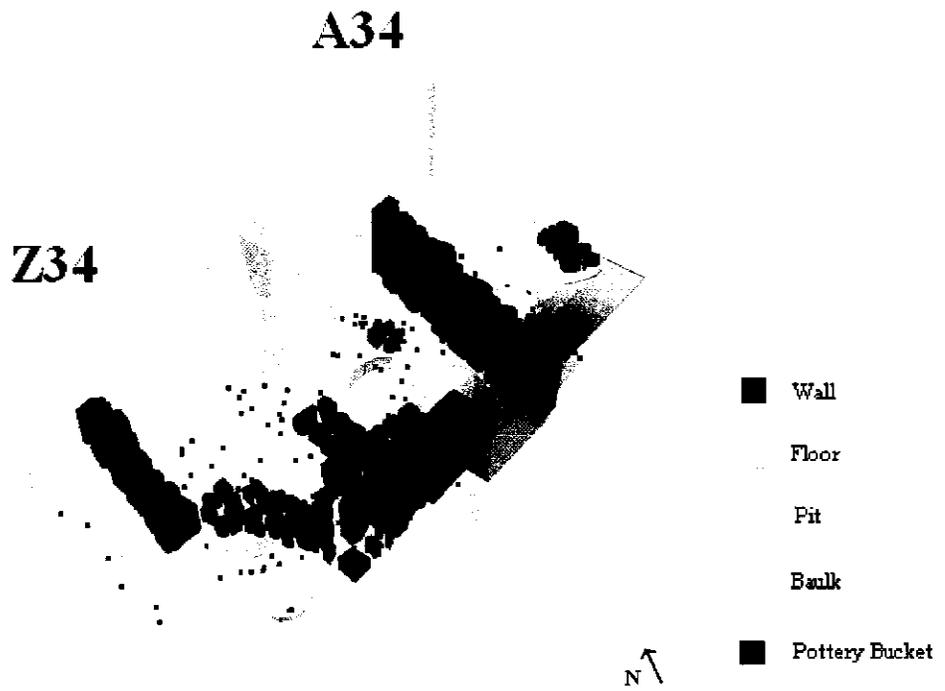


Figure 4.10: Pottery bucket measurements of Area F modeled with site features and baulk.

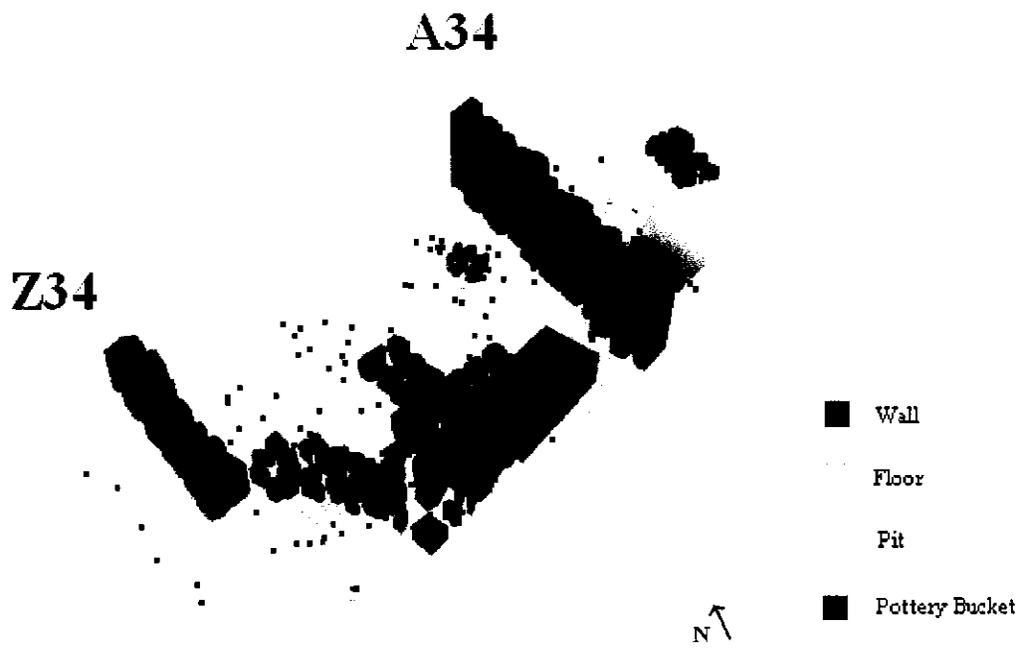


Figure 4.11: Pottery bucket measurements of Area F modeled with site features.

Once all artifacts were digitized into the model, the point file was broken into separate files dependent on the artifact type. Artifact categories included complete vessels, stoppers, bronze artifacts, iron artifacts, flint tools, flint cores, mudbrick, slag, burnishing stones, stone vessels and several other types. The point file also consisted of other important information such as elevation measurements of the baulks and pottery bucket locations. In doing this, each category can be displayed separately or in combination.

The next step in data integration was to model the layers (distinct stratigraphic units) within each of the excavation squares. As the excavation progressed in the field the top and bottom elevations of a unit layer were recorded and the general region that it existed horizontally was hand mapped in the field book. In some cases, pottery bucket measurements marked transition points between layers and were used as elevation data for those respective layers. Layer thickness was calculated by measuring the difference between the top and bottom measurements. To properly digitize the area of each layer, the hand maps were used as digitizing templates and polygons were created to represent each layer in the GIS (Figure 4.12). A colour scheme was applied to the digital layers that connected them to the phasing of the site. In Figures 4.12 – 4.15 many of the layers have the same colour since they come from the same phase. Although the hand mapped layers differ slightly from their real life counterparts, the digitizing process resulted in a very accurate reconstruction of the unit layers since they were generally located within distinct features, which, as mentioned earlier, had a very accurate spatial positioning.

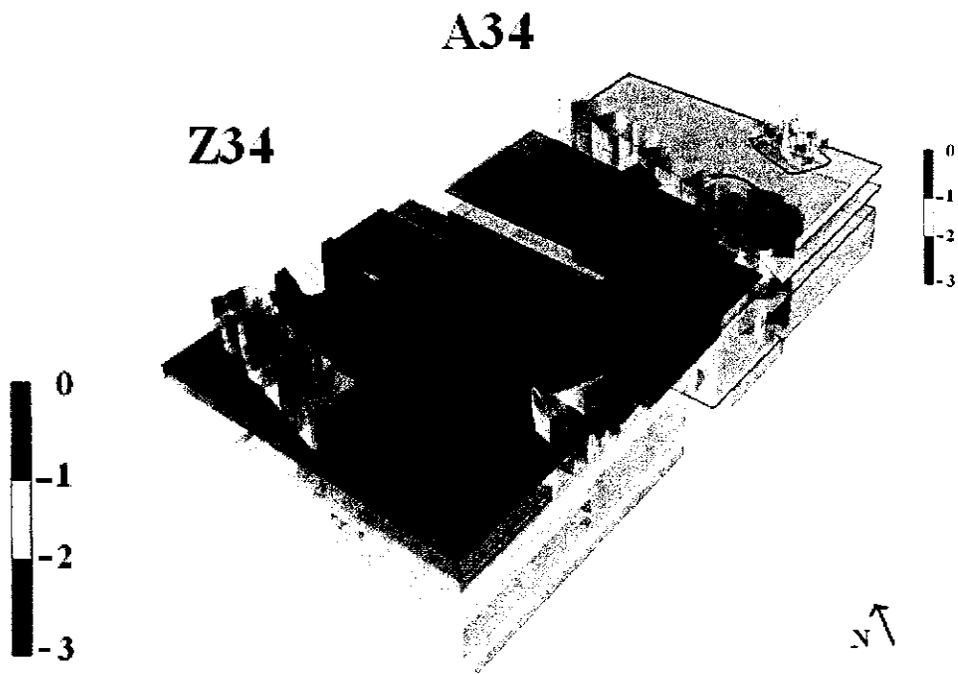


Figure 4.12: Layers rendered in excavation units Z34 and A34 of Area F. Colours are used to represent individual layers.

Site features that had not been drawn on the original 2001 – 2003 digital maps but were used for primary GIS data integration were digitized together with the layers above. In most cases the new digitized features were those that were exposed during the 2004 field season. As was the case with the layers, digital information containing x and y values for the position of the features was not available. To negate this problem, hand drawn maps from field books were used to supply their positions. Although they lacked exact x and y values, vertical measurements for the top and bottom of the features were available. Despite the lack of horizontal measurements, spatial positions of the features

remained very accurate (<15cm error) for two main reasons: 1) the relatively small size of each excavation unit (5m x 5m); and 2) accurately detailed hand drawn maps.

Once all layers in Area F were digitized, the GIS the model could be phased (a term that describes the grouping of archaeological remains belonging to the same major occupation based on stratigraphic relationships). Phasing information was included in the 2003 and 2004 field reports, which were used as a reference to properly assign all the GIS data, including artifacts, pottery buckets layers and features to a particular phase. All artifacts, layers, pottery buckets and features were already coded for distinct layers (although tedious, this task was systematically carried out). Thus, the only cases where remains belonged to more than one phase were features used through multiple periods (i.e. large walls). These features were given multiple colours to represent their use through several occupations. All other remains were given a single colour to represent the phase they correspond to (Figures 4.13 – 4.15).

All methods described in this section were also applied to Area D of the Tel, however, due to data constraints only Area F could be fully integrated into the GIS model. Aspects of Area D were also added into the GIS for testing and visualization purposes (Figure 4.16).

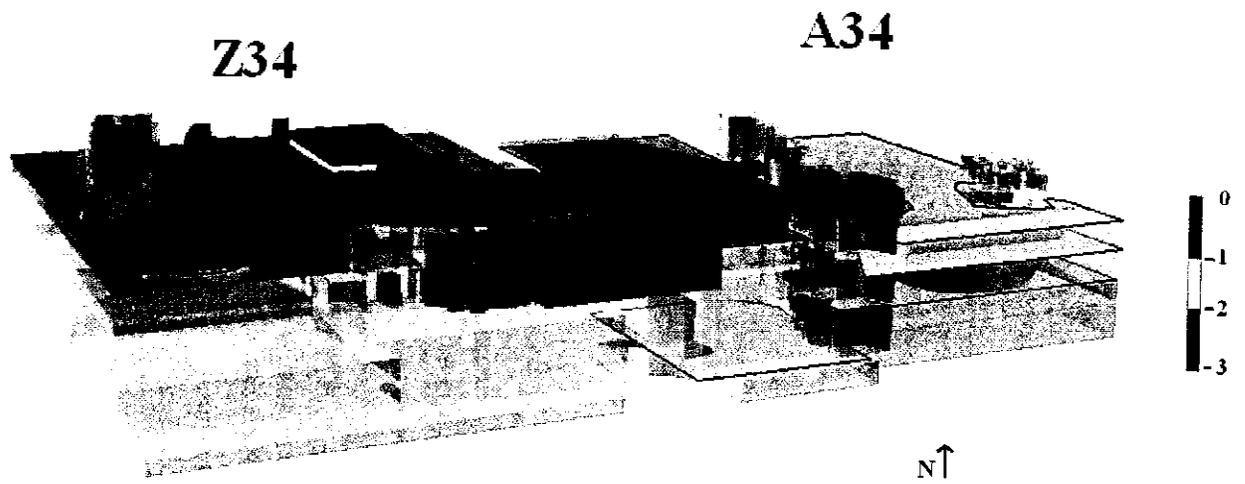


Figure 4.13: Tel Beth-Shemesh Area F units Z34 and A34 with features and layers coloured to show the occupational phasing scheme based on field data.

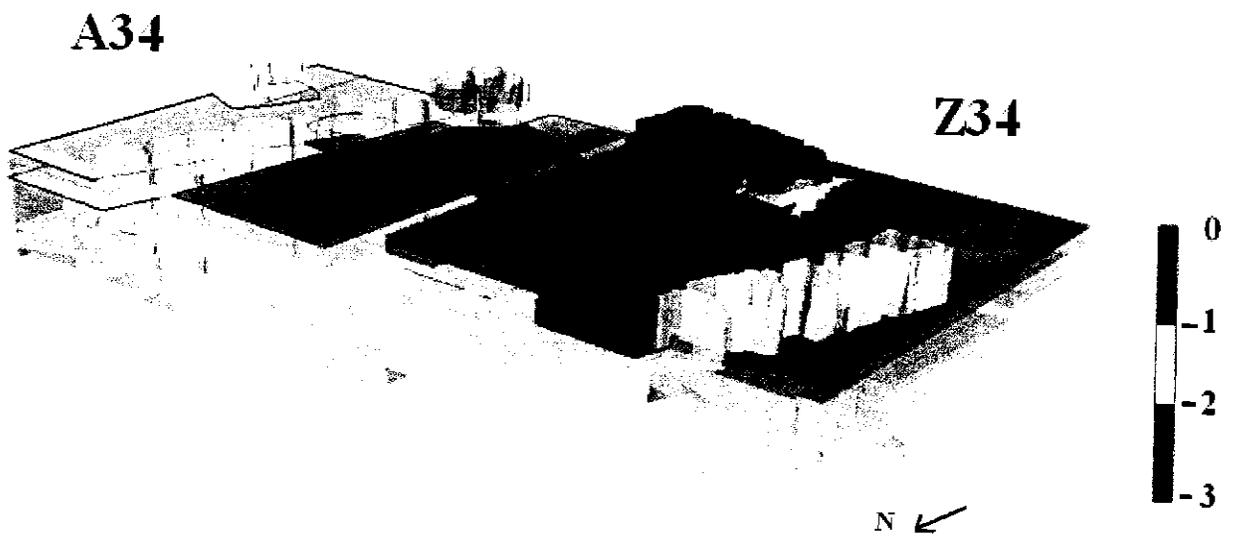


Figure 4.14: Alternate View of Figure 4.13.

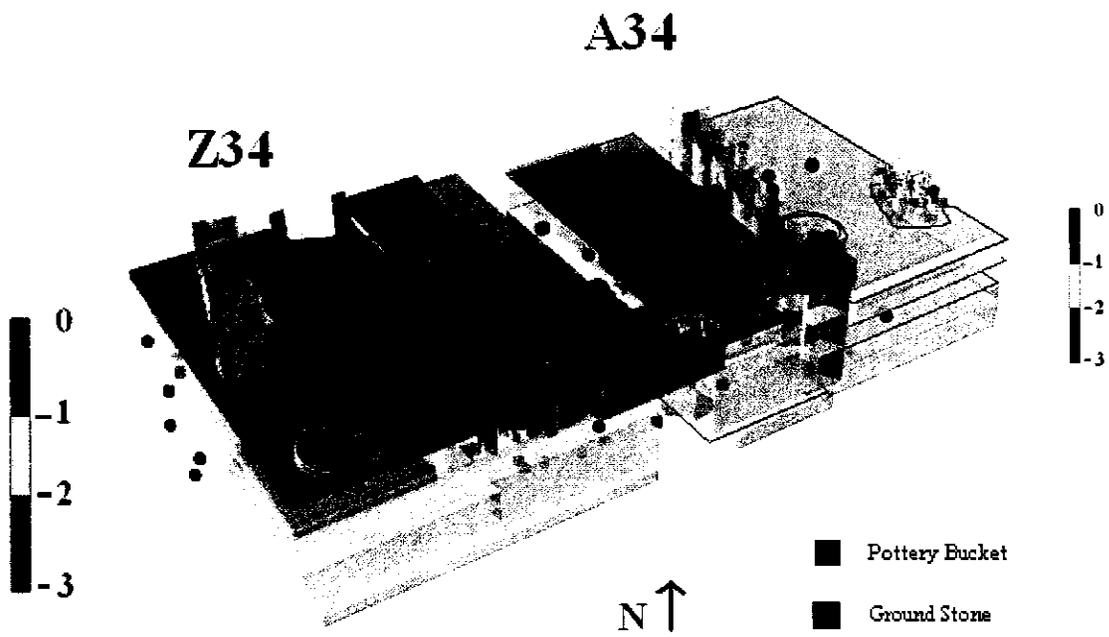


Figure 4.15: Tel Beth-Shemesh Area F shown with features, layers and select artifacts.

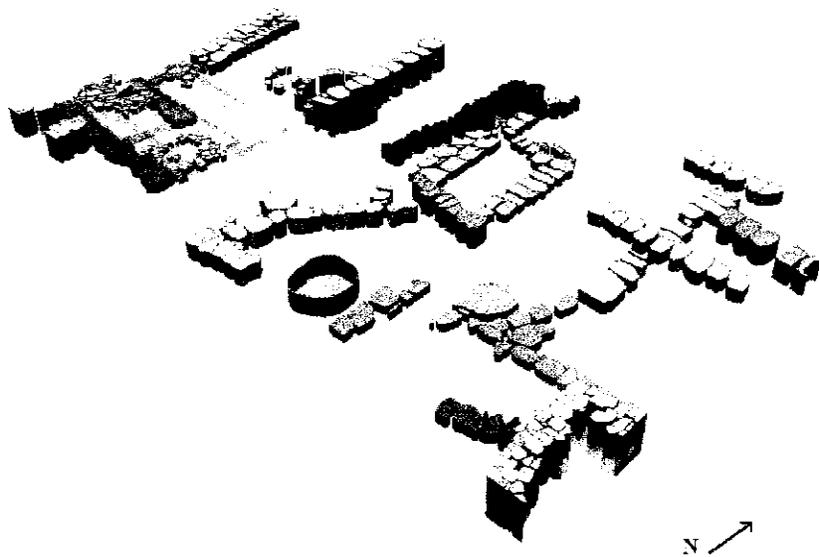


Figure 4.16: Tel Beth-Shemesh Area D shown with digitized features and layers. Six 5m x 5m units are shown, two of which have early digitized layers. Colours are used to represent different site features.

#### 4.6 Site Phasing and Feature Validation Using the GIS Model

The completed GIS model was used to test and hopefully validate the information in the field reports from the 2003 and 2004 field excavations. By using the model in conjunction with the recorded data, it was possible to determine whether or not the archaeological remains (including pottery buckets and layers) accurately fit into the phasing scheme as described in both field reports. Increasing the accuracy of site phasing would provide a more effective approach to assigning occupation phases into specific periods (i.e. Late Bronze, Iron I) in the Near East, and even to define the periods themselves. This is one of the main goals of the Tel Beth-Shemesh research project.

It is possible to identify discrepancies between the GIS model and the field reports because the original recorded data were used. It is also possible to detect errors in the recording of field data such as pottery buckets assigned to the wrong layer during excavation. If data were recorded incorrectly in the field the phasing may be misinterpreted, resulting in an incorrect time line for the site. The GIS model provides the ability to visually and interactively validate and explore the field data.

These tests were carried out by identifying the same feature, pottery bucket or archaeological remain in the GIS model and field report, and then testing it to see whether or not they both fell into the same archaeological phase.

In all but a few cases the features and pottery buckets were recorded in the appropriate phases, or multiple phases if the feature was reused through successive occupations. The GIS model validated both scenarios by comparing it with the excavation report. Remains that were incorrectly recorded were “red flagged”, and reported to the archaeologists. Once enough data has been collected in Area F and D

from the Late Bronze and Iron I, the GIS model can be used to identify and validate the transition between these periods as well.

#### 4.7 Feature Validation Using a Chronological Model

The archaeological remains were then displayed according to chronology. This process was not very time consuming because the layer phasing had already been completed and was connected to the chronology in both the 2003 and 2004 field reports. Ultimately, only the colour of the different components of the model had to be changed to reflect the correct chronology of the excavation area.

In this case the model (Figures 4.17 and 4.18) below displays the chronology of Area F of the Tel. The model shows three separate chronological periods including: Iron I (red) Iron IIa (yellow) and Iron IIb (green). It can also be seen that the number of Iron I remains is far larger than those of Iron IIa and Iron IIb. The model only truly reflects the complex chronology of Area F, indicating that there were more successive occupations of the site (6 phases) during the Iron I period than any of the other periods. This is a significant discovery at this site as it points to a more complex and changing Iron I occupation than was previously thought.

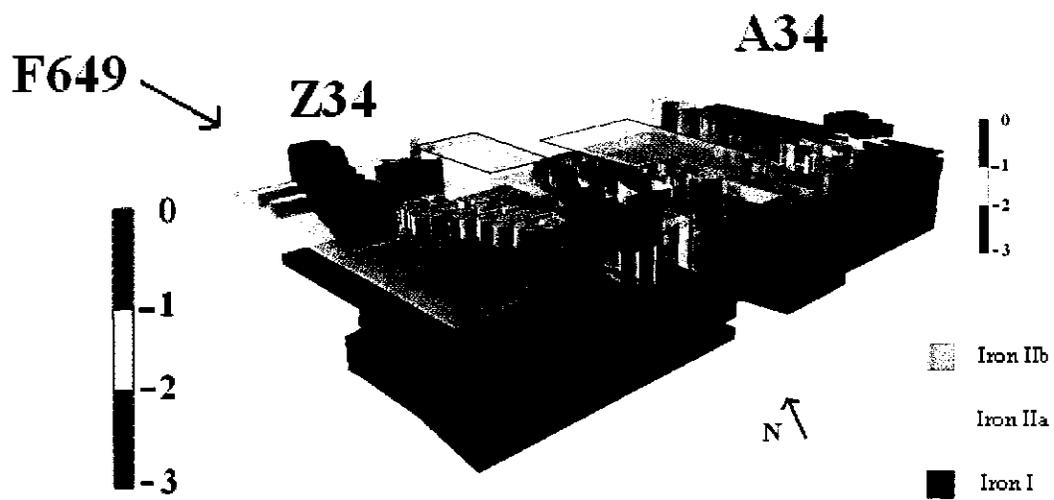


Figure 4.17: Tel Beth-Shemesh Area F, units Z34 and A34 display features and layers in chronological phases: Iron I (red), Iron IIa (yellow) and Iron IIb (green).

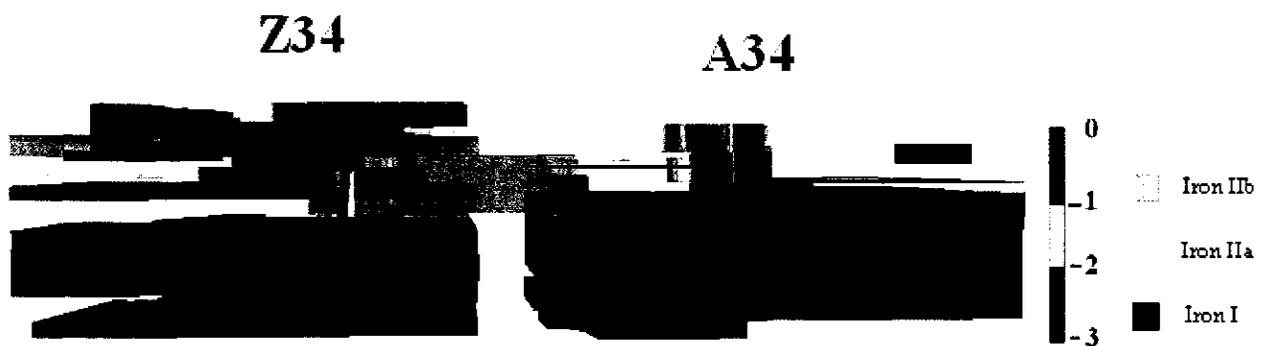


Figure 4.18: The chronological phases of Tel Beth-Shemesh Area A, shown in cross section from the South Facing Profile.

By using the chronologically based model, it was determined that all but 1 of the 26 features (F649) shown in the upper left corner of Figure 4.17 was correctly integrated into the GIS model. The error was detected in the model based on its vertical position in relation to the colour scheme used. Currently, it is not known how the feature was incorrectly recorded, however, it is likely that it occurred during excavation when a simple mistake had been made while recording this information to the daily field report. It seemed unusual to have an older feature (red colour) higher up in the stratigraphy, mixed with younger features (green). The field reports were then checked and it was found that this feature did in fact belong to an earlier chronological phase. It is likely that its position was incorrectly recorded in the field thus producing the error. Next, the field reports were cross checked, and finally the original digital scans that were used to perform data integration into the GIS model were once again examined. Using this model together with the field notes made it possible to identify whether the error was produced in the GIS model or the field data. In this case the GIS model showed that the original archaeological interpretation of the feature was incorrect.

In each version, a chosen variable can be used to explore and analyze the data. Although not carried out in this project, it would now be possible to combine the phased or chronological model with a statistical analysis, such as the density analyses that were carried out at the Fincastle Kill Site. These types of analyses have the ability to produce tabular data that can be explored in a three dimensional virtual environment.

This alternate version of the Tel Beth-Shemesh model is just one of many possible variations that can be created using different parameters as input values for the visualization scheme. Other versions could incorporate material type, the context of the

remains (i.e. *in situ* vs. sieved remains) and cultural association. The model can also be used to record the excavation procedure itself. If the appropriate information is collected, the model can be used to display when the remains were excavated, by whom, and what techniques were used to excavate.

#### 4.8 Summary

Two goals were achieved in this chapter: 1) the excavated features of Area F were successfully delineated to the proper period; and 2) the spatial position of those features were validated based on a chronological scheme. Both goals were accomplished by using the strong data manipulation and visualization capabilities of the Tel Beth-Shemesh GIS model.

The Tel Beth-Shemesh GIS model can be used for a number of different analyses, both qualitative and quantitative in nature. This chapter has shown several ways in which the model can be used in order to visualize and analyze the archaeology of a site. It was found that once the process of integrating the field data into the GIS digital format became streamlined, the data could be utilized in the model on an almost real-time basis with the excavations. This is important for archaeologists because the GIS model can store, visualize and interpret data and serves as a powerful tool for archaeologists both during the field season and during laboratory analysis.

Future plans aim to incorporate more areas of the Tel and to carry out spatial analyses of the existing and future areas in the model. As each future excavation season is completed, more data accumulates, to be digitally integrated. The model is something that has the ability grow within the excavations. As briefly mentioned above, future

directions aim to use the model as a platform for quantitative based analyses such as those used at the Fincastle Kill Site (density analyses). It is the ability to integrate qualitative and quantitative based approaches in the model that makes it a far more versatile tool for archaeologists than those discussed in the literature.

## Chapter 5 Discussion

### 5.1 Introduction

This section of the thesis integrates concepts of theory and methodology for both the Fincastle Kill Site and Tel Beth-Shemesh. Structuring the chapter this way allows direct comparison and conclusions to be made, in regards to both sites. A significant amount of the material discussed in this chapter applies to not only the Fincastle Kill Site and Tel Beth-Shemesh, but also to the general use of GIS in archaeological research. A broad outline of the topics presented in the chapter are: 1) using GIS as an analysis tool (Section 5.2 ); 2) the impact that GIS use has on planning and field protocol (Section 5.3); 3) the importance of three dimensional visualization (section 5.4), 4) using GIS as a qualitative and quantitative research tool (Section 5.5); 5) using GIS to preserve and share archaeological data (Section 5.6); and 6), problems encountered using the GIS models (Section 5.7).

### 5.2 GIS as an Analysis Tool for Archaeologists

Although not a new idea, the use of GIS as an analysis tool in archaeological research has seen little advancement for some time. The goal of this research was not to develop new tools for GIS analysis, but to develop new procedures and ideas for the archaeologist who uses GIS as an analytical tool.

In many disciplines the scope of the project generally dictates the number of research components required to produce a robust study. This is also true in archaeology.

A robust analysis of a site requires numerous components such as a geoarchaeological study, artifact analyses, dating methods, cultural analysis and so on. In essence, GIS is just one component of many. It would be impossible to answer questions about an archaeological site by relying on a GIS analysis alone. However, it can be used to develop new insight about the site, test certain hypotheses, analyze particular site elements and validate fieldwork.

### 5.3 The Impact of GIS on Excavation Planning and Field Techniques

It is important to note that even in the early stages of this research project a tremendous amount of time was spent exploring the possibilities of GIS analyses in archaeology. This involved the initial planning of field procedures to ensure that the field data could be integrated into a working GIS model. Although traditional excavation techniques produce a wide range of data that can be used in GIS analyses, excavation methods that are planned for GIS data acquisition will provide data essential to building GIS models with analytical capabilities. To effectively use GIS in an archaeological project it must be integrated at a number of levels, rather than as an afterthought at the analysis stage. Therefore, careful study of the use of GIS at the field acquisition stage is necessary. Depending on the type of site and excavation methods used, in combination with the hypotheses tested, different GIS planning is required. Two very different sites were used in this research, namely the Fincastle Kill Site in North America and Tel Beth-Shemesh in the Near East. Therefore, unique GIS oriented planning had to be carried out.

Compared to Tel Beth-Shemesh, less modification of the field techniques at the Fincastle Kill Site was required. This was mostly due to the nature of North American plains archaeology, where, regardless if GIS will be used, the position of each artifact is normally measured in three dimensions (x, y, and z). In this case a system had to be built so excavation data could be digitized into the GIS and referenced to digital imagery. The field methods were not altered a great deal from that of a traditional archaeological approach that does not use GIS. However, a constant measurement of datum points with the Total Station was needed to ensure a high degree of spatial accuracy in the GIS. Data integration could have been streamlined if digital tablets were used for mapping the artifacts in the field. This would have meant that the scanning and re-digitizing process could have been eliminated from the project, saving a considerable amount of time. However, due to the high cost of digital tablets, they were not an option for this project.

To integrate field data from Tel Beth-Shemesh into a GIS, a considerable amount of planning was needed before the excavations began. Fortunately, there was already field data from 2001 and 2003 that could be used to experiment with. With these datasets it was possible to explore how to integrate them into a GIS model, and how techniques would need to be altered to streamline data acquisition in the field. Due to the nature and scope of Near Eastern sites, including Tel Beth-Shemesh, only particular archaeological phenomena can be measured and recorded in the field.

Even before the 2004 excavations began it had to be decided which remains should be measured and recorded. This step is very important as the analyses can only be as good as the data. This is especially true in archaeology due to the fact that once something is excavated it is no longer *in situ* and unless its position was recorded it

becomes useless for spatial analysis. It would be ideal if all remains could be measured in the event that the data could be used in some way or another, but this is impractical when thousands of ceramic sherds along with other artifacts would need to be recorded. In 2001, the archaeological remains were not recorded with spatial information and therefore could not be integrated into a GIS model. As a result, a balance between what is practical in the field and sufficient for GIS analysis was needed. It was decided in 2003 that the position of the features and artifacts (excluding broken ceramics) that were still *in situ* would be measured.

At the Fincastle Kill Site the director had always intended to use GIS at the beginning, thus all the data required for analytical modeling was recorded throughout the project. This was different than Tel Beth-Shemesh, where it was only recently decided to use GIS. The 2003 and 2004 excavations, in a history of 14 excavation seasons dating back to 1990, were the first to use it. Therefore, the data and analysis potential with a GIS is greater for the Fincastle Kill Site than Tel Beth-Shemesh, but both have shown to be significant.

Excavating an archaeological site will always result in a biased sample of the 'complete' archaeological record. Artifacts may have been removed or destroyed by natural or cultural formation processes, thus, even using the best excavation methods possible, there will always be artifacts that are missing or lost from what was left behind by the occupants of the archaeological site. Furthermore, because individuals will excavate using different styles, there will ultimately be a variation in the amount of archaeological remains discovered *in situ*, and a variation in the overall amount of archaeological remains recorded during the excavation process. One method in which to

combat this problem is to implement some type of control. For example excavations at the Fincastle Kill Site excavations required measuring of *in situ* archaeological remains and the screening through a 1/8" mesh to collect all material missed while trowelling. Although the material taken from the sieve was not used as part of the GIS database, it would be possible to use these and the *in situ* remains together. These remains would then be grouped together and used as a representative number for each of the 1m<sup>2</sup> areas. In doing so, by using all of excavated material, we have essentially eliminated, or at least minimized, the problem of a biased sample based on the excavation techniques of the individual team members. However, the pixel resolution of the interpolated surface could only be at a maximum resolution of 1m<sup>2</sup>, which is far coarser than the 0.1m<sup>2</sup> pixel that was used in the actual analyses. The methodology outlined above would be a more effective approach when the overall size of the excavated area begins to increase, with a larger pixel size, in that case, being more appropriate.

Although it hasn't been explicitly stated, this thesis has provided the groundwork for delineating the appropriate methodology for collecting field data from an archaeological site (when there are intentions of using GIS as an analytical device). When GIS is used as a research tool, the most important thing to consider at the planning stage of the project is the type of analysis that will be conducted. In many cases, the amount of data and data type required from the field is dependent on the type of analysis that it will be used for. Each analysis type will require different data inputs, while some data will likely be useful for multiple applications. Field work can be modified and streamlined to fit the data requirements for each specific GIS application. Furthermore, it is not possible to delineate the exact data types that should always be recorded, because

each archaeological site will ultimately yield different archaeological remains. This is evident in the field methodology as discussed in Chapters 3 and 4 in this thesis. It can be said however, that more often than not, the more data collected the better. In certain cases though, there may be time constraints during the excavation season, and the field director may be faced with one of two options: 1) collect more detailed data over a smaller area; or 2) collect less detailed data over a larger area. Either of these approaches is subjective to the type of GIS work that is anticipated. It is vital when excavating with GIS in mind, to collect data that is inherently spatial in nature. Essentially, any useful element of the archaeological site that can be measured for location should be. It is also important to note that with most individual site applications, the location of these elements only needs to be recorded relative to one another. Only when multiple sites are used in a single analysis, is it important to obtain the true location. This can be seen in the laboratory methodology in Chapters 3 and 4 of this thesis.

#### 5.4 The Impact of Three-Dimensional Visualization

Three-dimensional visualization in GIS archaeological research has been mentioned several times throughout this thesis, however, its importance has not been specifically stressed. For decades, 3D visualization has been an essential tool for a number of research applications that employ GIS (Hoinkes *et al.* 1995). The ability to perceive data, be it the terrain of a region or models of buildings and roads in 3D virtual environments has helped GIS users to plan, analyze and share their data in a way that until recently has never been done (Shiode 2001). Humans can perceive spatial relationships, such as those described in this thesis, far better when they are displayed in

a graphic form (GIS) versus a raw form (data tables). Furthermore, when studying the three-dimensional spatial relationships of archaeological phenomena, it makes sense to display and analyze data in three dimensions. Moreover, when explaining these data or their interpretation to others, such as students or patrons of a museum, it is more likely that they will better understand the information and conceptualize the data when displayed in three dimensions (a viewing format that the human brain is accustomed to). This is not to say that three-dimensional visualization is compulsory for the GIS analyst to obtain results. Analyses can be done without the use of 3D visualization, but it is significantly aided with it.

As explained in previous sections of this thesis, the use of three-dimensional visualization in GIS studies has fallen predominately into two main categories: 1) urban modeling; and 2) terrain modeling. These are general categories that have a wide range of applications over a number of disciplines, some of which have been discussed in detail in this study. The combined research of the Fincastle Kill Site and Tel Beth-Shemesh has utilized both of these general themes of 3D visualization and applied them in an archaeological context.

## 5.5 Qualitative and Quantitative Archaeological Analysis with GIS

This study has produced three separate types of analyses: 1) viewshed analysis; 2) artifact density analysis with surface interpolation; and 3) field data validation with visualization models. Of these three analyses, the viewshed study, though technical in nature, can be classified as a qualitative analysis. The amount of area in and around the dune of the Fincastle Kill Site where the hunters could have hidden in wait of an ambush

was determined based on the terrain of the site. Although the viewshed itself is derived from a statistical model, the results of the analysis do not require statistical interpretation. The use of statistics to support the viewshed results of this study does not add information to further prove that there either were or were not areas of the dune that the bison could see from where they were killed. This study must take into account other factors (some qualitative and some quantitative) that could possibly affect the interpretation of the analysis. However, information on the geoarchaeology of the dune, or hunting practices that are contemporary with the age of the site will ultimately dictate whether or not the results from the viewshed analysis are applicable to the site. In other words, the results from the GIS analysis must always be interpreted by the researcher.

The artifact density analysis with surface interpolation at the Fincastle Kill Site shows a much more quantitative based approach to GIS in archaeology. Similar to the viewshed analysis, results of this analysis can be displayed immediately through a graphic medium. However, the spatial correlation of the surface values using statistical analysis is also available. This analysis showed a high spatial correlation between the position of debitage and the faunal remains at the site. Like the viewshed analysis, the density analysis required more than just statistics to validate results. The density analysis only indicated that a spatial correlation exists between the two types of archaeological remains. It does not answer the question “why a correlation exists where it does”. The results from the analysis done at the Fincastle Kill Site point to possible explanations of high density clusters caused by retouching of the stone tools and butchering. However, further research outside of the GIS realm is required to test this and possibly validate the

ideas generated from this analysis, and to support and explain the cultural activities of the site.

For the archaeologist, the ability to statistically correlate the positions of archaeological remains is valuable for interpreting and disseminating results within and outside the discipline. Using data that could be generated from a number of different archaeological sites, an archaeologist working at another site could test correlations and build up more extensive cultural interpretations. The visualization model constructed for Tel Beth-Shemesh integrates both quantitative and qualitative methodologies. It has been shown how the GIS model can be used to cross reference excavation data. Additionally, the visualization capabilities inherent in the model lend themselves well to the archaeologist or non-archaeologist who requires an understanding of the chronology and the spatial relationships between the site's archaeological remains. These capabilities are qualitative as they do not produce numerical results that represent information gathered from the analysis performed using the GIS model. However, the information gained from these types of results can be just as valuable as quantitative results. New ideas about the archaeology of the site may be established, and these ideas can be conveyed using this model.

The Tel Beth-Shemesh GIS model can also be studied on a quantitative basis using two different approaches. One of the most practical uses of the model is calculating the concentration (i.e. density) and spatial positions of the archaeological remains of the site. From this, the interpolated surfaces can be built (using the same methods applied at the Fincastle Kill Site). They can then be compared to statistically analyze the spatial correlations between different groups of remains from the site.

However, unlike the Fincastle Kill Site, this statistical analysis has the possibility to be far more sophisticated due to the nature of Tel Beth-Shemesh. Essentially, the analysis can be broken down and looked at as different components. An example of this would be analyzing artifact densities and comparing them across multiple layers or phases within the site. Therefore, the quantitative analysis can be used in conjunction with many of the qualitative results established by the model. This type of integration can make the model a very useful tool for understanding the site.

It is important to reiterate here that computing the spatial correlation of the archaeological remains is important for two reasons. The correlation coefficient may reveal possible spatial relationships that were not apparent during the excavation, thus leading to new understandings or hypotheses about the site. Alternatively, the correlation coefficient, as demonstrated at the Fincastle Kill Site, can be used to support spatial relationships that are visually apparent during field excavation. Both cases have been demonstrated in the literature where, even before the analysis had been carried out, existing spatial patterns and possible relationships were identified, and a GIS analysis was used as a tool to either support the hypotheses about these relationships or develop new ones.

Due to the interpretive nature of archaeology and GIS, it is likely that research of this type will continue the use of both qualitative and quantitative analyses. In a discipline such as archaeology, it is not possible to understand and form hypotheses about a site without using both.

## 5.6 Preservation and Dissemination Benefits

One of the most important benefits of digital data capture in a GIS is undoubtedly the ability to reconstruct and preserve an archaeological site in virtual space, because when a site is excavated it is destroyed. Once the sediment has been moved and the remains excavated, the site no longer exists as it was. One is not able to return to the site and excavate that same area. Therefore, archaeologists must record as much information during excavation as possible. This information can be stored and used for various types of analyses, GIS being one of these. Unfortunately, as noted above, many past excavations, including those at Tel Beth-Shemesh, failed to collect the information needed for GIS analyses, mostly because site reconstruction in a GIS virtual environment was not anticipated during these excavations. The Fincastle Kill Site study is an example of a new excavation that planned for GIS data integration and post excavation GIS analysis from the start. Ideally, other new and ongoing excavations that don't initially plan on using GIS should still attempt to maximize appropriate data gathering in the event that GIS analysis may be subsequently conducted.

Being able to reconstruct the site is also important for the dissemination of the results to the public. Throughout this study, preliminary results and visualization models have been shown to students, colleagues and archaeological interest groups. Even though they have never been to the Fincastle Kill Site or Tel Beth-Shemesh, they now have a sense of what the site was like prior to and following the excavations and are also able to interact with the site on a virtual level. In essence, they are able to take a journey to the site by using the computer in front of them. Reconstructing archaeological sites in a GIS virtual environment could even impact the way schools and museums function. Imagine

taking a group of people on a trip to a virtual archaeological site over 5,000 kilometers away without having to travel on a plane. As more sites are excavated using this method, people inside and outside the archaeological community will benefit. There are obviously certain things that the virtual reconstruction cannot replace. However, it is a valuable tool for the archaeologist to use to convey ideas.

### 5.7 Problems with the GIS Model

One of the biggest challenges encountered in this research was during the excavation phases. A significant amount of time was required to meticulously record the excavation data needed to build reliable models for the basis of the analyses. Because this was the first time that GIS analysis was used for both excavations, the data collection process was sometimes slow. Hopefully, excavation data collection will become more streamlined during field seasons now that it is known what particular data are needed for analysis. For both the Fincastle Kill Site and Tel Beth-Shemesh excavations, certain analyses, such as the site reconstruction, were planned from the beginning. However, it was uncertain what other studies would be conducted later in the project. Therefore, almost all types of data imaginable were collected, which slowed the excavation progress at times. As mentioned in the previous section it is always better to record more information whenever possible, as one can never re-create a site. Of course, the collected data are always limited to what the archaeologist can envision and technically record.

Another common problem with GIS is the “wow factor”. Many people believe that because a highly sophisticated program is being used to study a site, the results of an analysis are sure to be correct and beneficial. It is important to understand that the GIS

model/analysis can only be as good as the data that is put into it and the intensity of its analysis interpretation. If careful recording in the field and precise data integration into the GIS are not carried out, the analysis will suffer and produce results that may not directly represent the archaeological site. This relates directly to the time consuming nature of the excavation process. At the Fincastle Kill Site and Tel Beth-Shemesh a great deal of care was taken to ensure that data would be collected in the field and integrated into the GIS with the utmost accuracy. However, small amounts of error were likely induced during excavation and integration stages, and these may be magnified by the GIS model. In many cases one cannot estimate how many errors are induced in the data. However, since both the Fincastle Kill Site and Tel Beth-Shemesh were excavations of relatively small size, the amount of possible error that could have been introduced into the model is minimal.

The idea of abstract representations of real life phenomena is another problem with GIS use, especially in a three dimensional context. In the Tel Beth-Shemesh model the features and other archaeological remains were rendered with proper width and height, but they lack some of the true dimensional characteristics of their real life counterparts. This means that although they retain most of the real dimensions, the GIS software cannot render the model with all of the small nuances that occur in reality. As for negating problems with three dimensional abstraction, there are only two real solutions; either continue to put countless hours into the construction of GIS models so they better represent their real life counterparts or to update GIS software to better render the available data. More detail can be added, but only by a considerable increase in workload in the field and laboratory. One must question what is more important: a model

that looks good, or one that functions well on an analytical basis. Television documentaries often use a number of highly sophisticated computer models of the Egyptian pyramids, Roman architecture and other archaeological phenomena for example. These beautiful models have little or no information useful for analysis, however, they do serve as excellent visualization models. A GIS model must serve both as a visual and analytical tool, and be more than just satisfactory in both these regards. Therefore, before building an analytical model one must decide which type of function it will serve.

### 5.8 The “High Detail” Model

It has been stated in this thesis that the GIS models that have been created are of “high detail”. In many regards, this term has been used on a relative basis. What the literature implies is that there is a lack of GIS applications in archaeological research that focus on modeling smaller type objects such as individual artifacts. Thus, the term “high detail” in this case refers to archaeological remains that are small in size. Alternatively, “Low detail” would include studies focusing regional scale models. There are of course, GIS applications outside of the archaeological sciences that have used much higher detail models than the ones demonstrated here. It should also be noted, that the data type is what drives the detail of the GIS model, and in the cases of the Fincastle Kill Site and Tel Beth-Shemesh, the models have attained the highest level of detail possible with the data that has been used.

## Chapter 6

### Summary and Conclusions

#### 6.1 Overview

The main research objectives of this thesis were: 1) use GIS technology to develop new tools for the archaeologist to study a given site; 2) demonstrate these tools by analyzing multiple archaeological sites; and 3) formulate new and/or support existing hypotheses about these sites using the information obtained from the GIS analyses. These objectives were primarily met by performing adequate background research of GIS applications and their use in the archaeological sciences, early testing with available data, and careful planning prior to the Fincastle Kill Site and Tel Beth-Shemesh 2004 field seasons. Extensive field work was also required, which, in turn, led to a considerable amount of data being available for research and development of GIS tools and analytical models for archaeological applications that far surpass current work in this field. These tools were then used to develop and evaluate hypotheses that would be difficult, if not impossible, using conventional techniques.

Chapter 3 (the Fincastle Kill Site) brought forth a hypothesis about the hunting techniques used at the site and implemented GIS to support it. Using a viewshed analysis it was shown that the hypothesized hunting style could have been used as an effective approach to killing the bison inside the main dune that now encompasses the site. Additionally, the two and three dimensional surface interpolation analyses helped discern regions of the excavation area where correlations of high densities of faunal and lithic

remains exist. These correlations were then used to show where an increased level of butchering may have taken place.

Chapter 4 (Tel Beth-Shemesh) implemented the use of pre-existing and newly collected (from the 2004 field season) data in order to produce working GIS models of Area F and Area D of the tel. It was shown that these models could be used not only for visualization capabilities, but also for analytical purposes. Chapter 4 discussed the creation of the Area F model using the GIS software. This model was then used to validate the 2003 and 2004 excavation data and visually inspect the chronology of the site features based on these field data.

Chapter 5 discussed many of the important issues surrounding the use of GIS in archaeological analyses. The need for pre-excavation preparation and an abundance of planning in the field are required to produce data that can be used for post-excavation analysis is one such issue. Moreover, if sufficient care is not taken during the excavation, the data may be unreliable and produce analysis results that do not truly reflect the archaeological site. Other issues such as qualitative and quantitative approaches and the dissemination of GIS results were also addressed. The ideas considered in this chapter had direct relevance to the case specific research in this thesis and aimed to follow up on particular questions that arose in Chapters 3 and 4.

## 6.2 Research Perspectives

Although the research conducted for this thesis is finished, excavations at the Fincastle Kill Site and Tel Beth-Shemesh are still ongoing. Data will continue to be collected and integrated in the constructed GIS models for the sites. As the databases for

both sites increase, further analyses that implement far more variables into the GIS model can be carried out. The viewshed model at the Fincastle Kill Site, for example, could possibly incorporate such variables as the time of day and prevailing winds.

At this time many details remain unknown about both sites. As more information is gathered, the GIS models will become more of a true reflection of the sites. It must be noted that GIS can further the information gained. As discussed throughout this thesis, the GIS models rely on other components of the archaeological analysis, such as geoarchaeology, lithics analysis, faunal analysis and historical interpretations. It is not until these research components are more complete that the GIS model can integrate some of the most important data that are needed to answer questions and form new hypotheses about the archaeology of these sites.

Although this thesis has shown the importance of GIS analysis in archaeology, the question must be asked “is it really necessary?”. Archaeological research has been carried out for decades without using GIS. Is it really needed now? Of course archaeology can go on without GIS, but this study has revealed many ways GIS can aid archaeologists in the research of a site. Furthermore, GIS can help create a more robust approach to understanding the archaeology of a site. In this thesis, several examples of GIS analysis were explored that would otherwise be impossible to carry out using traditional approaches. The viewshed analysis of the Fincastle Kill Site and the visualization model of Tel Beth-Shemesh are prime examples of this. In conclusion, the archaeologist does not have to use GIS for analysis, but if they want to achieve a more complete understanding of a site they will indeed incorporate it into their research.

This work does not answer any profound questions about the occupants of the Fincastle Kill Site or Tel Beth-Shemesh, but it does use GIS to visualize, analyze and develop hypotheses about both sites in new ways. Through these analyses it can be seen that GIS remains only one component of the complete analysis of a site and will always rely on the multidisciplinary approach of archaeological science to produce more reliable results. GIS will never be the “be-all end-all” tool for archaeologists, but it does add one more very useful component to the analysis of a site.

### 6.3 Future Prospects

Because GIS is still relatively new to archaeology, there remains a tremendous number of unknown applications that it may be useful for. The applications shown in this thesis represent a small number of possibilities that GIS has to offer to the archaeological sciences. Sadly, the time consuming nature of integrating GIS into archaeological projects and the general lack of GIS knowledge in the archaeological world seem to be two factors limiting its growth and exposure.

Alternatively, the integration of remote sensing into archaeological projects, such as aerial photography, and more currently, satellite imagery, has been done for site detection for some time now. Recent advances have developed remote sensing technology capable of imaging in high detail. This means that remote sensing techniques can be used for site detection and even mapping archaeological remains. These sensors make use of laser detection and ranging and can be used to digitally map the site features during excavation. This could provide the archaeologist an ability to bypass certain time consuming stages of GIS data integration. Rather than having to measure and map out

the remains in the field, and then convert them to a digital GIS format, the excavators can use the remote sensing equipment to perform all of these tasks in one process. Endeavors such as this are currently limited by the high cost of the specialized remote sensing equipment and also by the fact that they can only collect “visual data” that in turn requires interpretation by the archaeologist.

It is certain that archaeologists will continue to utilize GIS as a tool to map, study and understand archaeological sites all over the world. Unfortunately, it may take some time before GIS applications exceed anything beyond the rudimentary tasks that it has been used for until now. Further research, such as the methodology applied in this project, must continue to drive analytical techniques not only forward, but also in new directions.

This thesis has accomplished the goal of designing and implementing new analytical tools for the archaeologist. At certain times throughout this research the Fincastle Kill Site and Tel Beth-Shemesh GIS models took on new directions and evolved in unexpected ways. In the end, two working GIS models were created that contribute to future GIS research in the archaeological sciences. These models push the present limitations of GIS use in archaeology. Hopefully this work will help create a path to a world of archaeological research where applications, such as the ones described in this thesis, are widely used, and new ones are continually being created.

## References

- Allen, K.M.S., Green, S.W. and Zubrow, E.B.W., 1990, *Interpreting Space: GIS and archaeology*, 398p, Taylor & Francis Inc., 1900 Frost Road, Suite 101, Bristol, PA 19007.
- Andretto, M., Brusco, N., and Cortalezzo, G.M., Automatic Modeling of Archaeological Objects, 2003, Paper presented at the 2003 Conference on Computer Vision and Pattern Recognition Workshop. (CVPRW '03).
- Brandt, R., Groenewoudt, B.J., and Kvamme K.L., 1992, An Experiment in Archaeological Site Location: Modeling in the Netherlands Using GIS Techniques, *World Archaeology*, Vol.24, No.2, Analytical Field Survey (Oct., 1992), 268 – 282.
- Burrough, P.A., and McDonnell, R.A., 1998, *Principles of Geographic Information Systems*, 1998, Oxford University Press, Great Clarendon St., Oxford, England, 0X2 6DP
- Burton, N.R., and Shell, C.A., 2000, GIS and Visualizing the Paleoenvironment, *Computer Applications and Quantitative Methods in Archaeology*, 2000, 81 – 89.
- Ebert, D., 2004, Applications of Archaeological GIS, *Canadian Journal of Archaeology*, 319-341, V. 28 No. 2.
- Frison, George C. 1974, *The Casper Site: A Hell Gap Bison Kill On the High Plains*. New York: Academic Press.
- Gerber, M., 2000, Predictive Site Reconstruction Based on Algorithmic Complexity:  $C_R$ -Signatures of Partly Destroyed Mudbrick Buildings. Printed as part of a manuscript submitted for publication. Institute of Ancient Near Eastern Archaeology and Languages, Dept. of Archaeology, University of Berne.
- Gerber, M., 2000, Progress Report on the CPSR-Project 1999/2000 (Predictive Site Reconstruction). Institute of Ancient Near Eastern Archaeology and Languages, Dept. of Archaeology, University of Berne.

Groger, G., and Plumer L., 2003, Exploiting 2D Concepts to Achieve Consistency in 3D GIS Applications, Presented at GIS'03, November 7 – 8, New Orleans, Louisiana, U.S.A.

Guillot, D., and Leroy, G., 1995, The Use of GIS for Archaeological Resource Management in France: the SCALA Projet, with a Case Study in Picardie, *Archaeology and Geographical Information Systems: A European Perspective*, 15 – 26.

Harris, T. 1986, Geographic Information System Design for Archaeological Site Information Retrieval, *Computer Applications and Quantitative Methods in Archaeology*, 148 – 161.

Harris, T., 1988, Digital Terrain Modeling and Three-Dimensional Surface Graphics for Landscape and Site Analysis in Archaeology and Regional Planning, *Computer Applications and Quantitative Methods in Archaeology*, 161 – 172.

Hunt, E.D., 1992, Upgrading Site-Catchment Analyses With the Use of GIS: Investigating the Settlement Patterns of Horticulturalists, *World Archaeology*, Vol.24, No.2, Analytical Field Survey (Oct., 1992), 283 – 309.

Kohler, T.A. and Parker, S.C., 1986, Predictive Models for Archaeological Resource Location, *Advances in Archaeological Method and Theory*, Vol. 9, 397 - 453.

Kvamme, K.L., 1992, Terrain Form Analyses of Archaeological Location Through Geographic Information Systems, *Computer Applications and Quantitative Methods in Archaeology*, 127 – 136.

Llobera, M., 2001, Building past perceptions with GIS: Understanding Topographic Prominence, *Journal of Archaeological Science*, 28, pp.1005 – 1014.

Madry, S.L.H. and Rakos, L., 1996, Line-of-Site and Cost-Surface Techniques for Regional Research in the Arroux river Valley, *New Methods Old Problems: Geographic Information Systems in Modern Archaeological research*, Center for Archaeological Investigations, Occasional Paper No. 23, 104-126.

Mazar, A., 1992, *Archaeology of the land of the Bible*, Doubleday Dell Publishing Group Inc., 1540 Broadway, New York NY 10036.

Perkins, P., 2000, A GIS Investigation of Site Location and Landscape Relationships in the Albegna Valley, Tuscany, *Computer Applications and Quantitative Methods in Archaeology*, 133 – 140.

Renfrew C. and P. Bahn, 2000, *Archaeology, Theories Methods and practice*, Thames & Hudson Inc., 500 5<sup>th</sup> Ave., New York NY, 10110.

Romano, D.G. and Schoenbrun B.C., 1993, A Computerized Architectural and Topographic Survey of Ancient Corinth, *Journal of Field Archaeology*, Vol. 20, 177-190.

Romano, D. G. and Tolba O., 1994, Remote Sensing, GIS and Electronic Surveying: Reconstructing the City Plan and Landscape of Roman Corinth, *Computer Applications and Quantitative Methods in Archaeology*, 163-174.

Romano, D. G. and Tolba O., 1996, Remote Sensing and GIS in the Study of Roman Cunturiationin the Corinthia, Greece, *Computer Applications and Quantitative Methods in Archaeology*, 457- 463.

Shiode, N., 2001, Urban Models: Resent Developments in the Digital Modeling of Urban Environments in Three-Dimensions, *Geo Journal*, Vol. 52, 263 -269.

Walde, D., D. Meyer, and W. Unfreed, 1995, The Late Period on the Canadian and Adjacent Plains. *Revista de Arqueología Americana* Vol. 9, 7-66.

Wansleben, M. 1988, Applications of Geographical Information Systems in Archaeological Research. In Rahtz, S.P.Q. (ed.) *Computer and Quantitative Methods in Archaeology*, BAR International Series 446 (ii). Oxford: British Archaeological Reports. pp. 435-451.

Waters, M.R., 1992, *Principles of Geoarchaeology*, University of Arizona Press.

Wheatley D., 1995, Cumulative Viewshed Analysis: A GIS-Based Method for Investigating Intervisibility, And Its Archaeological Application. In *Archaeology and Geographical Information Systems: A European Perspective*, edited by G. Lock and Z. Stancic, pp. 171-185, London: Taylor and Francis.

Yuan. M., 2004, Temporal GIS and Spatio-Temporal Modeling, Department of Geography, The University of Oklahoma, <http://www.ncgia.ucsb.edu>.

## Glossary of Terms

Baulk: a strip of earth left standing between different excavation units so that the vertical sections can be studied, datums are more secure, and for ease of access.

Debitage: the collective term used by archaeologists to refer to the waste material left over when creating a stone tool.

Digital Elevation Model (DEM): a quantitative model of a part of the Earth's surface in digital form.

Excavation Unit: a distinct area of space used as a control measure during the excavation process.

Faunal Remain: animal (often bone) remain.

Fire Broken Rock: a rock of any type that has been cracked and/or broken due to deliberate heating.

Geoarchaeology: archaeological research using the methods and concepts of the earth sciences. Geoarchaeologists often study soil and sediment patterns, and processes of earth formation observed at archaeological sites.

Geographic Information System: a set of computer tools for storing, retrieving, transforming and displaying spatial data.

Georeference: determine the true geographic location of a digital image.

Interpolation: estimation of the values of an attribute at unsampled points from measurements made at surrounding sites.

Lithic: a stone artifact, usually in the form of a stone tool or chipped debris (debitage).

Orthorectification: the process of removing geometric distortions from remotely sensed imagery, mainly aerial photography and satellite images, to facilitate reliable data for measuring and mapping purposes.

Phase: an archaeological term that defines an occupation at a site.

Pixel: contraction of picture element; smallest unit of information in a grid cell map or a digital image.

Polygon: a multi-sided figure representing an area on a map.

Projectile Point: a general term for stone points that were hafted to wooden shafts as spears, darts, or arrows.

Raster: a regular grid of cells covering an area.

Viewshed: those parts of the landscape that can be seen from a particular point.