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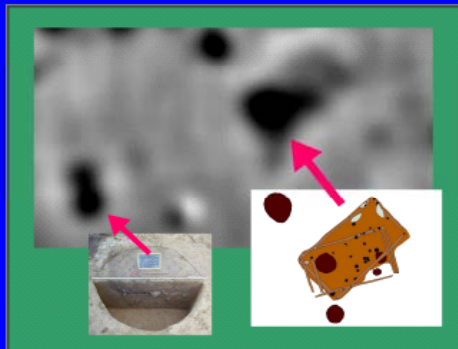
Geophysical Surveys in Archaeology: Guidance for Surveyors and Sponsors

Lewis E. Somers and Michael L. Hargrave
with contributions by Janet E. Simms

December 2003

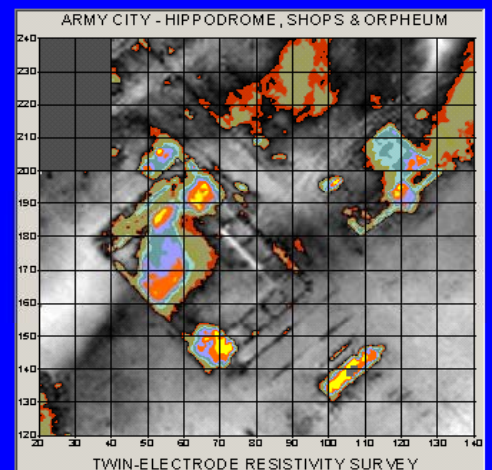


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Development Center



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Funding provided by the Legacy Resource Management Program

ATAGS 1.0
Automated Tool for
Archaeo-Geophysical Survey
Plains and Midcontinent Edition



Geophysical Surveys in Archaeology: Guidance for Surveyors and Sponsors

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Final Report

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ABSTRACT: The last few years have seen a significant increase in the use of geophysical techniques by archaeologists in the United States working in both academic settings and Cultural Resources Management (CRM). Since 1995, the Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) has made a concerted effort to assist the Department of Defense (DoD) in making efficient use of geophysics in managing the cultural resources at a number of installations. This report provides a set of guidance documents and decision support tools to help CRM managers and field practitioners, particularly those working at DoD installations, make effective use of geophysical techniques.

The ATAGS (Automated Tool for Archaeo-Geophysical Survey) software tool, described in this report, allows the user to develop an effective survey design for a geophysical survey at a particular site. ATAGS produces a detailed report that also provides guidance on project management. ATAGS is presently designed for use in the Midwest and Plains regions of the United States. Those working in the Mid-south and interior South will also find ATAGS useful. The survey designs are intended for geophysical instruments manufactured by Geoscan Research (USA), but can also be used (with minor revision) with all comparable instruments.

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Preface

This study was conducted for the Legacy Resource Management Program under Legacy Project 00127, “Decision Support Tools for Geophysical Applications in Cultural Resources Management.” The technical reviewer was Dr. Paul Green, Cultural Resources Manager, Air Combat Command.

The work was performed by the Land and Heritage Conservation Branch (CN-C) of the Installation Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Michael L. Hargrave. Special thanks go to Dr. Janet Simms, who assembled the annotated bibliography included in this report. The technical editor was Linda L. Wheatley, Information Technology Laboratory — Champaign. Dr. Lucy A. Whalley is Chief, CN-C, and Dr. John T. Bandy is Chief, CN. The associated Technical Director was Dr. William D. Severinghaus, CVT. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, EN, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

The last few years have seen a significant increase in the use of geophysical techniques by archaeologists in the United States working in both academic settings and Cultural Resources Management (CRM). Evidence of this increase includes a proliferation of World Wide Web (WWW) sites that illustrate and summarize the results of a wide range of geophysical surveys (e.g., *Archaeo-Physics* 2003; Hargrave 2003; Kvamme 2003; *Cultural Resources Analysts* 2003). A number of recent monographs and articles also document the increased use of geophysics (Bevan 1998; Clay 2000, 2001; Conyers and Goodman 1997; Hargrave et al. 2002; Kvamme 2001; Silliman et al. 2000).

Several Federal agencies presently have well-established programs in archaeological geophysics. The National Park Service (NPS) has, for many years, offered an annual training course that introduces CRM professionals to a wide range of geophysical methods (De Vore 1992). NPS also provides technical support in geophysical survey to a wide range of Federal and state land managing agencies and installations.

Since 1995, the Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) has made a concerted effort to assist the Department of Defense (DoD) in making efficient use of geophysics in managing the cultural resources at a number of installations. To date, ERDC/CERL has conducted geophysical investigations at Fort Bragg (NC), Fort Campbell (KY), Fort Leonard Wood (MO), Fort Leavenworth (KS), Fort Riley (KS), Wright Patterson AFB (OH), and Poinsett Electronic Combat Range (SC) (Ahler et al. 1999a; Ahler et al. 1999b; Hargrave 1999a, 1999b; Hargrave et al. 2002; Isaacson et al. 1999; Somers and Hargrave 2001; Idol et al. 2003; Zeidler 1997).

A broader awareness of the potential contributions of geophysics to CRM will almost certainly lead to further increases in the demand for geophysical surveys. Maintaining the quality of geophysical investigations during a period of rapid expansion in their use will, in the near future, pose a challenge to the geophysical and CRM professions. A number of universities now offer geophysical

courses of study, resulting in a growing cadre of young technicians and researchers who are well-trained in archaeological geophysics. Nevertheless, there is a danger that a shortage of competent geophysical practitioners and the limited availability of suitable instruments will limit access to the benefits of geophysical surveys.

A related concern is that the growing demand for geophysical surveys of archaeological sites will encourage unqualified consultants to offer their services to DoD and other CRM practitioners. Here it is important to understand the diversity of the geophysical profession and the unique character of archaeological sites. The vast majority of professional geophysicists in the United States work in areas such as geology, mineral prospecting, hazardous waste management, unexploded ordnance (UXO), and land mine detection. In general, these subfields are concerned with the detection of large-scale and/or high-contrast targets. Geophysics is frequently used to map geological strata and other large-scale phenomena, to detect buried hazardous material containers ranging from 50-gallon drums to large storage tanks, or to differentiate metal shrapnel from live ordnance (UXO). Only in the case of largely plastic landmines do non-archaeological geophysicists focus on very small targets.

In the United States, prehistoric archaeological features tend to be small (often less than 1 meter in greatest dimension) and exhibit a very subtle contrast with the surrounding soil. This is particularly true for the prehistoric period, for which the most common type of feature is the small, earth-filled storage or cooking pit. With very few exceptions, prehistoric sites in the United States lack metal artifacts. Across much of the country, there is little or no evidence of stone architecture. Thus, geophysicists trained in non-archaeological disciplines are generally not well-qualified to design surveys capable of detecting prehistoric archaeological features. They may have substantial expertise with a variety of instruments, modeling, and imaging techniques, but they lack an understanding of the subtle nature of the archaeological record and a familiarity with appropriate processing methods and algorithms.

On balance, there is a growing demand in the United States for geophysical surveys of archaeological sites. Effective archaeo-geophysical surveys require both geophysical expertise and an in-depth familiarity with the ephemeral nature of the archaeological record.

Objective

The objective of this project was to develop a set of guidance documents and decision support tools to help CRM managers and field practitioners, particularly those working at DoD installations, make effective use of geophysical techniques.

Approach

Practical guidance on the effective use of geophysical survey techniques in CRM was developed in two formats: (1) as an automated software tool and (2) as a series of nontechnical guidance documents. The guidance in both formats is designed for two user groups: (1) geophysical practitioners who have not yet acquired the depth of knowledge and experience needed to develop their own survey designs and (2) CRM professionals who want to incorporate geophysics into their CRM and research programs through consulting contracts with professional geophysicists.

ATAGS (Automated Tool for Archaeo-Geophysical Survey) is a software tool that allows the user to develop an effective survey design for a geophysical survey at a particular site. The term “survey design” refers here to a set of decisions about the appropriate instrument, instrument configuration, data density, and data processing. ATAGS prompts the user for information about the survey purpose, the nature of a site’s soil, and expectations about the archaeological record. The program uses this information to specify a survey design that will allow the user to achieve his/her survey goals. ATAGS produces a detailed report that also provides guidance on project management.

The present version of ATAGS is designed for use in the Midwest and Plains regions of the United States. Those working in the Mid-south and interior South will also find ATAGS useful for many sites. The survey designs are intended for geophysical instruments manufactured by Geoscan Research (USA), but can also be used (with minor revision) with all comparable instruments.

This report is a collection of resources for geophysical surveyors and CRM professionals who may sponsor geophysical surveys. Chapter 2 is a user’s manual for ATAGS. Chapter 3 shows an example of the reports generated by ATAGS, and its format differs from that used elsewhere in this report. Chapters 4 through 11 present the Supplemental Documents that are included in ATAGS. These documents provide rather detailed guidance on data collection and data processing, examples of successful surveys (with geophysical maps), a nontechnical glossary of key terms and concepts, an annotated bibliography of recent ref-

erences, advice on how to develop an effective Statement of Work (SOW), several examples of complete SOW, and advice on how to avoid or solve common problems. The Supplemental Documents are diverse; some are essentially checklists whereas others are expository. Some were originally designed to be highly technical addenda to ATAGS. These can be printed individually as needed by surveyors working in the field. Despite the diversity in purpose, content, and style, it seems useful to present here all of the supplemental guidance documents under one cover, to ensure that they are available to the widest possible user group.

This report presents the initial version of ATAGS. The tool has not yet been reviewed by users working at a wide range of sites. The developers welcome comments on this version, including suggestions for improvements and requests for future versions designed for use in other regions (e.g., the desert Southwest). To contact the developers, e-mail comments to:

Michael.L.Hargrave@erdc.usace.army.mil

2 ATAGS User's Guide

ATAGS is an automated tool for archaeo-geophysical survey design. This chapter provides a brief introduction to ATAGS and step-by-step guidance for its use. The figures presented here are derived from the ATAGS screens. A sample report produced by ATAGS is presented in Chapter 3.

The ATAGS user-friendly software tool is designed to help geophysical surveyors plan and execute effective surveys at particular archaeological sites. The tool will also help survey sponsors gain valuable understanding of the requirements for successful geophysical surveys at particular sites. The version of ATAGS discussed here is designed for use in the Midcontinent and Plains regions of the United States. This version should also be useful for many sites in the interior South.

ATAGS requires the user to provide information about the objective of the survey, soil characteristics, expectations about the nature of prehistoric and/or historic archaeological features that may be present at the site, and the nature of factors (such as recent metallic debris) that may complicate the survey. Using this information, ATAGS produces a report that includes recommendations about data sample density and distribution requirements and estimates of the number of hours that would be required to execute the survey fieldwork.

Basic Issues in Geophysical Survey

Why is there a need for an automated tool to assist in the planning of a geophysical survey? Archaeologists are well aware of the wide range of variation in the nature of cultural deposits, soil, rocks, vegetation, moisture, bioturbations, and recent cultural impacts that can be present at a site. Each site is unique in terms of how these factors interact to influence the degree to which the site as a whole is amenable to geophysical survey. Experienced geophysicists who are familiar with the local archaeology can often predict which instruments are likely to be appropriate for use at a particular site. Even experienced surveyors often find it necessary to try several instruments and to modify their instrument configuration and field strategy in order to identify a survey design that will meet their sponsor's research or CRM objectives. While ATAGS cannot hope to

obviate the need for technical expertise and practical experience, it can help novice surveyors and survey sponsors design surveys that are appropriate to particular sites. Proper use of ATAGS will improve the likelihood of survey success, and will substantially reduce the risk of survey failures and cost overruns that could have been avoided.

Designing a geophysical survey is similar in many ways to designing an archaeological survey. In an archaeological site reconnaissance (survey), one must make decisions about the intensity of survey coverage and its effects on site discovery and project cost. For example, doubling the distance between shovel tests or pedestrian survey transects will reduce project costs but will also reduce the chances of detecting small sites. One must make decisions about the smallest size of site one wants to be able to reliably detect. Some small sites will be detected when a single shovel test or pedestrian transect fortuitously intersects them, but many will be missed.

Similarly, in designing a geophysical survey, one must make decisions about data sample density and distribution, and their impacts on feature detection and survey cost. Data sample density is the number of geophysical readings recorded per unit area (typically, per square meter). Data sample distribution is the manner in which those data readings are distributed across the area. In general, data sample density is positively correlated with field time and thus project cost. If proper decisions are made about data sample distribution, data sample density will also be positively correlated with feature detection.

ATAGS prompts the user to input assumptions about the depth, dimensions, and geophysical contrast (with the surrounding soil) of the various feature types that may be present at the site. To use ATAGS effectively, one must identify “target features,” i.e., those feature types that need to be detected (or more specifically, detectable) if the survey is to be successful. If the target features are relatively large, a low data density and low cost survey can be conducted with a good chance of success. Here success means detecting a large percentage of the target features that are present at the site. A geophysical survey can also be successful even if no features are detected, so long as none are present in the surveyed area. If, however, the target features are relatively small, a high data density and relatively high cost survey will be required to detect them. Thus, decisions about target features should be carefully considered.

Guidance for ATAGS Users

Opening ATAGS

The ATAGS program is available in compact disk (CD) format (a CD accompanies this report) or can be downloaded from the ERDC website. When the ATAGS CD is opened, find the ATAGS.exe file. Double click this file to open the program. The ATAGS initial entry screen (Figure 1) will appear. Pull-down menus titled *File* and *Edit* will be present at the top of the screen (these are not shown in Figure 1).

Opening *File* and choosing *New Survey* will cause the Survey Site Information screen to appear (Figure 2). Fill in as much of the information as possible. Information about the survey will appear in the Current Survey box (Figure 3) throughout the ATAGS session.

Clicking the *Forward* button on the Survey Site Information screen (Figure 2) will cause the Survey Purpose Screen to appear (Figure 4).

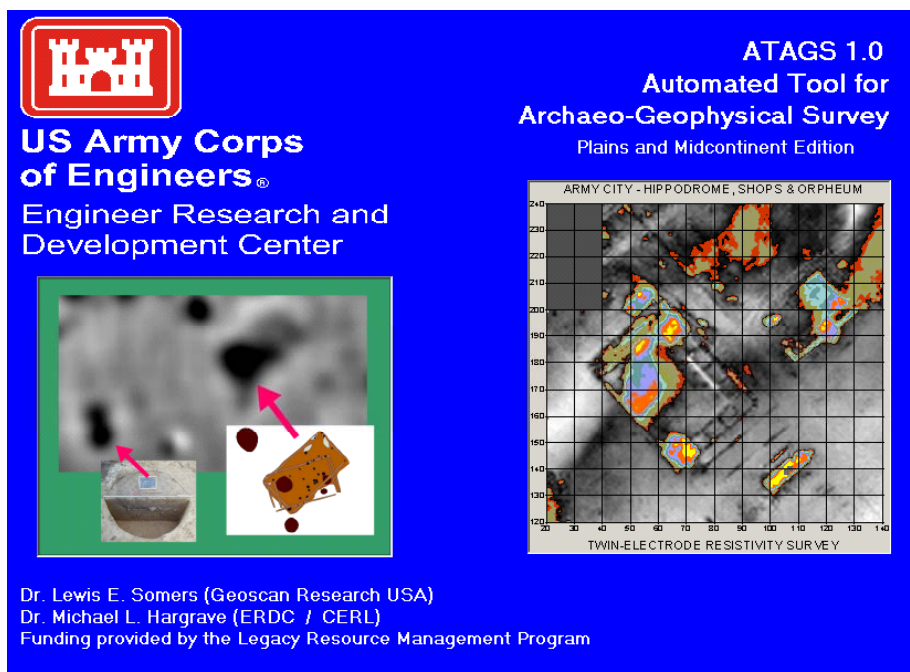


Figure 1. ATAGS 1.0 initial entry screen.

Survey Site Information

Enter Site and User Info

Site Name	Grossmann
Site Number	
Site Location	Shiloh
County	St. Clair
State	Illinois
7.5 Min. Quad	Scott AFB, Illinois, 1985
Coordinates	
Principal Inv.	Michael L. Hargrave
Organization	ERDC-CERL
Address	Champaign, IL
Secondary Inv.	Tim Pauketat
Organization	University of Illinois
Address	Champaign, IL

Cancel Forward

Figure 2. Survey Site Information screen.

Current Survey

Current Survey Info

- File Name:
- Site Name
- Site Num.
- Site Loc.
- County
- State
- 7.5 Min. Quad
- Coordinates
- Principal
- Org.
- Org. Addr.
- Secondary
- Org.
- Org. Addr.

Figure 3. Current Survey box.

Survey Purpose

Detection Detection - The purpose of the survey is to document the existence and approximate distribution of features at the site. It is a low cost, maximum area, large / high contrast feature detection survey.

Mapping Mapping -The purpose of the survey is to reliably map the distribution of features at the site. It is the most common survey design and goal for most surveys.

Integrity Integrity - The purpose of the survey is to map a wide diversity of features in great detail and high spatial resolution with excellent image quality.

Select ONLY one (1) purpose.

Survey Purpose: If budgetary considerations were not important, one would prefer to do most geophysical surveys using a high density of data points. A high data density increases the likelihood of detecting and accurately mapping archaeological features. In reality, survey cost is almost always an important consideration, and data density is positively correlated with field time and cost. For these reasons ATAGS allows the user to select from 3 survey purposes: Detection, Mapping, and Integrity.

DETECTION should be chosen if one simply needs to identify the presence of some of the larger features and/or higher contrast features. Detection is a viable option for most historic sites and many intensively occupied late prehistoric (e.g., Woodland, Mississippian) sites. Detection should not be selected for sites where subsurface features are likely to be small, widely spaced, and not characterized by rich fill (i.e., most Archaic sites, and later sites that do not appear to exhibit intense occupation). MAPPING represents a viable purpose for such occupations, and should reveal a wider range of feature types at late prehistoric and historic sites. INTEGRITY should be selected if a) one needs to maximize the likelihood of detecting small, widely spaced, low contrast features; b) one needs to maximize the reliability with which any site is mapped; or c) one wants to use geophysical data to assess the degree to which features exhibit a good state of preservation.

Back **Cancel** **Forward**

Figure 4. Survey Purpose screen.

Survey Purpose

On the Survey Purpose screen, ATAGS allows the user to select from three survey purposes: (1) Detection, (2) Mapping, and (3) Integrity.

Detection

Detection should be chosen if one simply needs to identify the presence of some of the larger and/or higher contrast features. Detection is a viable option for most historic sites and many intensively occupied late prehistoric (e.g., Woodland, Mississippian) sites. Detection should not be selected for sites where subsurface features are likely to be small, widely spaced, and not characterized by rich fill (i.e., most Archaic sites, and later sites that do not appear to exhibit intense occupation).

Detection surveys are associated with lower survey costs, but image resolution and the potential for detecting features will also be less than for mapping and integrity surveys.

Mapping

Mapping represents a viable purpose for early and nonintensive later prehistoric occupations, and should reveal a wider range of feature types at late prehistoric and historic sites.

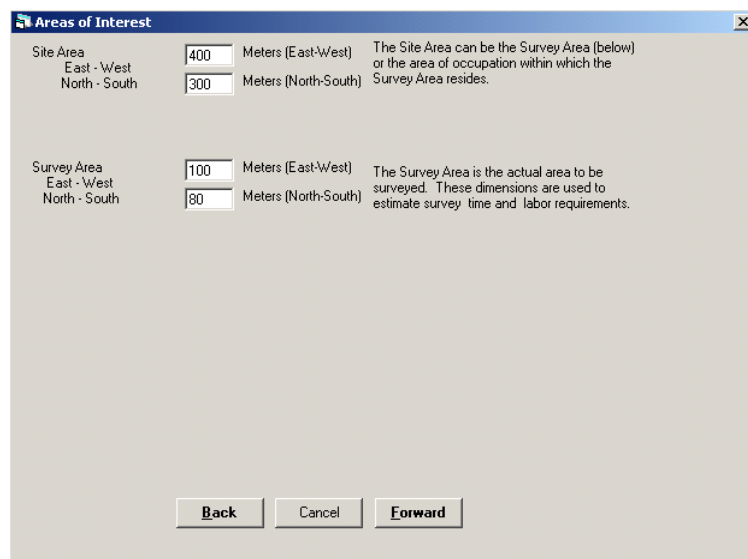
Mapping is the most common survey purpose and is suitable for most sites. Mapping surveys are associated with intermediate costs, image resolution, and potential for feature detection.

Integrity

Integrity should be selected only if one wants to (a) maximize the likelihood of detecting small, widely spaced, low-contrast features; (b) maximize the reliability with which any site is mapped; or (c) use geophysical data to assess the degree to which features exhibit a good state of preservation.

Integrity surveys are used to map a wide diversity of features in great detail with high resolution and excellent image quality. However, the costs associated with integrity surveys will be greater than mapping surveys and much greater than detection surveys.

Clicking the *Forward* button on the Survey Purpose screen (Figure 4) will open the Areas of Interest screen (Figure 5). It is important to enter into the Survey Area window the dimensions of the area that one actually intends to survey. ATAGS uses these dimensions to estimate the amount of time it will take to complete the survey fieldwork.



The screenshot shows a window titled "Areas of Interest" with a close button (X) in the top right corner. The window contains two sections of input fields:

- Site Area:**
 - East - West: 400 Meters (East-West)
 - North - South: 300 Meters (North-South)

The Site Area can be the Survey Area (below) or the area of occupation within which the Survey Area resides.
- Survey Area:**
 - East - West: 100 Meters (East-West)
 - North - South: 80 Meters (North-South)

The Survey Area is the actual area to be surveyed. These dimensions are used to estimate survey time and labor requirements.

At the bottom of the window, there are three buttons: "Back", "Cancel", and "Forward".

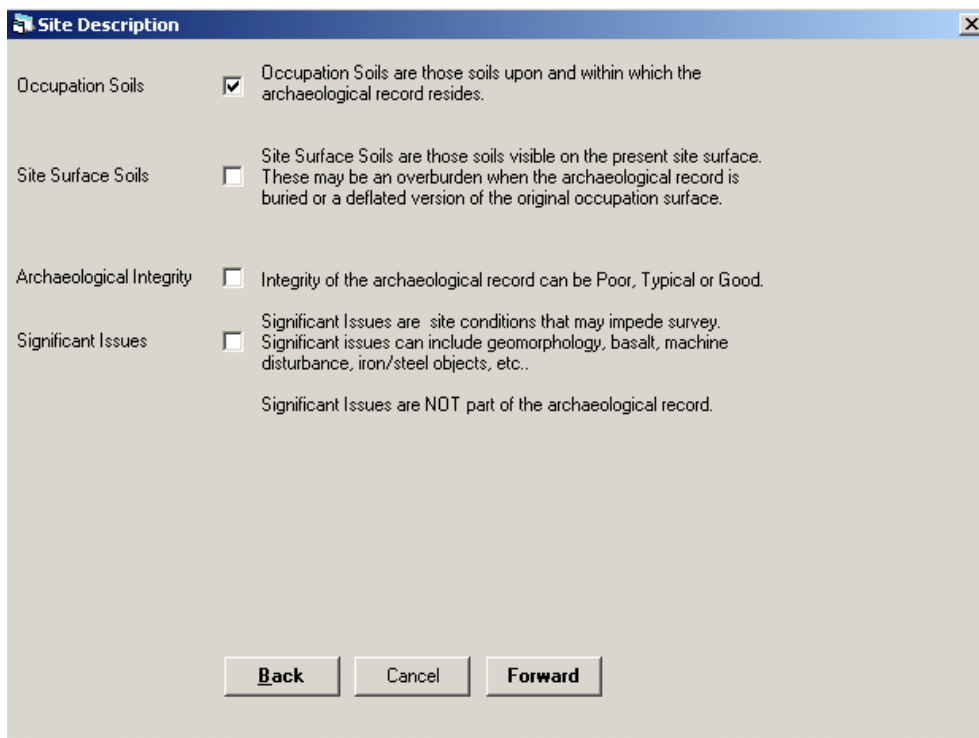
Figure 5. Areas of Interest screen.

Site Description

Clicking the *Forward* button on the Areas of Interest screen (Figure 5) will open the Site Description screen (Figure 6). The Site Description screen prompts the user for information on four issues:

1. Occupation Soils are those soils upon and within which the archaeological record resides.
2. Site Surface Soils are those soils visible on the present site surface. These may be an overburden when the archaeological record is buried or a deflated version of the original occupation surface.

Checking the box for Occupation Soils and Site Surface Soils causes ATAGS to open the Soils Form screen (Figure 7). Here ATAGS requires the user to enter information about the Occupation Surface or Site Surface Soils. The table lists ranges of the clay, silt, and sand percentages in a number of common soil categories. Note that it is not necessary to determine precise percentages. For example, if the soil at the site to be surveyed is properly described as Silty Clay Loam, any combination of the percentage ranges provided by the table for that soil category will be acceptable, so long as they sum to 100 percent.



The screenshot shows a window titled "Site Description" with a close button (X) in the top right corner. The window contains four rows of text, each with a checkbox on the left and a descriptive sentence on the right:

- Occupation Soils: Occupation Soils are those soils upon and within which the archaeological record resides.
- Site Surface Soils: Site Surface Soils are those soils visible on the present site surface. These may be an overburden when the archaeological record is buried or a deflated version of the original occupation surface.
- Archaeological Integrity: Integrity of the archaeological record can be Poor, Typical or Good.
- Significant Issues: Significant Issues are site conditions that may impede survey. Significant issues can include geomorphology, basalt, machine disturbance, iron/steel objects, etc..
Significant Issues are NOT part of the archaeological record.

At the bottom of the window, there are three buttons: "Back", "Cancel", and "Forward".

Figure 6. Site Description screen.

Site Description

Occupation Soils Occupation Soils are those soils upon and within which the archaeological record resides.

Site Surface Soils

Archaeological Integrity

Significant Issues

Soils Form - Occupation Surface

Occupation Surface Soils

Percent Clay

Percent Silt

Percent Sand

Indicate the soils properties in percent (%). Approximate values are acceptable, a precise description is not required.

Soil	%Clay	% Silt	% Sand
Clay Loam	27-40%	0%	20-45%
Loam	7-27%	28-50%	<52%
Sandy Clay Loam	20-35%	<28%	>45%
Sandy Loam	7-20%		>52%
Silt Loam	>49%	12-27%	
Silt Loam	<12%	50-80%	
Silty Clay Loam	27-40%		<20%

Done Cancel

Figure 7. Soils Form screen.

Click the *Done* button on the Soils Form to close that form and return to the Site Description screen (Figure 6). Next check the box for Site Surface Soils and again complete the Soils Form. Clicking *Done* will again return the user to the Site Description screen (Figure 6).

3. Archaeological Integrity refers to the quality of preservation of subsurface features at the site.

Check the box for Archaeological Integrity to open the Integrity screen (Figure 8). The user can choose between Poor, Typical, and Good Integrity. This choice should be made using available evidence (e.g., previous test units, the absence of evidence for severe bioturbations or adverse impacts other than normal plowing, etc.).

Choose Poor if archaeological features are believed to be severely disturbed. This could result from deep and destructive bioturbation (e.g., rodents, tree roots), feature movement in unconsolidated soils, or very deep plow zones (e.g., repeated chisel plowing).

Choose Typical if archaeological features are assumed to be intact, recognizable, and to retain scientific and cultural value.

Choose Good if archaeological features are believed to be intact and well preserved. This might be the case at sites that have not sustained continuous modern agriculture.

Click the *Done* button on the Integrity screen (Figure 8) to return to the Site Description screen (Figure 6).

4. Significant Issues are site conditions that may impede a geophysical survey. These conditions can include geomorphology, basalt (which is highly magnetic), machine disturbance (other than agricultural equipment), and the presence of iron/steel objects. Note that Significant Issues do not include archaeological phenomena. Thus, if a historic site includes numerous nails, these will be present in the magnetic data, but they do not impede the survey. In contrast, the presence of a recent scatter of metal objects (e.g., multiple pin flags) at a prehistoric site would represent a significant issue.

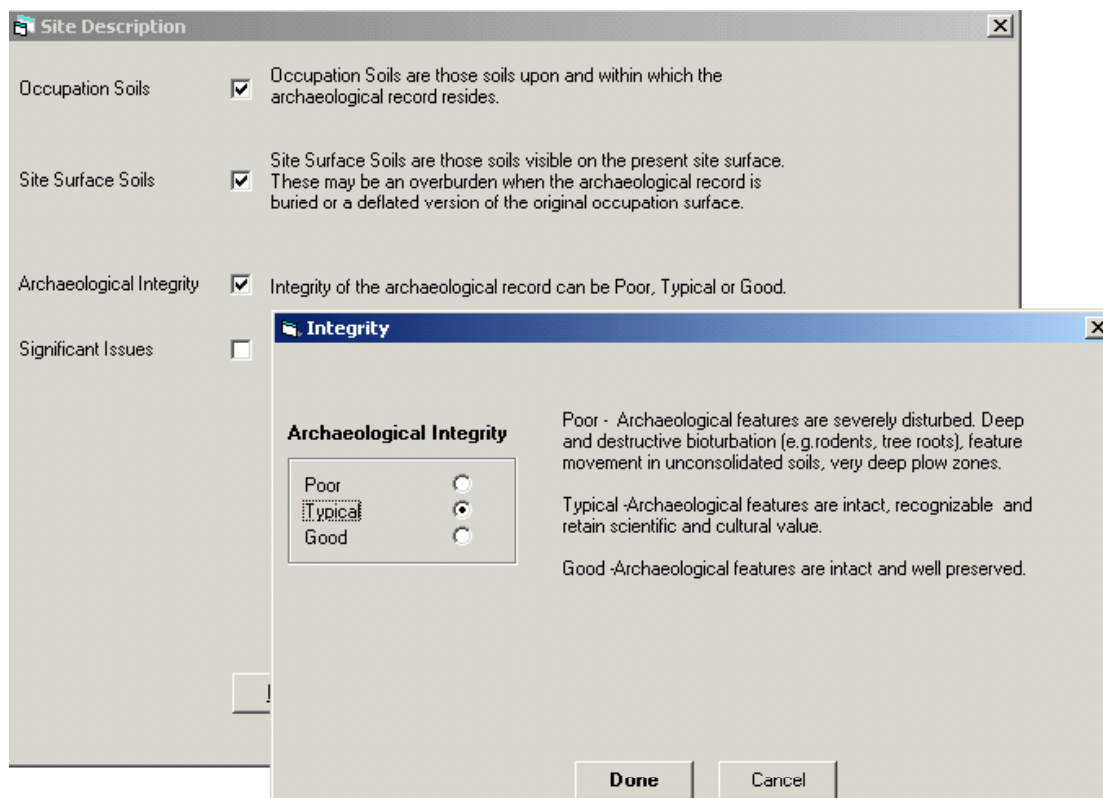


Figure 8. Integrity screen.

Check the box for Significant Issues to open the Significant Issues screen (Figure 9). Significant Issues include the following:

- basalt bedrock within 20 meters of the survey area (vertically or horizontally)
- basalt rock or boulders within 20 meters of the survey area (vertically or horizontally)
- iron, steel, metal: Fence wire, rebar (e.g., datum markers), multiple pin flags or large nails within 20 meters of the survey area are some the most common significant issues
- bioturbations that are significant to the archaeological record. All sites have sustained some damage from bioturbations. Here the focus is on large tree roots, extensive rodent burrows, etc.

After checking the appropriate boxes, click the *Done* button to return to the Site Description screen (Figure 6).

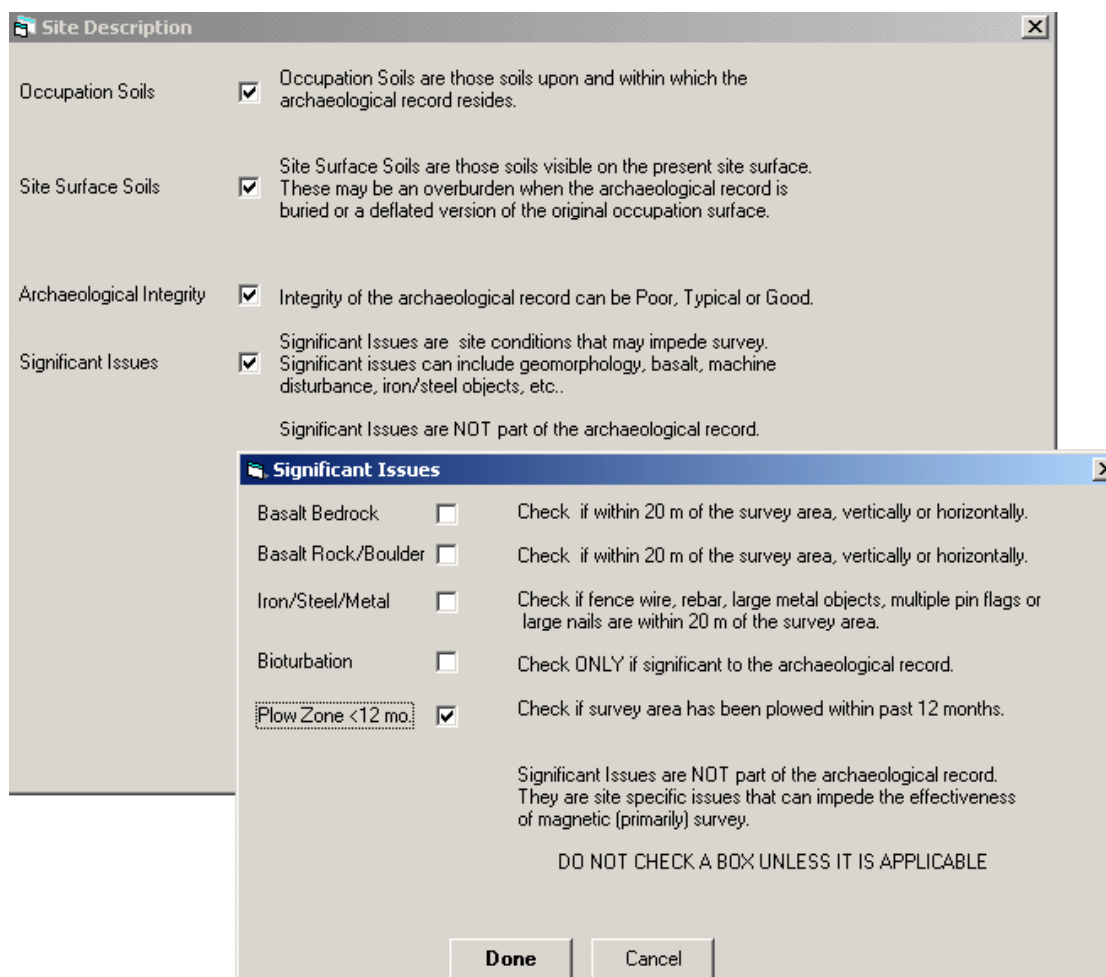
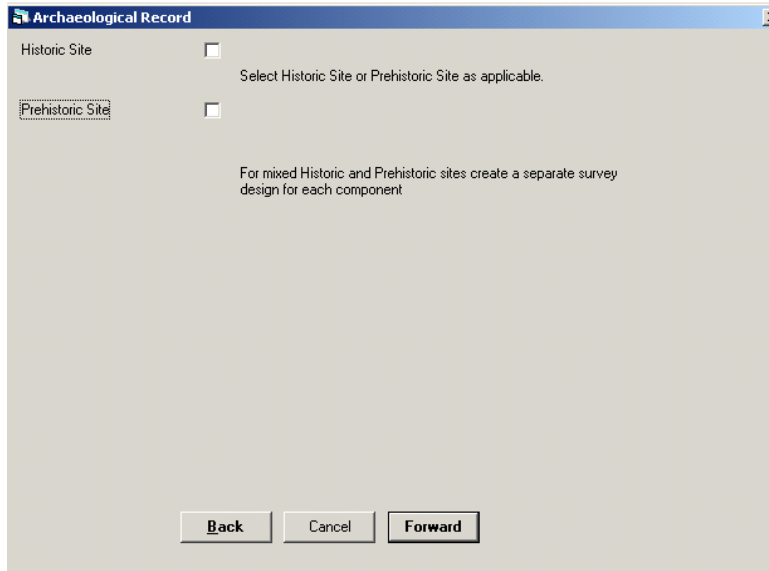


Figure 9. Significant Issues screen.

Archaeological Record

Clicking the *Forward* button on the Site Description screen (Figure 6) will cause ATAGS to open the Archaeological Record screen (Figure 10).



Archaeological Record

Historic Site

Select Historic Site or Prehistoric Site as applicable.

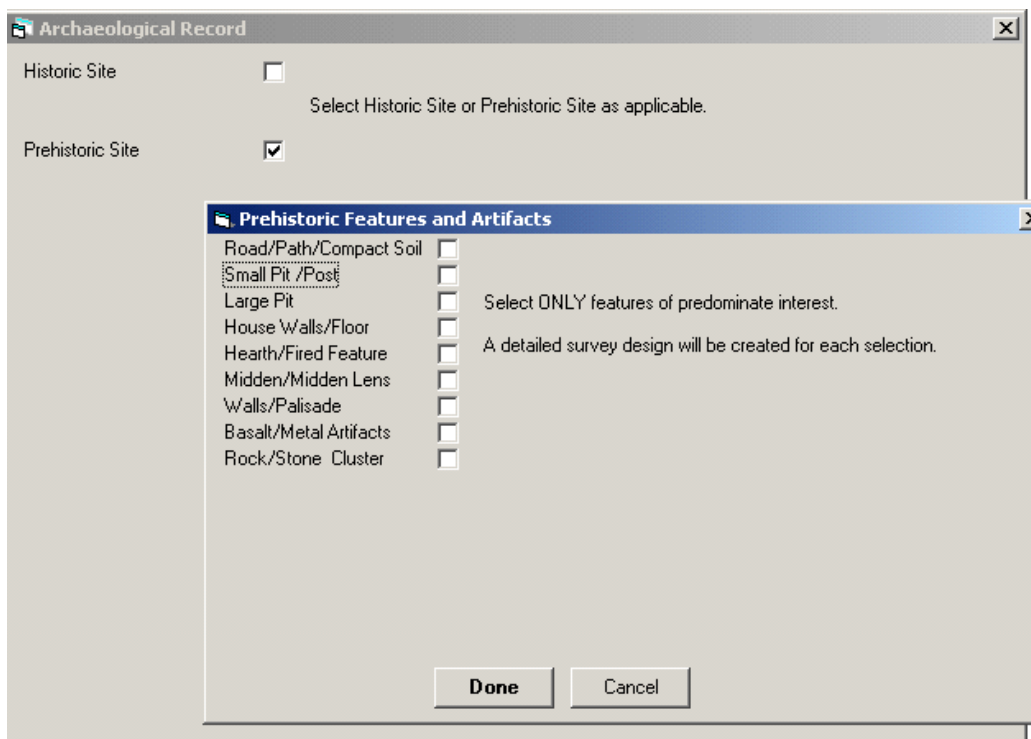
Prehistoric Site

For mixed Historic and Prehistoric sites create a separate survey design for each component

Back Cancel Forward

Figure 10. Archaeological Record screen.

Checking the box for Prehistoric Site, for example, will cause ATAGS to open the Prehistoric Features and Artifacts screen (Figure 11).



Archaeological Record

Historic Site

Select Historic Site or Prehistoric Site as applicable.

Prehistoric Site

Prehistoric Features and Artifacts

Road/Path/Compact Soil

Small Pit /Post

Large Pit

House Walls/Floor

Hearth/Fired Feature

Midden/Midden Lens

Walls/Palisade

Basalt/Metal Artifacts

Rock/Stone Cluster

Select ONLY features of predominate interest.

A detailed survey design will be created for each selection.

Done Cancel

Figure 11. Prehistoric Features and Artifacts screen.

Check the box for each of the Features of Predominate Interest to be included in the survey design. Features of Predominate Interest (also referred to as Target Features) are those for which detection is critical to the survey's success. Note that the choices made here will have direct implications for the survey design. For example, if one chooses only Large Pit, the survey design may not include a data density sufficient to detect Small Pits or Posts. A survey design targeted to detect Small Pits and Posts will also detect Large Pits, but it will be associated with relatively higher field time and costs.

ATAGS will produce a survey design for each of the selected Features of Predominate Interest. The user will ultimately have to select one of the survey designs for use at the site. This selection process provides another opportunity for the user to choose the desired balance between survey cost and the potential for detecting small and/or low-contrast features.

Each time the user checks one of the feature-type boxes, ATAGS will display a screen similar to the one shown in Figure 12. On this details screen, one enters estimates for maximum feature diameter and depth below surface. Depth refers to the distance from the ground surface to the vertical midpoint of the feature. For example, if the top of the feature is 20 cm below surface, and the base of the feature is estimated to be 120 cm below surface, the value to be entered for depth should be 70.

The screenshot shows a software window titled "Archaeological Record" with a sub-window "Prehistoric Features and Artifacts". In this sub-window, "Small Pit / Post" is checked. A "Small Pit / Post Details" dialog box is open, containing the following fields and options:

- Diameter:** 30 CM
- Depth below site surface:** 25 CM
- Resistivity Contrast:** Radio buttons for Low, Mid, and High. The "Low" button is selected.
- Magnetic Susceptibility Contrast:** Radio buttons for Low, Mid, and High. The "Low" button is selected.

Explanatory text on the right side of the dialog box:

- Diameter*** is the maximum dimension of an oval or circular feature (hearth, pit, floor) or the width of a long linear feature (wall, trench).
- Depth** is the distance from the site surface to the top of the feature.
- Resistivity Contrast*** is the DIFFERENCE in resistivity between the feature and the surrounding soils. Features with similar soils are LOW contrast. Significantly different soils are MID contrast and differences in moisture and/or soluble ion concentration are HIGH contrast. Brick, stone and concrete are HIGH contrast unless in sand or gravel.
- Susceptibility Contrast*** is the DIFFERENCE in magnetic susceptibility between the feature and the surrounding soils. Features with similar soils are LOW contrast. Significantly different soils are LOW to MID contrast. High contrast susceptibility features are associated with highly fired soils and dense concentrations of sherds or brick.

A note at the bottom states: "*Please Note: Diameter, Resistivity Contrast and Magnetic Susceptibility Contrast are not relevant for the Small Iron/Steel/ Nail/Hardware or the Large Iron/Steel Objects Artifacts. An entry must be made but it will not affect the survey design." Buttons for "Done" and "Cancel" are at the bottom.

Figure 12. Small Pit / Post Details screen.

Perhaps most challenging for the novice surveyor is ATAG's requirement to characterize Resistivity Contrast and Magnetic Susceptibility Contrast as Low, Mid-Range, or High.

Resistivity Contrast is the difference in resistivity between the feature and the surrounding soils. Features with fill similar to the surrounding soils are low contrast. Significantly different soils are mid-range contrast. Differences in moisture and/or soluble ion concentrations are high contrast. Brick, stone, and concrete are high contrast unless they occur in a matrix of sand or gravel.

Magnetic Susceptibility Contrast is the difference in magnetic susceptibility between the feature and the surrounding soils. Features with soils similar to the surrounding soils are low contrast. Significantly different soils are low or mid-range contrast. High contrast susceptibility features are associated with highly fired soils and dense concentrations of sherds or brick.

Note that selecting low contrast will tend to result in a survey design characterized by greater data density, greater field costs, and (as intended) an increased likelihood of detecting low-contrast features. Conversely, selecting high contrast will tend to result in a survey design characterized by lower data density and lower field costs, but a lower likelihood of detecting low-contrast features.

Clicking *Done* on the Feature Details screen (Figure 12) will cause ATAGS to display the Archaeological Record screen (Figure 10). Although many sites have both prehistoric and historic components of interest, ATAGS does not produce survey designs based on a mixture of prehistoric and historic features. The user should treat the prehistoric and historic components separately, as if they were two different surveys.

Creating a Survey Design Report

Click the *Forward* button on the Archaeological Record screen (Figure 10) to open the Create Report screen (Figure 13).

To create a Survey Design Report, first click the *Generate Report* button on the Create Report screen (Figure 13). The report will appear in the large window at the bottom of the Create Report screen. To save the report as a file and/or to print the file, the user must next click the *Copy to Clipboard* button shown on Figure 13. Next, open a word processing program, create a new file that will contain the ATAGS report, and paste the report (which now resides in the clipboard) to the new file. The ATAGS report can now be edited (e.g., annotated) and/or printed. Chapter 3 provides an example ATAGS report.

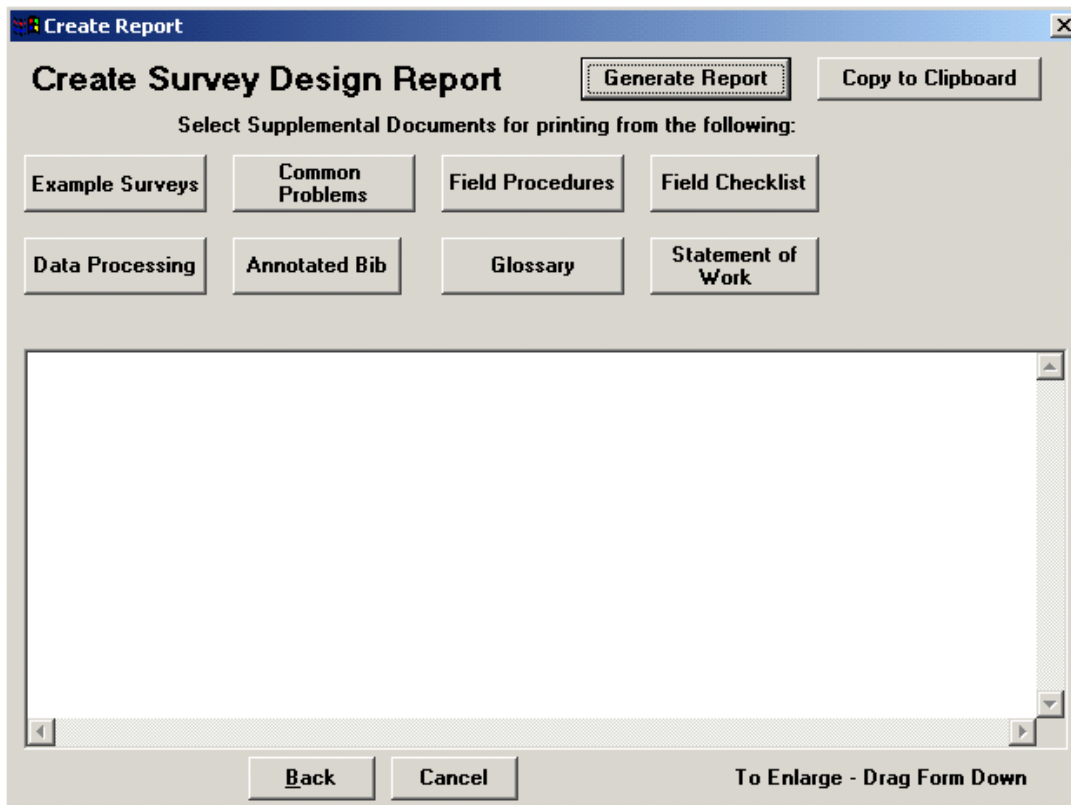


Figure 13. Create Report screen.

ATAGS includes a series of Supplemental Documents. Each of these can be accessed by clicking the appropriate button on the Create Report screen (Figure 13). Each of these Supplemental Documents is included (in slightly revised format) in the present report (Chapters 4–11).

3 Example ATAGS Report

The example ATAGS report presented in this chapter pertains to the Grossmann Site, an Early Mississippian period settlement in St. Clair County, IL. A map resulting from a magnetic field gradient survey of Grossmann is presented in Chapter 4. Note that the ATAGS report format is somewhat different from that used throughout the remainder of this report.

ATAGS GEOPHYSICAL SURVEY DESIGN

Site Name

Grossmann

Site Number

Location

Shiloh

County

St. Clair

State

Illinois

7.5 Min Quad

Scott AFB, Illinois, 1985

Coordinates

Principal Investigator

Michael L. Hargrave

Organization

ERDC-CERL

Address

Champaign, IL

Second Investigator

Tim Pauketat

Organization

University of Illinois

Address

Champaign, IL

09/19/2003

Survey Design by ATAGS 1.0*

* ATAGS, an Automated Tool for Archaeo-Geophysical Survey is a computer program that creates detailed resistivity and magnetic field gradient survey designs for Plains and Midcontinent archaeological sites. The designs are based on information provided to the program by the archaeologist.

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- 4.0 Overall-Site Survey Design at Grossmann
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1.0 INTRODUCTION

ATAGS, an Automated Tool for Archaeo-Geophysical Survey, provides archaeologists with resistivity and magnetic field gradient survey designs that are based on the user's specific survey goal and purpose as well as detailed information about the archaeological record, site features, and soils. A feature-specific survey design is created for each feature type. Guidance is then provided for selecting an overall site survey design based on the features of predominate interest, i.e., target features.

ATAGS also provides guidance for survey program management as well as detailed field procedures designed to ensure quality data collection. These and other topics are addressed in a series of Supplemental Documents which can be selected and printed directly from within ATAGS. Topics include Example Surveys, Common Problems, Field Procedures, Field Checklist, Data Processing, Statement of Work, Glossary, and Annotated Bibliography.

2.0 ATAGS INFORMATION AND SURVEY DESIGN IN ARCHAEOLOGY

Geophysical survey design in archaeology has two principal components. These are: (1) Feature Specific Survey Design and (2) Overall Site Survey Design. The former is based on feature geometry, contrast, stratigraphy, etc. and is relatively unique to each feature type. The latter, site survey design, is a process which reviews the feature specific designs and selects an optimum overall site survey design. A key element in this selection process is identifying features of predominate interest, i.e., "target features" whose presence in the geophysical survey can be immediately associated with the survey goals. In the Plains and Midcontinent, these will be small pits/posts and large pits. Other feature types may be of special interest but will be relatively rare and, in most surveys, should not be the target features used to select the overall site survey design.

An example: at many Plains and Midcontinent prehistoric sites, most features could be categorized as small pits/posts or as large pits. A survey design suitable for detecting small pits will be associated with higher field time and cost due to the required high data sample density. In contrast, survey designs for large pits will be associated with lower field time and cost due to lower data sample density.

For sites with only one target feature type, the feature-specific design will also be the overall site survey design. When many target feature types are present, multiple designs are examined and a balanced compromise selected for the overall site design. The survey design associated with small or low-contrast target

features often dominates this choice. Site integrity or other site-specific issues will also influence the compromise design.

Beyond the ATAGS survey design details, it is important to realize that using more than one survey method at most sites is very desirable because different methods respond to different components in the archaeological record and the incremental cost of a second method can be small. For example, a hearth may have relatively low resistivity contrast but very high magnetic contrast while the associated floor may have high resistivity contrast and low magnetic contrast.

3.0 FEATURE-SPECIFIC SURVEY DESIGNS AT GROSSMANN

Feature-specific resistivity and magnetic field gradient survey designs are presented in sections 3.1 and 3.2 respectively. There is one survey design for each selected feature type.

3.1 RESISTIVITY SURVEY DESIGNS

Resistivity survey designs are presented on the following pages. These designs reflect the survey purpose (Detection, Mapping or Integrity) and are appropriate for the majority of sites. Guidance for selecting and implementing site-specific survey designs is provided in section 4.

The survey equipment referred to in these designs consists of a resistance meter and a probe array. The resistance meter (e.g., RM-15) injects an electric current into the ground and measures the electrical resistance at that point on the site. The current is conveyed to the ground by means of a metal (current) probe and the resistance is measured by a meter connected to an adjacent (voltage) probe. Both probes are mounted on a horizontal beam and the beam - probe combination is called a probe array. The distance between the current and voltage probes determines the approximate depth of survey and, along with data sample density, is one of the survey design parameters. The survey equipment also includes an accessory multiplexer, the MPX, which provides the necessary electronic interface between the probe array and the resistance meter.

Probe arrays (e.g., PA-5) come in various lengths, 50 and 100 cm are common. ATAGS resistivity survey designs assume the use of a 1-m long PA-5 array. By limiting the array length to 1 m, ATAGS survey designs are limited to feature depths not exceeding 1.5 to 2 m. Deeper resistivity surveys can be done with longer arrays or with a “chain” method. Refer to section 7 for additional information.

Note that some survey designs recommend collection of 1 data value per meter in the east-west (E-W) direction. In such cases, 1 value per meter E-W should be adequate. For those using the MPX accessory, it is highly recommended that all 25, 50, and 75 cm deep surveys be performed in the parallel-twin mode. This will provide additional data sample density in the E-W direction and improve statistical data quality with a small increase in survey time. ATAGS survey time estimates assume the MPX and parallel-twin mode are being used. The parallel-twin mode cannot be used for surveys greater than 100-cm deep. To achieve a data sample density of 2 per meter in the E-W direction, the surveyor must use 50 cm traverses, centering the 1-m-wide array on each traverse line. Finally, note that the field survey time estimates do not include breaks for meals, etc.

FEATURE-SPECIFIC RESISTIVITY SURVEY DESIGN

SMALL PIT / POST FEATURES

Based primarily on survey purpose (Mapping), feature dimensions, depth, and contrast the following survey design is recommended:

INSTRUMENTATION

Geoscan Research RM-15 Resistance Meter with MPX Multiplexer
PA-5 Twin-Electrode Probe Array (1 meter)

DATA SAMPLE DENSITY AND CURRENT-VOLTAGE PROBE SPACING *

The recommended data sample density for this feature:

Direction	Density
N-S	2 / meter or 50 cm between data samples
E-W	4 / meter or 25 cm between data samples

The recommended current-voltage probe spacing (survey depth) is 25 cm. Use the Parallel-Twin mode whenever possible, refer to section 4.2.

FIELD TIME ESTIMATES FOR RESISTIVITY SURVEY

The estimated field time (median) for this survey when implemented with the RM-15/PA-5/MPX equipment is 23 hours for one surveyor with one instrument scanning in the zigzag mode. This time estimate assumes the presence of a survey grid, that any vegetation obstruction issues have been accommodated, and that one field hand is available to assist with survey tapes and miscellaneous field support items. Allow 1 hr each for survey set-up and teardown.

SUMMARY OF FEATURE PARAMETERS AND SURVEY PURPOSE

The feature parameters used in this design were:

Survey Purpose	Mapping
Area of Survey	100 meters E-W by 80 meters N-S
Feature	small pit / post
Diameter	30 cm
Depth	25 cm
Contrast	low - mid

* In some cases, survey results will not be consistent with archaeological expectations (e.g., features are not detected at a site where they are expected). In such situations, one should resurvey a portion of the site using a more conservative survey design. This will involve increases in data density and field time per unit area, and will increase the likelihood of detecting features. Data sample densities for a conservative survey are:

Direction	Density
N-S	4 / meter or 25 cm between data samples
E-W	4 / meter or 25 cm between data samples

FEATURE-SPECIFIC RESISTIVITY SURVEY DESIGN

LARGE PIT FEATURES

Based primarily on survey purpose (Mapping), feature dimensions, depth, and contrast, the following survey design is recommended:

INSTRUMENTATION

Geoscan Research RM-15 Resistance Meter with MPX Multiplexer
PA-5 Twin-Electrode Probe Array (1 meter)

DATA SAMPLE DENSITY AND CURRENT-VOLTAGE PROBE SPACING *

The recommended data sample density for this feature:

Direction	Density
N-S	2 / meter or 50 cm between data samples
E-W	2 / meter or 50 cm between data samples

The recommended current-voltage probe spacing (survey depth) is 75 cm.
Use the Parallel-Twin mode whenever possible; refer to section 4.2.

FIELD TIME ESTIMATES FOR RESISTIVITY SURVEY

The estimated field time (median) for this survey when implemented with the RM-15/PA-5/MPX equipment is 19 hours for one surveyor with one instrument scanning in the zigzag mode. This time estimate assumes the presence of a survey grid, that any vegetation obstruction issues have been accommodated, and that one field hand is available to assist with survey tapes and miscellaneous field support items. Allow 1 hr each for survey set-up and teardown.

SUMMARY OF FEATURE PARAMETERS AND SURVEY PURPOSE

The feature parameters used in this design were:

Survey Purpose	Mapping
Area of Survey	100 meters E-W by 80 meters N-S
Feature	large pit
Diameter	100 cm
Depth	75 cm
Contrast	low - mid

* In some cases, survey results will not be consistent with archaeological expectations (e.g., features are not detected at a site where they are expected). In such situations one should resurvey a portion of the site using a more conservative survey design. This will involve increases in data density and field time per unit area, and will increase the likelihood of detecting features. Data sample densities for a conservative survey are:

Direction	Density
N-S	4 / meter or 25 cm between data samples
E-W	2 / meter or 50 cm between data samples

3.2 MAGNETIC FIELD GRADIENT SURVEY DESIGNS

Magnetic survey designs are presented on the following pages. There is one survey design for each selected feature type. These designs reflect the purpose of the survey (Detection, Mapping, or Integrity) and are relatively conservative to ensure adequate data density. Modifications required for site-specific issues and other considerations are addressed in section 4. In the all too common case of magnetic survey for low-contrast susceptibility targets in the presence of iron or steel objects (e.g., steel pin flags), magnetic survey can be very difficult. Section 4 also addresses this issue.

The survey equipment referred to in these designs consists of two magnetic sensors mounted on a vertical shaft. In the case of the FM-36 and the FM-256, the vertical distance between sensors is 50 cm, and the combination is referred to as a magnetic gradiometer or simply a gradiometer. The FM-36 and the FM-256 are very similar instruments. The FM-256, a more recent design, is faster, has much larger memory, and adjustable sensitivity. Both are applicable to all survey designs.

In operation, all vertical gradiometers measure the magnetic field at both sensors and record the difference. That is to say, the gradiometer data are obtained by subtracting the top sensor readings from the bottom sensor readings. This difference can be a positive number or a negative number. The difference is zero when the top and bottom readings are the same, i.e., when there are no anomalies present and the magnetic field is uniform.

It is possible to survey with two FM-256 instruments or one FM-36 and one FM-256 at the same time. This will halve the field survey time, double the survey area for a given field time, or double the data sample density. The dual gradiometer-carrying frame (an accessory) is required to synchronize the two gradiometers. ATAGS survey time estimates are for single instrument surveys.

ATAGS magnetic survey designs can be used with other gradiometers. Most cesium, potassium, and proton magnetometers can be operated in gradiometer configuration and the ATAGS recommended data sample densities are applicable with these instruments.

Finally, note that the field survey time estimates do not include breaks for meals etc.

FEATURE SPECIFIC MAGNETIC FIELD GRADIENT SURVEY DESIGN

SMALL PIT / POST FEATURES

Based primarily on survey purpose (Mapping), feature description and feature depth as well as the absence of high remanent magnetization (iron, steel, basalt) material, the following survey design is recommended:

INSTRUMENTATION

Geoscan Research FM-36 or FM-256 gradiometer or equivalent

DATA SAMPLE DENSITY *

The recommended data sample density for this feature:

Direction	Density
N-S	8 / meter or 12.5 cm between data samples
E-W	2 / meter or 50 cm between data samples

FIELD TIME ESTIMATES FOR MAGNETIC FIELD GRADIENT SURVEY

With a 12.5 cm (N-S) by 50 cm (E-W) data sample distance, the (median) time for this survey is 13 hours for one surveyor with one FM-256 gradiometer scanning in the zigzag mode. The corresponding time for one surveyor with one FM-36 gradiometer is 16 hours. These time estimates assume the presence of a survey grid, that vegetation obstruction issues have been accommodated, and that one field hand is available to assist with survey tapes and miscellaneous field support items. Survey time can be reduced 50% with two FM gradiometers and the dual gradiometer accessory. Allow 1 hour each for survey set-up and teardown.

SUMMARY OF FEATURE PARAMETERS AND SURVEY PURPOSE

The feature parameters used in this design were:

Survey Purpose	Mapping
Area of Survey	100 meters E-W by 80 meters N-S
Feature	small pit / post
Diameter	30 cm
Depth	25 cm
Contrast	low

* In some cases, survey results will not be consistent with archaeological expectations (e.g., features are not detected at a site where they are expected). In such situations, one should resurvey a portion of the site using a more conservative survey design. This will involve increases in data density and field time per unit area, and will increase the likelihood of detecting features.

The data sample densities for a conservative survey design are:

Direction	Density
N-S	8 / meter or 12.5 cm between data samples
E-W	4 / meter or 25 cm between data samples

FURTHER GUIDANCE FOR MAGNETIC SURVEY DESIGNS

Features and artifacts tend to have either strong (high contrast) or weak (low-contrast) magnetic fields. Strong fields are usually associated with iron/steel and basalt objects and many intact fired features like hearths, bricks, and other architectural ceramics. Weak magnetic fields are usually associated with disturbed or differentiated soil features like pits, midden lens, road/paths, unburned house pits, etc. Prehistoric sites are often dominated by low-contrast features and artifacts, while historic sites usually have both high and low-contrast features.

For the FM-256, when the conservative survey design calls for 8 or 16 N-S samples per meter, configure the instrument accordingly. When additional sensitivity is required, use the averaging mode; average 4, 8, 16, or 32 readings as required.

For the FM-36, when the conservative survey design calls for 8 N-S samples per meter, configure the instrument accordingly. When the design calls for 16 N-S data samples per meter, a feature not available on the FM-36, continue to collect 8 N-S samples per meter and double the data sample density in the E-W direction. When this is not practical, consider scanning at half the speed, collecting 16 samples per meter and simultaneously reducing the N-S dimension of each grid from 20 m to 10 m. Additional sensitivity in the averaging mode is not available on the FM-36.

When conservative survey designs are necessary, it is advisable to collect data using the parallel scan mode rather than the zigzag mode. Data quality for weak (low-contrast) features will improve significantly, and the field survey time will increase approximately 20%.

Occasionally the recommended and conservative survey designs (data sample densities) are the same. This indicates that the recommended design is adequate and that little will be gained from a higher density survey. Finally, in magnetic surveys, data collection scans should never be oriented in the same direction as known long linear features because the Zero-Mean Traverse filter (a necessary part of data processing and analysis) may remove the linear feature from the survey data.

FEATURE SPECIFIC MAGNETIC FIELD GRADIENT SURVEY DESIGN

LARGE PIT FEATURES

Based primarily on survey purpose (Mapping), feature description, and feature depth as well as the absence of high remanent magnetization (iron, steel, basalt) material, the following survey design is recommended:

INSTRUMENTATION

Geoscan Research FM-36 or FM-256 gradiometer or equivalent

DATA SAMPLE DENSITY *

The recommended data sample density for this feature:

Direction	Density
N-S	8 / meter or 12.5 cm between data samples
E-W	2 / meter or 50 cm between data samples

FIELD TIME ESTIMATES FOR MAGNETIC FIELD GRADIENT SURVEY

With a 12.5 cm (N-S) by 50 cm (E-W) data sample distance, the (median) time for this survey is 13 hours for one surveyor with one FM-256 gradiometer scanning in the zigzag mode. The corresponding time for one surveyor with one FM-36 gradiometer is 16 hours. These time estimates assume the presence of a survey grid, that vegetation obstruction issues have been accommodated and that one field hand is available to assist with survey tapes and miscellaneous field support items. Survey time can be reduced 50% with two FM gradiometers and the dual gradiometer accessory. Allow 1 hour each for survey set-up and teardown.

SUMMARY OF FEATURE PARAMETERS AND SURVEY PURPOSE

The feature parameters used in this design were:

Survey Purpose	Mapping
Area of Survey	100 meters E-W by 80 meters N-S
Feature	large pit
Diameter	100 cm
Depth	75 cm
Contrast	low

* In some cases, survey results will not be consistent with archaeological expectations (e.g., features are not detected at a site where they are expected). In such situations one should resurvey a portion of the site using a more conservative survey design. This will involve increases in data density and field time per unit area, and will increase the likelihood of detecting features.

The data sample densities for a conservative survey design are:

Direction	Density
N-S	16 / meter or 6.25 cm between data samples
E-W	4 / meter or 25 cm between data samples

FURTHER GUIDANCE FOR MAGNETIC SURVEY DESIGNS

Features and artifacts tend to have either strong (high contrast) or weak (low-contrast) magnetic fields. Strong fields are usually associated with iron/steel and basalt objects and many intact fired features like hearths, bricks, and other architectural ceramics. Weak magnetic fields are usually associated with disturbed or differentiated soil features like pits, midden lens, road/paths, unburned house pits, etc. Prehistoric sites are often dominated by low-contrast features and artifacts, while historic sites usually have both high and low-contrast features.

For the FM-256, when the conservative survey design calls for 8 or 16 N-S samples per meter configure the instrument accordingly. When additional sensitivity is required use the averaging mode; average 4, 8, 16, or 32 readings as required.

For the FM-36, when the conservative survey design calls for 8 N-S samples per meter configure the instrument accordingly. When the design calls for 16 N-S data samples per meter, a feature not available on the FM-36, continue to collect 8 N-S samples per meter and double the data sample density in the E-W direction. When this is not practical, consider scanning at half the speed, collecting 16 samples per meter, and simultaneously reducing the N-S dimension of each grid from 20 m to 10 m. Additional sensitivity in the averaging mode is not available on the FM-36.

When conservative survey designs are necessary, it is advisable to collect data using the parallel scan mode rather than the zigzag mode. Data quality for weak (low-contrast) features will improve significantly, and the field survey time will increase approximately 20%.

Occasionally the recommended and conservative survey designs (data sample densities) are the same. This indicates that the recommended design is adequate and that little will be gained from a higher density survey.

Finally, in magnetic surveys, data collection scans should never be oriented in the same direction as known long linear features because the Zero-Mean Traverse filter (a necessary part of data processing and analysis) may remove the linear feature from the survey data.

4.0 OVERALL SITE SURVEY DESIGN AT GROSSMANN

4.1 SITE SURVEY DESIGN AND IMPLEMENTATION

Site survey design is straightforward. First, review all feature types and select the target features most relevant to the survey purpose. Second, select two target feature designs, the ones that require the highest and lowest data sample density. In many cases, these types will be small pits and large pits. Note these survey designs and their requirements. The overall site survey design will most likely fall in the range between these two target feature designs. Third, review the survey design selection guidance in section 4.4 for site-specific issues that may bias the survey design details in one direction or another. Fourth, select a survey design for the overall site. Fifth, implement the survey and evaluate the first few grids, typically the first day's work, to see if the results fulfill the survey's purpose. When they do, the survey design can be accepted. When they do not, the survey design must be improved, alternate geophysical survey methods considered, or the survey abandoned.

One of the most difficult situations will occur when a survey yields no indication of anomalies consistent with archaeological features. Here one has several options: (1) apply the same survey design to another portion of the site (i.e., increase sample size); (2) adopt a more rigorous (higher data density) survey; or (3) consider other geophysical survey methods. Ultimately, one must remain aware that many sites do not contain preserved features and that, in some (minority) cases, feature contrast may be too low to be detected by geophysical methods.

On a broader scale, there is no perfect survey. Each survey design is a compromise and budgets (time and money) will almost always limit what can be done. The following sections address these issues. Resistivity survey is discussed in section 4.2 and magnetic field gradient survey is discussed in section 4.3. Section 4.4 presents guidance and fine-tuning applicable to specific issues at Grossmann.

4.2 SELECTING A RESISTIVITY SURVEY DESIGN

A number of feature-specific resistivity survey designs have been presented. Examine the target feature survey designs and select those with the highest and the lowest data sample density. For many surveys in the Plains and Midcontinent, these will be the survey designs for small and large pits. When there is only one target feature type, the site survey design has been identified. When

there is a significant difference between the two survey designs, some form of trade-off or compromise must be made.

When minimum cost is essential, focus on the feature type requiring the lowest data sample density, remaining aware that smaller feature types may not be detected or mapped reliably. When this it is not acceptable, one can use the more rigorous (higher data density) survey design, and reduce the area to be surveyed. In any case, one should never implement a design that uses less than one sample per square meter. It is highly recommended that the RM-15/PA-5/MPX equipment be used in the Parallel-Twin mode (see manufacturer's documentation) for 25, 50, and 75-cm deep surveys. This will maximize the data sample density in the E-W direction, improve map quality, and add very little to field survey time. The ATAGS survey time estimates assume the Parallel-Twin mode is being used.

4.3 SELECTING A MAGNETIC FIELD GRADIENT SURVEY DESIGN

The archaeo-magnetic features and their associated magnetic fields fall into two different categories: strong magnetic features (iron, steel, basalt, highly fired clays) with strong magnetic fields and weak magnetic features (post molds, pits, floors) with correspondingly weak magnetic fields. Each category requires a different magnetic survey design.

In the absence of strong magnetic fields, magnetic survey design is similar to resistivity survey design. It too requires target feature selection and compromise. A number of feature-specific magnetic survey designs have been presented. Examine the target feature survey designs and select those with the highest and the lowest data sample density (use the recommended survey design, not the conservative design). When there is only one target feature, the site survey design has been identified. When there is a significant difference between two survey designs, some form of trade-off or compromise must be made. If minimum cost is essential, focus on the larger feature type (requiring the lower data sample density) or use dual gradiometers (with carry frame accessory). Remain aware that smaller feature types may not be detected or mapped reliably. When it is not acceptable to focus on the larger feature type, one can use the more rigorous (higher data density) survey design, and reduce the area to be surveyed. In any case, one should never implement a design with less than four data samples per meter in one direction (N-S) and one data sample per meter in the other direction (E-W).

In the presence of strong magnetic fields, there is no need for great instrument sensitivity and little opportunity for great spatial detail because (1) the strong fields are easily measured and (2) the map geometry of a strong magnetic anom-

ally bears little resemblance to the magnetic object (iron, steel, basalt) creating the field. Magnetic survey design in the presence of strong magnetic fields requires two different approaches. When the strong magnetic feature is part of the archaeological record (i.e., a target feature), the ATAGS survey design is appropriate.

When the strong magnetic features are not part of the archaeological record or are of no interest, the ATAGS survey design is still appropriate, but the survey results will be cluttered with the unwanted strong magnetic anomalies. This unfortunate combination often occurs when modern or historic iron is present at a prehistoric site. Steel pin flags, rebar and fence wire are common examples. Under these circumstances, it is best to remove the offending objects prior to survey because they cannot be removed effectively through data processing.

4.4 GUIDANCE ON SITE-SPECIFIC ISSUES AT GROSSMANN

Further guidance with respect to site-specific issues at Grossmann follows.

LONG LINEAR FEATURES, WIRES AND METAL PIPES

Long linear features (walls, ditches, roads, paths, canals, etc.) can usually be mapped successfully with a less dense data sample (in the direction of the linear feature) than that specified by ATAGS because long linear features are easily recognized in most survey maps. A very significant economy in field time and survey cost can be realized.

5.0 SURVEY MANAGEMENT

5.1 PROGRAM MANAGEMENT

A properly designed and executed geophysical survey can be very cost-effective relative to the information it provides. In some cases, however, even well-executed surveys may fail in the sense that features present at the site are not adequately detected or mapped. While these risks can never be reduced to zero, they can be maintained at an acceptable level through proper survey management. In larger surveys (more than a few field days), it is important to ensure that the fieldwork is oriented towards both data quality and data production (rate of area coverage). Field management must constantly monitor and motivate both.

One approach for minimizing cost and reducing financial risk implements a two-stage program of fieldwork. In Stage 1, one or two days of fieldwork are devoted to verifying that the survey design is appropriate. Stage 1 ends with an assess-

ment as to whether the survey can achieve the survey goals at acceptable cost. If Stage 1 data are found to be more than adequate for meeting the survey purpose, it should be possible to thin the data sample density and either reduce the total survey cost or increase the survey area. If the data are not adequate for the survey purpose and an increased data sample density appears useful, that increase can be effected at the expense of reduced area coverage or additional survey cost. Finally, if data quality is simply too poor to meet the survey requirements, the survey should be abandoned at the end of Stage 1, permitting resources to be re-allocated to traditional archaeological approaches.

5.2 FIELD MANAGEMENT, COMMON PROBLEMS, AND CONTRACTING

ATAGS provides additional guidance for survey program management as well as for the field practitioner. This is presented in a series of Supplemental Documents that can be selected and printed directly from within ATAGS. Topics include Example Surveys, Common Problems, Field Procedures, Field Checklist, Data Processing, Statements of Work, Glossary, and an Annotated Bibliography.

6.0 SUMMARY OF SITE INFORMATION PROVIDED TO THIS PROGRAM

Site Name - Grossmann

6.1 Survey Purpose

Site Mapping:

6.2 Area of Interest and Area of Survey

Total Area of Interest:

400 meters E-W

300 meters N-S

Area of Survey:

100 meters E-W

80 meters N-S

6.3 Site Description

Occupation Surface Soils:

35 Percent Clay

50 Percent Silt

15 Percent Sand

Site Surface Soils:

35 Percent Clay

50 Percent Silt

15 Percent Sand

Archaeological Integrity:

Medium

Significant Issues:

6.4 Archaeological Record

Site Type:

Prehistoric

Features and Artifacts:

Small Pit / Post

Large Pit

7.0 ATAGS SUPPORT

The ATAGS survey design tool was developed primarily to assist cultural resource managers with incorporating geophysical surveys into their programs. It is a first generation tool and, as such, has not had the benefit of critical feedback from the user community. The authors encourage questions and comments from all regions of the country/world. They should be directed to Michael.L.Hargrave@erdc.usace.army.mil (include ATAGS in the subject line).

ATAGS resistivity survey designs are limited to feature depths of 1.5 to 2 m, the limiting depth associated with 1-m probe spacing. Resistivity survey for deeper features requires probe spacing and array length greater than 1 m. Longer arrays as well as multi-meter 'chain' methods are available for deep surveys. Please consult Geoscan Research (USA) at 707-785-3384 or 970-946-9464 (cellular telephone) for further guidance and information.

It is recognized that no single computer program can adequately address all the survey design and implementation issues that arise from the wide diversity of site conditions found in North American archaeology. When the survey designs created by ATAGS “don't make sense,” the features of interest are not available on the input forms, the hardware or software does not perform as desired, or one would like to discuss survey design with experienced staff, the reader is invited to e-mail Dr. Michael L. Hargrave (Michael.L.Hargrave@erdc.usace.army.mil).

Geophysical survey instruments and software continue to evolve. During the use-life of this version of ATAGS, improvements will continue and readers are encouraged to contact equipment and software providers for current specifications and limitations.

8.0 SUGGESTED READING

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4 Example Surveys

This chapter presents ATAGS Supplemental Document 1, which provides the ATAGS user with brief summaries of several surveys. Information includes survey purpose, instrumentation, and results.

The first example is drawn from a very large-area resistivity survey of Army City, a World War I-era site at Fort Riley, KS. Army City exemplifies a situation where the need to survey a very large area within the confines of a finite budget required the use of a very low data density (1 data value per m²). The large dimensions and orderly arrangement of the architectural remains at Army City yielded a highly informative map. A similarly low data density survey of a pre-historic site characterized by relatively small features would probably not have been successful.

The second example is a magnetic field gradient survey of the Grossmann site, an early Mississippian settlement in Illinois. Archaeological features at Grossmann, including a large number of wall trench structures and pits, exhibit a very low contrast with the surrounding soil. Factors that appear to contribute to this low contrast include the modest magnetic susceptibility of the soil, the absence of fired clay daub and other areas of extensive burning, and a moderate organic component in the feature fill. In such situations, data processing involves the removal of isolated strong values in order to enhance the potential to detect very subtle anomalies. Minor errors in survey technique can show quite clearly because they produce anomalies that are, while weak in absolute terms, comparable to those associated with archaeological features.

Magnetic and resistivity surveys of the Late Woodland and Emergent Mississippian Harmon site are included here because they exemplify a moderately successful survey despite seemingly severe disturbance. Very limited ground truthing excavations revealed that several of the discrete, pit-sized anomalies were associated with archaeological features. However, several other features were documented in test units that were not recommended as promising anomalies. This underscores an important point that has not been addressed previously in this report. One of the challenges of a geophysical survey is to collect “good” data, i.e., data characterized by a relatively high signal-to-noise ratio and few survey defects. Interpretation of those data can be equally challenging. It is for-

tuitous to find that a majority of the strongest anomalies appear to be associated with cultural features. At many sites, however, the cultural features may well be associated with relatively weak anomalies, whereas the stronger values are related to bioturbations, recent disturbance, metal artifacts, etc. Chapter 8 provides guidance on the prioritization of anomalies, and recommendations for a multi-stage approach to ground truthing excavations.

A final example survey concerns Fort Phil Kearny, a military outpost constructed in Wyoming soon after the Civil War. This survey is interesting in a number of ways, including the abundance of metal artifacts found at the fort. At a prehistoric site, a light scatter of historic or recent metal can restrict the potential for a successful survey. At Fort Phil Kearny, the metal items include architectural materials that are a major component of the archaeological record. Here the metal contributes to the strong spatial patterning that makes this survey so useful to researchers and site managers.

Electrical Resistivity Survey of Army City, Fort Riley, Kansas

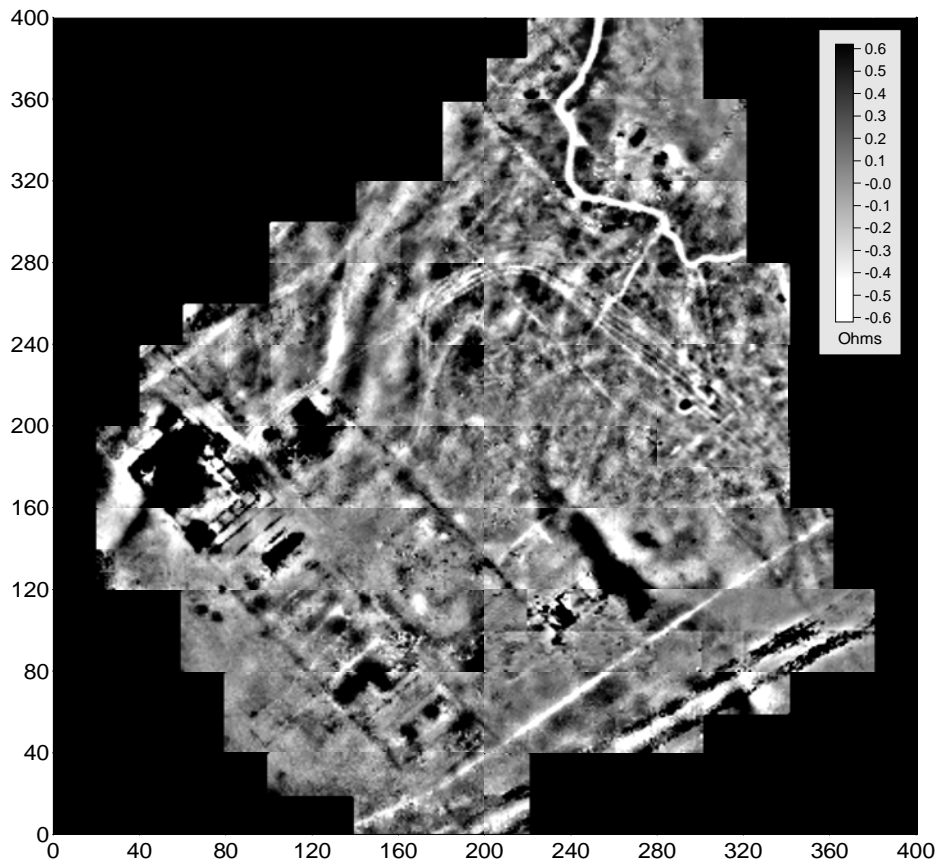


Figure 14. Electrical resistivity survey of Army City, Fort Riley, KS.

Site Name:	Army City	Survey Purpose:	Mapping
Site Number:	14RY3193	Area of Survey:	92,400 m ²
County:	Riley	Instrument:	Geoscan RM15
State:	Kansas	Instrument Settings:	40 V, 1 mA current
Surveyor:	Lewis Somers	Data Density:	1 per m ²
Organization:	Geoscan Research USA	N-S:	1
Sponsor:	Michael Hargrave	E-W:	1
Organization:	ERDC/CERL	Probe Spacing:	0.75 meter

Comments: Army City was a civilian-owned commercial complex constructed in 1917 to provide goods and services to soldiers training at Camp Funston, Fort Riley, KS. Structures in the (northwestern) commercial district included several large theaters and a variety of stores and restaurants. Other portions of the site included private residences, whereas other areas were never developed. Streets were unpaved although concrete sidewalks were present in some areas. Some of the structures had substantial concrete foundations or pads, but others sat atop

isolated piers. Following a fire in 1920, the remains of some structures in the commercial district were bulldozed. Undamaged structures were either moved intact to a nearby town or were disassembled and sold as scrap. The archaeological remains of Army City are complex and extensive.

The geophysical investigations were one component of an assessment of the site's eligibility for nomination to the National Register of Historic Places. The goal of the large-scale resistivity survey conducted in 1997 was to map as much of the site complex as possible given available funding. To this end, only one data value per m² was collected. A preliminary survey had demonstrated that this minimal data density would be adequate to map the locations of structures and other large features. Small-scale ground truthing excavations were conducted in the residential area (Kreisa and Walz 1997) and the commercial district (Larson and Penny 1998). This work documented the nature and condition of artifact and architectural remains, and confirmed that the site exhibited reasonably good depositional integrity and substantial research potential.

In the map shown in Figure 14, the differential appearance of various large portions of the site exemplifies the difficulty of "edge-matching" in a very large resistivity survey. These difficulties stem from changes in soil moisture during the course of a multi-week survey, as well as variation in the nature of the archaeological deposits.

Figure 15 shows a selected portion of the Army City commercial district including the Hippodrome Theater complex. Here low-contrast features are mapped in gray tones, whereas a color scale is used to depict variation in very high resistance anomalies. Most of the anomalies represent dense concentrations of concrete and other construction debris.

References: Hargrave 1999b; Hargrave et al. 2002; Kreisa and Walz 1997; Larson and Penny 1998.

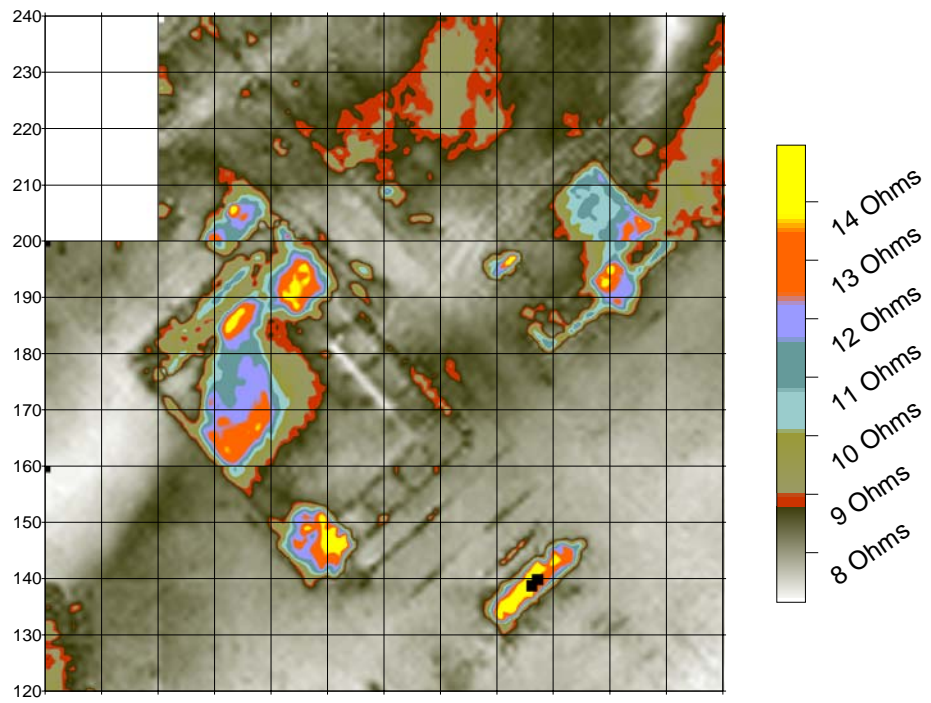


Figure 15. Electrical resistivity map of the Hippodrome Theater area.

Magnetic Field Gradient Survey of the Grossmann Site, Illinois

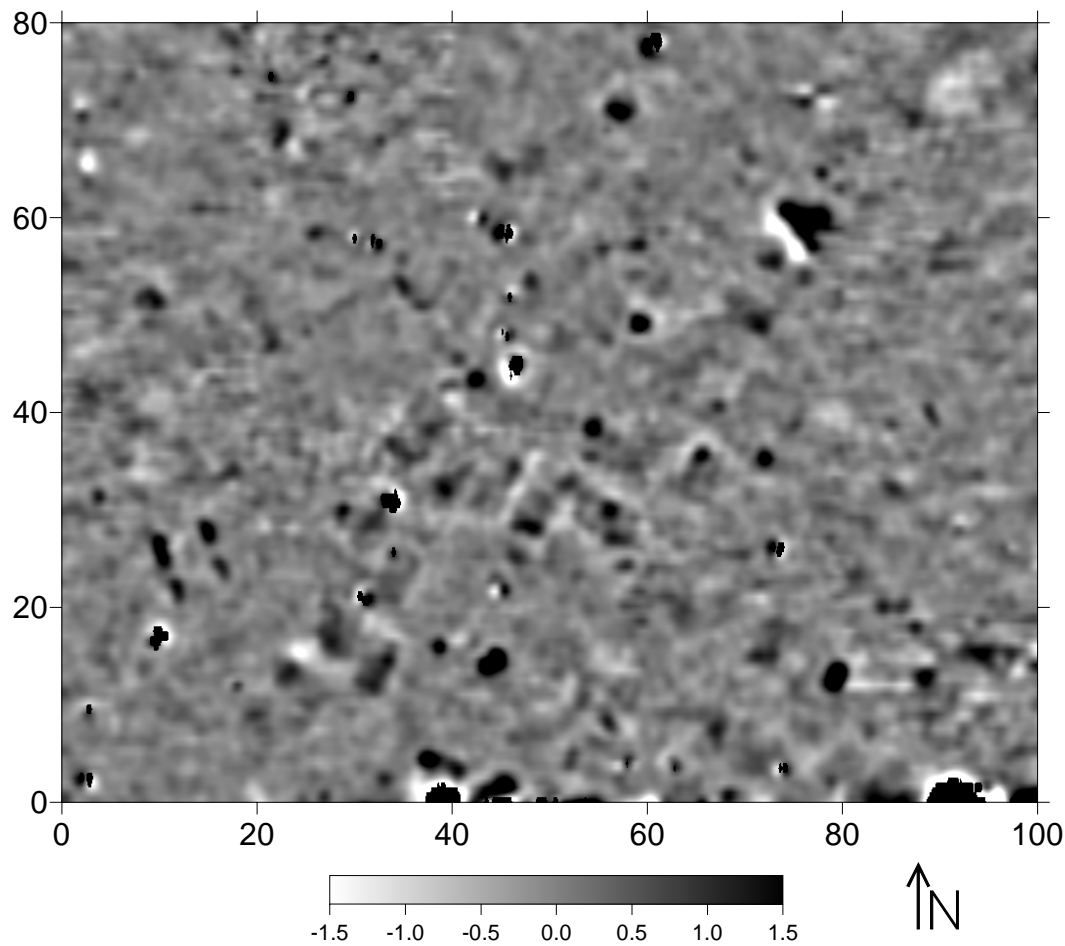


Figure 16. Magnetic field gradient survey of the Grossmann Site, Illinois.

Site Name:	Grossmann	Survey Purpose:	Mapping
Site Number:		Area of Survey:	3,800 m ²
County:	St. Clair	Instrument:	Geoscan FM36
State:	Illinois	Instrument Settings:	0.1 nT
Surveyor:	Michael Hargrave	Data Density:	16 per m ²
Organization:	ERDC/CERL	N-S:	8
Sponsor:	Timothy Pauketat	E-W:	2
Organization:	University of Illinois		

Comments: The Grossmann site is an early Mississippian settlement located on an upland ridge. The magnetic survey conducted in 2001 revealed a wide range of subtle anomalies. Some of these exhibited a size and shape consistent with rectangular house basins and wall-trench patterns. Excavations by the University of Illinois Field School and Richland Archaeological Project included the mechanical stripping of an area of 3,188 m². This work exposed 42 Mississippian

period structure complexes (55 building episodes) and 58 other features (pits, post pits, truss trenches, hearths, etc.). Overall, the Grossmann magnetic survey was quite successful. Using a statistical threshold of 4 standard deviations, about 60% of the structures and 40% of the other features were detected. Less than 20% of the anomalies were false positives (i.e., anomalies that were not associated with prehistoric features).

Electrical Resistivity Survey of the Harmon Site, Illinois

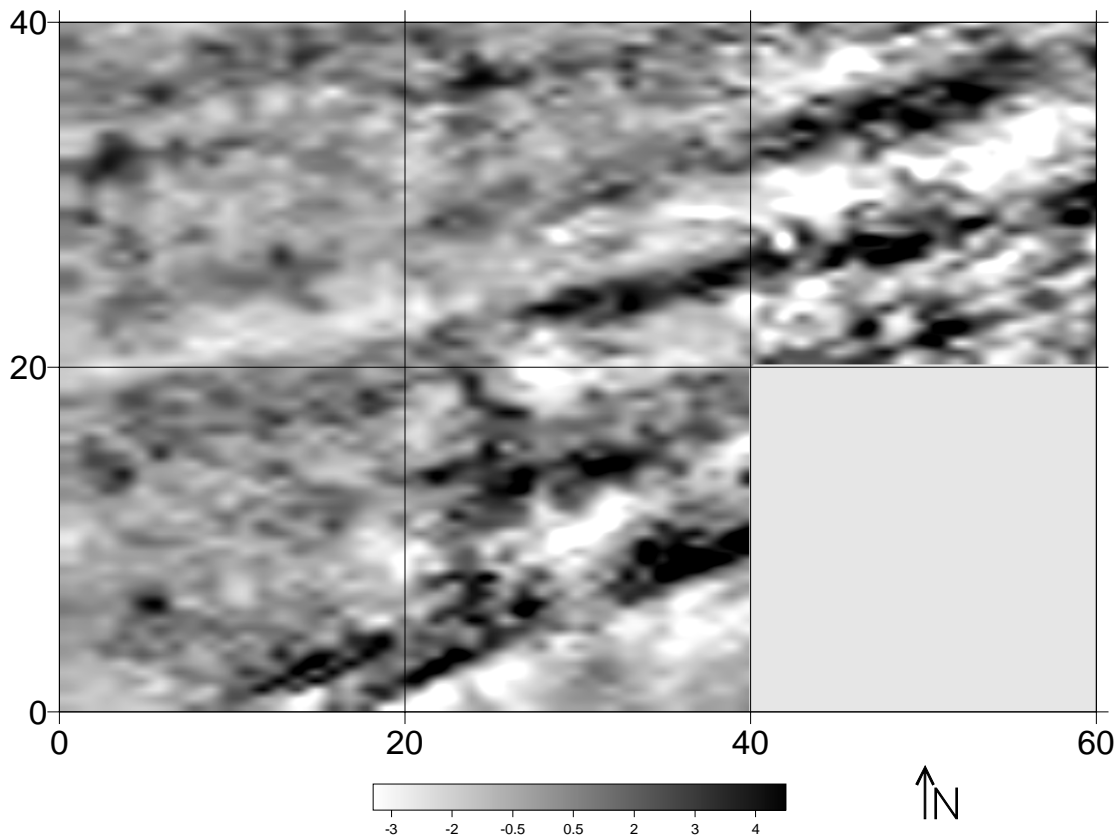


Figure 17. Electrical resistivity survey of the Harmon Site, Illinois.

Site Name:	A.E. Harmon	Survey Purpose:	Mapping
Site Number:	1MS136	Area of Survey:	2,000 m ²
County:	Madison	Instrument:	Geoscan RM15
State:	Illinois	Instrument Settings:	
Surveyor:	Michael Hargrave	Data Sample Density:	2 per m ²
Organization:	ERDC/CERL	N-S:	2
Sponsor:	Julie Holt	E-W:	1
Organization:	SIUE	Probe Spacing:	0.5 meter

Comments: This portion of the Harmon site had sustained several types of impact prior to the resistivity survey. The wedge-shaped area of low resistance in

the south-central block is the result of previous excavation and backfilling. Excavations here by the Illinois Transportation Archaeological Research Program (ITARP) encountered a cluster of late prehistoric pits. Strong linear anomalies running NE-SW were associated with an old haul road and the movement of heavy vehicles. Despite these impacts, discrete resistance anomalies were interpreted as possible pit features. Limited ground truthing excavations by the Southern Illinois University, Edwardsville (SIUE) Field School under Dr. Julie Holt in 2002 determined that some of the designated anomalies (including 1 resistance anomaly) were associated with pits. Several other pits and a small late prehistoric pit house identified in the excavations had not been detected in the resistance survey. On balance, survey results were satisfactory, particularly in view of the extent of previous impacts to the site.

Magnetic Field Gradient Survey of the Harmon Site, Illinois

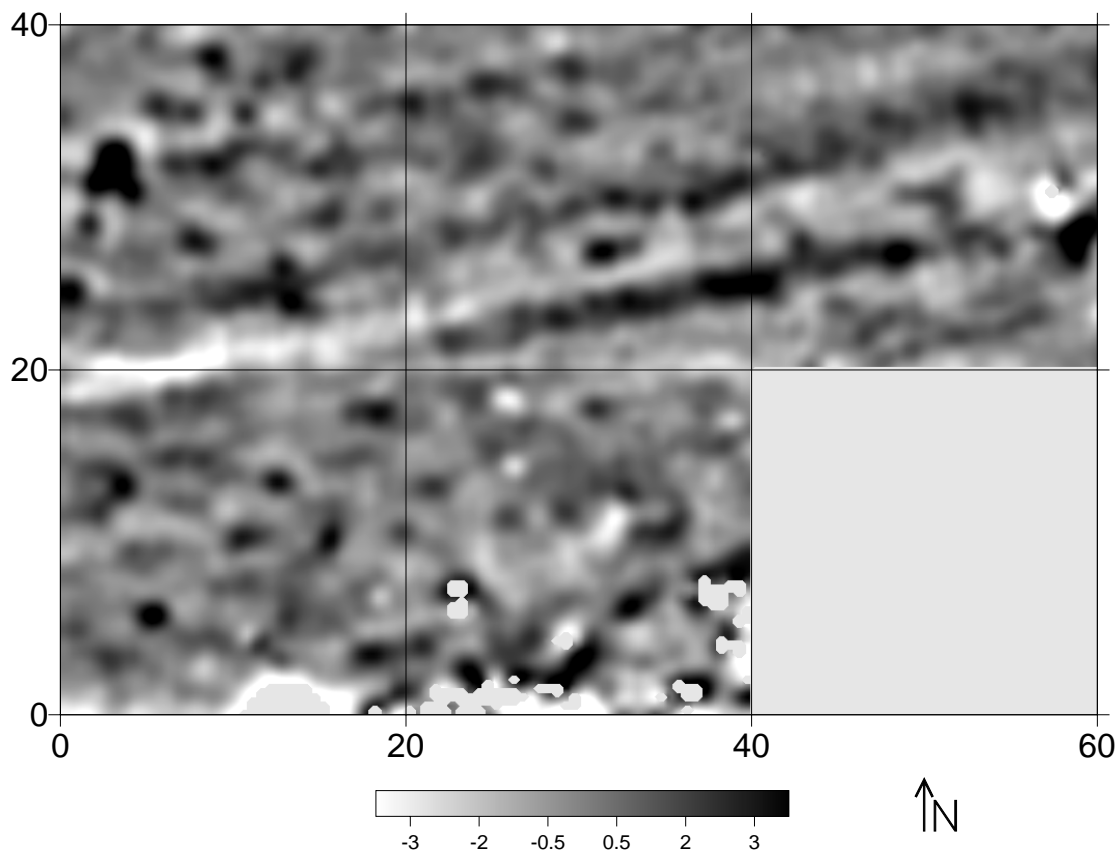


Figure 18. Magnetic field gradient survey of the Harmon Site, Illinois.

Site Name:	A.E. Harmon	Survey Purpose:	Mapping
Site Number:	11MS136	Area of Survey:	2,000 m ²
County:	Madison	Instrument:	Geoscan FM36
State:	Illinois	Instrument Settings:	0.1 nT

Surveyor:	Michael Hargrave	Data Density:	16 per m ²
Organization	ERDC/CERL	N-S:	8
Sponsor:	Julie Holt	E-W:	2
Organization:	SIUE		

Comments: This portion of the Harmon site had sustained several types of impact prior to the magnetic survey. Areas of missing data (homogeneous light gray) along the lower edge of the survey area represent very strong values associated with datum nails abandoned after previous excavations. Strong linear anomalies running NE-SW were associated with an old haul road and the movement of heavy equipment. Despite these impacts, discrete magnetic anomalies were interpreted as possible pit features. Ground truthing excavations by the SIUE Field School under Dr. Julie Holt in 2002 determined that some of the designated anomalies were associated with pits. Several other pits and a small late prehistoric pit house identified in the excavations had not been detected in the magnetic survey. On balance, survey results were satisfactory, particularly in view of the extent of previous impacts to the site.

Magnetic Field Gradient Survey of Fort Phil Kearny

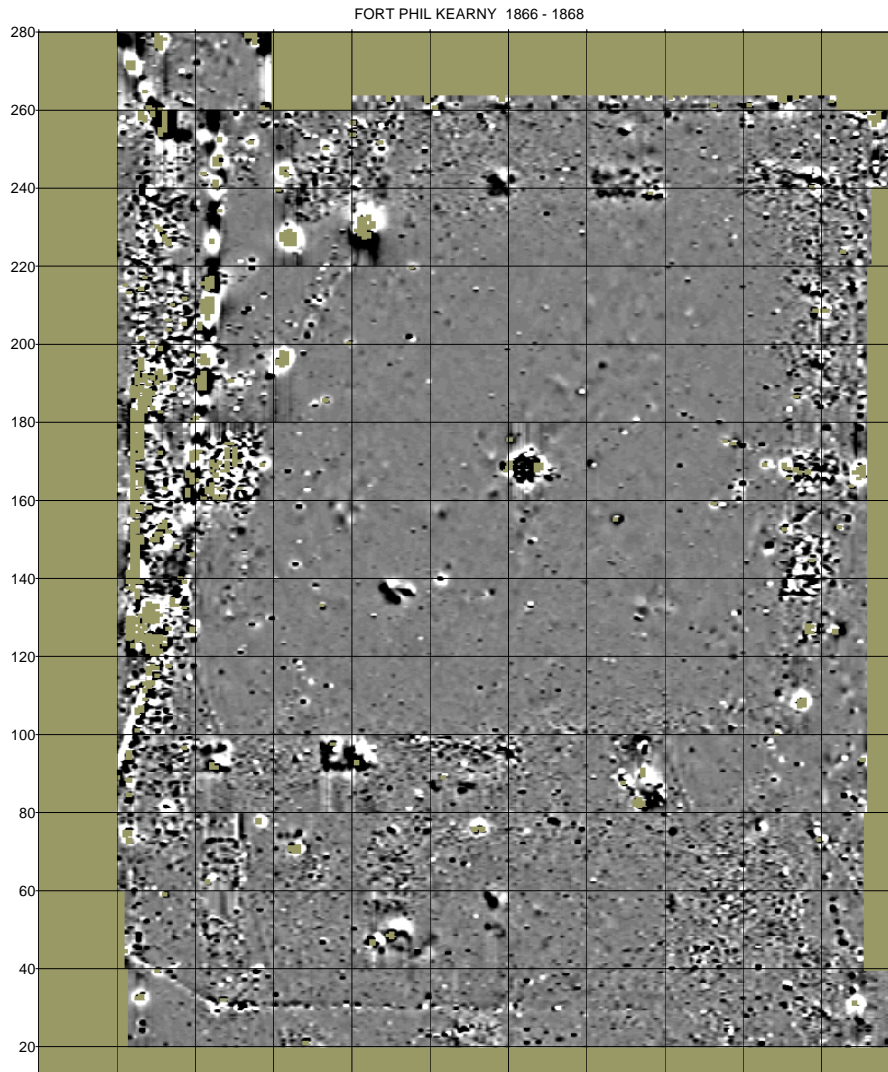


Figure 19. Magnetic field gradient survey of Fort Phil Kearny, WY.

Site Name:	Fort Phil Kearny State Historic Site	Survey Purpose:	Mapping
Site Number:	48J070	Area of Survey:	131,000 m ²
County:	Johnson	Instrument:	Geoscan FM36
State:	Wyoming	Instrument Settings:	.1 nT
Surveyor:	Students (directed by Lew Somers)	Data Density:	8 per m ²
Organization:	Bozeman Trail Association	N-S:	8
Sponsor:	Robert Wilson	E-W:	1
Organization:	NPS		

Fort Phil Kearny, WY, was constructed in 1866 to protect Euro-American travelers along the Bozeman Trail. The 10-acre fort consisted of two sections: a rectangular military stockade and a trapezoidal stockade occupied by civilians and military support personnel.

In 1998 Dr. Lewis Somers of Archaeo-Physics, LLC and Absaraka Cultural Resource Consultants, Inc. (Sheridan, WY), working under contract for LTA, Inc. (Laramie, WY), conducted a geophysical survey of portions of the Fort Phil Kearny Historic Site. The geophysical survey was one phase of a multi-component project that also includes archaeological investigations and the reconstruction of four corners of the fort stockade. Results of the geophysical survey were used to guide placement of archaeological units and as a management tool for planning future work at the site.

The image shown above displays the magnetic field gradient data with minimal processing (zero mean traverse, interpolation of data points, data clipped to ± 30 nT). Strong bipolar anomalies are presumed to be associated with substantial brick, iron, or steel objects. More subtle variation may be associated with nails or other small metal objects, or disturbed, burned, or organically enriched soils.

5 Solutions to Common Problems

The guidance provided in this document (ATAGS Supplemental Document 2) should help surveyors and survey sponsors avoid many of the problems that can be associated with a geophysical survey. Unanticipated problems will, however, occasionally arise. This guidance should help resolve or at least ameliorate problems that could not be (or simply were not) avoided.

Negative Findings

One of the most frustrating outcomes of a geophysical survey is the absence or extreme scarcity of anomalies that are likely to be associated with subsurface cultural features. Such negative findings are particularly troubling when other evidence (e.g., an abundance of artifacts on the surface, the presence of midden deposits or discrete features in test units) strongly suggests that features should be present at the site. Possible explanations for negative findings and suggested action include the following:

- a. Discrete features such as pits, hearths, and architectural remains are simply absent or occur in very low frequency.
- b. Features are present but have not been detected by the geophysical instrument used.

Several courses of action are recommended:

- (1) Inexperienced surveyors should review their survey design, particularly their field technique and data processing. If the focus is on detection of prehistoric features, ensure that strong data values are removed from the data, enhancing the potential to detect very weak anomalies. Surveyors should next consider the following options:

- (2) Survey the most promising areas using one or more different geophysical instruments. Here the most promising area would be where topography, artifact distributions, the absence of surface impacts, or other factors suggest that features are most likely to occur.

(3) Survey the most promising areas with the original instrument using a more rigorous survey design. In most cases, this will entail an increase in data density, commonly achieved by using more closely spaced transects. For example, a magnetic survey conducted with transects spaced at 1-m intervals could miss relatively small and/or low-contrast features. Reducing the transect spacing to 0.5 m will significantly increase the likelihood of detecting such deposits. Doing a survey with higher data density will reduce the area that can be covered in a given amount of time.

Unfortunately, it is always possible that features are present at a site but are simply not amenable to geophysical detection. This may occur in well-preserved sites when the features exhibit a very low contrast with the surrounding deposits. The low contrast could be due to an ephemeral occupation that resulted in the introduction of little organic, burned, and/or artifactual material into the feature fill. At intensively occupied sites, a rich stratum of midden could mask the presence of underlying discrete features. In this situation, however, it should be possible to detect the edges of the midden.

Too Many Anomalies

Archaeologists often use a geophysical survey as a basis for deciding where to locate their excavation units. The high costs associated with controlled excavation limit the number of test units that can be excavated. Where the overall project goal is simply to determine a site's eligibility for the National Register of Historic Places, it is often possible to excavate only a few test units. In some situations, a geophysical survey can result in the detection of far more anomalies than can be investigated. In this situation, two practices are recommended:

a. Prioritize the anomalies – The goal here is to differentiate anomalies likely to be associated with archaeological features from those related to natural phenomena or recent cultural phenomena. Criteria that can be used to prioritize the anomalies include amplitude (i.e., the geophysical data value), size, shape, and distribution. All of these criteria must be viewed with some caution, especially in magnetic survey data. For example, Bevan notes that anomalies detected in many magnetic surveys may be circular. “These circular patterns are just caused by the fact that the objects are rather small, and the magnetic survey did not reveal anything about their shape ... As features become larger or longer, a magnetic map will begin to reveal their shape. However, the shape will still be blurred and it will only approximate the actual shape of the feature” (Bevan 1998:25-26). Anomalies can be prioritized most effectively when the surveyor has considerable information about (1) the nature of the local archeological re-

cord (e.g., common feature types), and (2) the local soil and geology (e.g., the presence of geological clutter).

The presence of metal in a surveyed area introduces many problems when one is attempting to identify prehistoric features. In many cases, a very small piece of metal can produce a weak anomaly similar in size and shape to that associated with a prehistoric pit feature. Prioritization of anomalies is thus much easier in situations where little or no metal or other highly magnetic natural material is present. Prioritization is also most useful in surveys characterized by a moderate to high data density. Low data density surveys will provide less reliable information about anomaly size and shape.

With a cognizance of the potential complications, it is often useful to prioritize anomalies using the following categories:

- (1) anomalies that are too large and asymmetrical to be associated with cultural features (i.e., nonfeatures)
- (2) strong dipole anomalies likely to be associated with metal or iron-rich materials (nonfeatures)
- (3) weak anomalies with dimensions similar to those of prehistoric features (possible features)
- (4) weak amorphous or asymmetrical anomalies (less likely to be features).

In addition to size and shape, the distribution of anomalies may help identify those associated with features. Large-area excavations often reveal that features are spatially clustered. Categorization of anomalies based on their spatial distribution is relatively subjective if no ground truthing has been done.

b. Multi-staged ground truthing – A multi-staged approach to ground truthing excavation has been effective for prioritizing anomalies at several sites in the Midwest (Ahler et al. 1999a, 1999b). The approach here is to use a series of increasingly invasive and expensive methods to eliminate from further consideration anomalies that are unlikely to be associated with cultural features. The following stages may be useful, depending upon local soil conditions and the nature of the archaeological record.

- (1) Visual inspection – visually inspect the locus of each anomaly. Eliminate from further consideration those anomalies associated with seemingly natural depressions, wet spots, trees, vehicle ruts, etc.

- (2) Metal detection – use a good quality metal detector to eliminate those anomalies where metal objects are present. This approach is suitable for virtu-

ally all prehistoric sites, given the extreme rarity of metal (e.g., copper) artifacts. At historic sites, however, this approach could eliminate anomalies associated with features that contain metal artifacts.

(3) Soil cores – use a small diameter (e.g., Oakfield) soil core to inspect the soil from within the anomaly. Compare this with a soil core collected nearby but outside the anomaly. Eliminate from further consideration those anomalies for which the soil core exhibits no evidence for feature fill (organic staining, artifacts, oxidized soil, carbon flecks, etc.).

(4) Shovel tests – Compare the results of shovel tests excavated inside and immediately outside of the anomaly. As in step (3), eliminate anomalies that exhibit no evidence of features.

(5) Test units – Excavate a test unit to further investigate anomalies that have survived the preceding four steps. Remain aware that (a) there is nearly always some valid explanation for the existence of a geophysical anomaly, but (b) some anomalies may be associated with the remains of features or other phenomena that are not readily discernable to the naked eye. The archaeologist should take care to note evidence for subtle differences in soil compaction, moisture retention, and mixing, as well as the distinctions in color, texture, and artifact contents that are the more familiar indications of a feature.

(6) Mechanized stripping – Mechanized removal of the plow zone using a backhoe or track hoe with a wide, toothless bucket is an effective way to ground truth geophysical anomalies. Disadvantages associated with this approach include impacts to the site, including the loss of artifacts in the plow zone and potential damage to fragile materials.

Problems With Vegetation

Ideally, the nature of the vegetation in a survey area will be carefully described in the SOW. It is extremely useful to the geophysicist for the sponsor to provide several photographs showing the vegetation cover at the site. Unfortunately, it often happens in CRM that a survey planned for the spring or fall is delayed until summer, when vegetation poses a major problem. Survey sponsors are sometimes guilty of underestimating the impact of site vegetation on survey results. Particularly inexperienced sponsors may assume that archaeologists can work in the woods or in densely overgrown old-fields, and geophysicists should be able to do so as well.

Dense vegetation can have a variety of negative effects on a geophysical survey, including (a) a reduced rate of coverage and (b) reduced data quality (increased noise or randomness). The latter is associated with a decreased signal-to-noise ratio.

It is useful to note differences among the main geophysical instruments in the needs for vegetation clearing. Note, however, that it is often desirable (and sometimes essential) to use more than one instrument in a geophysical survey. For all instruments, the sponsor should keep in mind that the surveyor will often be looking down rather than ahead, monitoring instrument readings, his/her position relative to a tape, etc. Clearing of undergrowth should remove tree branches that might strike the surveyor in the face.

a. Ground penetrating radar – In a GPR survey, the instrument will be pulled along closely spaced (1 meter or less) transects marked by tapes or ropes. It is important for the antenna to remain in contact with the ground surface. If saplings and other small diameter plants are cut and removed, they should be cut right at the ground surface so that the stumps do not represent obstacles for the antenna.

b. Magnetic field gradient – Gradiometer surveys require relatively thorough vegetation clearing. For example, the Geoscan FM-36 must be carried perpendicular to the ground surface, with the two sensors in vertical alignment. Survey maps are made assuming that the data points are distributed along the transects marked in the field by ropes or tapes. If the surveyor must dodge around obstacles, he/she will introduce a substantial amount of noise into the data. This is likely to compromise survey results, particularly if the features of primary interest are relatively small, low-contrast targets such as pits, hearths, etc.

c. Electrical resistance – Resistance surveys can be conducted in less thoroughly cleared vegetation than can GPR or gradiometer surveys. The resistance instrument is connected to a pair of remote probes by a long (ca. 50 meters) cable. To collect data, one must position the instrument and then lightly press the probes attached to its frame into the ground. One is free to maneuver in and out among trees and undergrowth, so long as the actual data collection point is properly located.

Note that, when surveying in the woods (even after clearing), it is almost essential to have one (and preferably two) individuals assist in moving the tapes used to mark the survey transect and, in the case of resistance and GPR survey, the instrument cables. In an open field, the surveyor can easily move the tape.

Problems With Metallic Debris

Many archaeological sites in the United States are characterized by a light scatter of recent metallic debris. Items such as nails, fence wire, small pieces of agricultural implements, etc. can be abundant in the vicinity of historic structures.

On archaeological sites, metal pin flags pose a particular problem. Depending upon its position and magnetic characteristics, a pin flag can corrupt the data values across an area several meters in diameter. Numerous pin flags can prevent the reliable detection of prehistoric features. Often the worst situations occur at sites where pin flags have been used to mark the locations of artifacts, closely spaced shovel tests, or the corners of controlled surface collection units. In some cases, it may be effective to locate the pin flags using a metal detector and to remove them prior to geophysical survey. In other cases, however, the pin flags are rusted and broken into multiple pieces, making it impossible to adequately reduce their impact on a magnetic survey.

Metallic debris is less of a problem at historic sites. This is because historic features often include materials characterized by a relatively strong contrast with the surrounding soil. At historic sites, many of the metal objects may be an intrinsic part of the archaeological record. Pin flags and other recent metallic debris will complicate the situation, but may not preclude the detection of many of the historic archaeological features.

One of the most difficult situations is where a historic component co-occurs with a prehistoric component, and the latter is of primary interest. In most cases, it will not be possible to reliably detect the prehistoric features. Subtle anomalies associated with those features will generally be masked by the effects of historic metal artifacts and high-contrast historic features.

Problems With Surface Disturbance

Disturbance of the uppermost soil stratum at a site can have varying effects on the potential for detecting prehistoric features. In most situations, agriculture does not pose a serious problem beyond the reduction of feature integrity. Where possible, geophysical surveys should be scheduled to occur as long as possible after the most recent plowing, preferably after one or more freeze and thaw cycles. Particularly deep (e.g., chisel) plowing can damage features to greater depth than does moldboard plowing and disking. In most cases, the presence of a few deep vehicle tracks or tire ruts will not seriously impact a geophysical survey, although the tracks and ruts are likely to appear in the data. Situations

that can seriously reduce the effectiveness of a geophysical survey include grading by heavy equipment, and intensive traffic by heavy vehicles such as earth moving equipment and military vehicles.

Problems With the Weather

The effects of extreme weather conditions vary among the instruments:

a. Electrical resistance surveys can best be executed under conditions of intermediate soil moisture. In arid settings (which do not characterize most of the Plains and Midwest), the uppermost several inches of soil may be difficult to penetrate. Once this is achieved, however, reliable readings can be collected, and features may exhibit high contrast with their surroundings. Good data can also be collected when soils are quite wet, although the presence of tall wet grass may increase the chances of problems such as striped data when collecting multiple readings at each station. Resistance surveying should not be conducted when any portions of the survey area may be frozen.

b. Magnetic surveys can be conducted under most soil conditions. The instruments are generally designed to be water resistant, although it is not advisable to use them in heavy rain for extended periods. Frozen soils pose no problem for magnetic survey.

c. GPR surveys can be conducted under many soil conditions, although a high clay content may prevent penetration to a useful depth. The effects of moisture content on radar wave attenuation are complex and depend in part on soil characteristics (Miller et al. 2002). GPR surveys of frozen soils can be productive, but proper data collection and interpretation require extra care and substantial previous experience.

6 Field Procedures for Resistivity and Magnetic Field Gradient Survey

This chapter presents ATAGS Supplemental Document 3, an overview of field procedures. The purpose of this overview is to ensure that surveyors will implement the field procedures required to ensure a successful survey. A familiarity with geophysical field methods will also be useful to survey sponsors. Note that this document assumes a rudimentary familiarity with Geoscan resistivity and magnetic instruments and Geoplot 3.0 software (Figures 20 and 21). Five principal field procedures are discussed in the order that they are usually implemented.

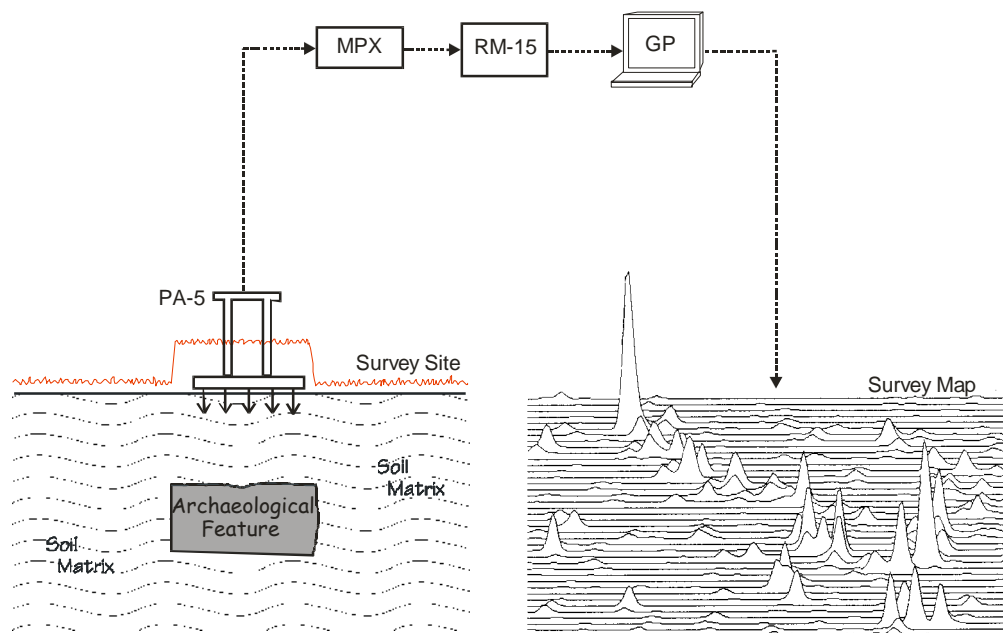


Figure 20. Diagram depicting major components of electrical resistivity survey.

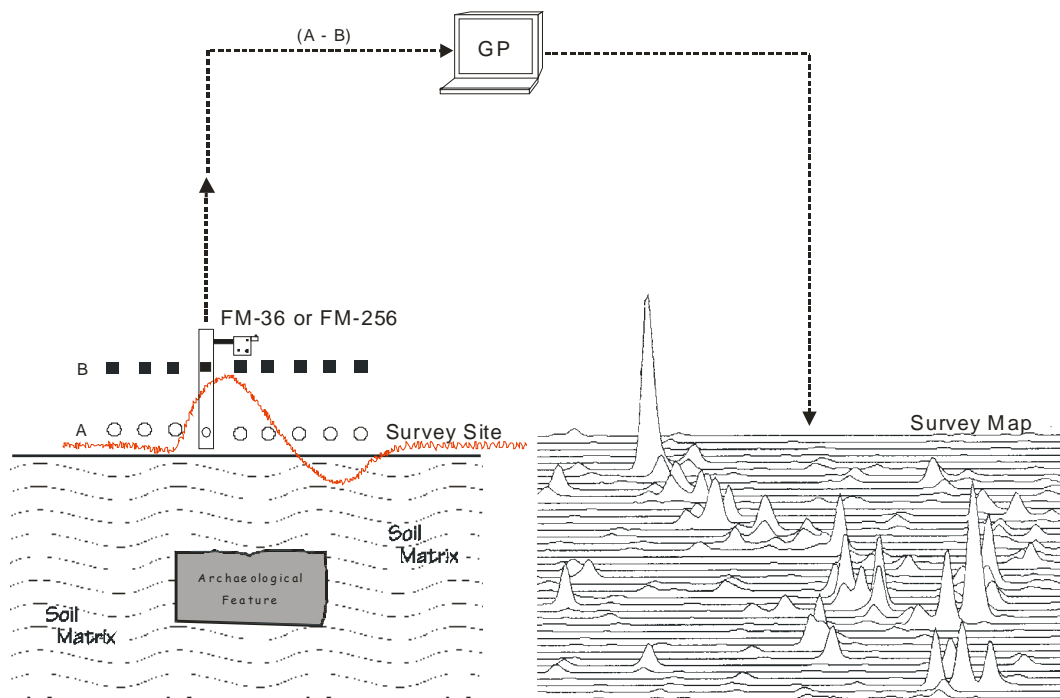


Figure 21. Diagram depicting major components of magnetic field gradient survey.

Resistivity Survey Field Procedures

Initial Site Assessment

Deploy the remote electrodes to an arbitrary but centrally located position on the site. Choose a location that will minimize the number of times the remote probes must be repositioned as the survey progresses.

Station Configuration

When conducting a large (multi-day) resistivity survey, it is very useful to establish a Configuration and Drift/Calibration Station. The station consists of four arbitrary but precisely maintained probe positions: one for each of the two remote probes and the two mobile probes. Probe position must be maintained within ± 3.0 mm in both depth and location. The instrument should be returned to this station periodically. Ideally, the resistivity reading observed at this station will remain constant throughout the survey. In fact, it is likely that changes in soil moisture will result in changes in resistivity. In addition, if the four probes are arranged in a Wenner array, an absolute soil resistivity measurement can be recorded at this station.

Instrument Configuration

RM-15 resistivity meters are capable of recording resistivity measurements with a dynamic range greater than 1:2000. This dynamic range is critical to the detection of both very subtle and very strong anomalies. To achieve this dynamic range, it is essential to configure the Output Voltage, Current, Gain, and Auto-Log Speed appropriately. This can be achieved as follows:

1. Place the probe array in the ground at the configuration station and turn on the instrument.
2. Open Menu Number 2
 - Set the Gain to 1
 - Set Current to 0.1 mA
 - Set Frequency to 137 Hz
 - Exit the menu twice.
3. Open Menu Number 3
 - Set Output Voltage to 40 V
 - Set Auto-Log Speed to slow
 - Set High-Pass Filter to 13 Hz
 - Set Mains Frequency to 60 Hz (USA)
 - Do not reset RM-15
 - Exit the menu twice.
4. A resistance value should be visible on the screen.
 - Re-enter Menu Number 2
 - Increase the Gain until a minimum of three digits is visible on the screen. Examples might be XXY , $X.XY$, and $XX.Y$. It is important that a minimum of three digits be present in order to detect relatively weak anomalies. The decimal point location is not important.
5. Note the stability of the right-hand digit (Y).
 - If it is stable (unchanging) in a 15-30 second period, instrument configuration is satisfactory and the survey can begin.
 - If it is not stable (unchanging) return to Menu Number 2
 - Increase the Current to 1.0 mA
 - Reduce the Gain by a factor of 10
 - Exit the menu twice.
6. Note the stability of the right-hand digit (Y).
 - If it is stable (unchanging) in a 15-30 second period, start the survey.

- If it is not stable (unchanging), return to Menu Number 2
- Increase the Current to 10.0 mA
- Reduce the Gain by a factor of 10
- Exit the menu twice.

7. At this point the RM-15 is configured to provide the greatest dynamic range available at the site, whether or not the right-most digit, Y, is stable.

8. Complete instrument configuration and proceed with the survey.

Data Collection Protocol

By convention and to be compatible with data processing software and data file management protocols, it is essential to start surveying each grid in the southwest corner. Data collection proceeds from the southwest corner to the north edge of the grid (first traverse). Subsequent data collection can be performed along transects in the parallel or zigzag mode. Note that resistivity data can be collected along transects oriented in any direction, so long as one begins in the “lower left” corner (if one imagines looking at the grid from above).

All surveys are performed in rectangular grids or units (e.g., 20 x 20 m, 30 x 30 m, 5 x 20 m, etc). The site is divided into these units by land survey methods. Grid subdivision for data sample location is implemented by means of fiberglass survey tapes combined with the automated data logging features in the survey instrument. Each grid data set in these surveys is referenced to the south edge and the southwest corner of the grid unit. By using this standard and preserving the grid corner location, it is possible to relocate a map feature in the field to within a small fraction of a meter.

Quality Control

Data quality control is a field activity. The surveyor must monitor the stability and “reasonableness” of each reading as values are collected for sample-to-sample for continuity. For example, readings that differ wildly (e.g., by a factor of 2) from previous readings are either very significant or very erroneous. In either case, they should be confirmed by re-sampling.

Magnetic Field Gradient Field Procedures

Five principal field procedure issues in magnetic field gradient survey are discussed here in the order that they are usually implemented. Note that this

document assumes a rudimentary familiarity with Geoscan magnetic instruments and Geoplot 3.0

Initial Site Assessment

Magnetic objects (vehicles, wheelbarrows, shovels, trowels, rebar, pin flags, etc.) must not be present in or adjacent to the survey area. Small iron objects associated with the archaeological record should remain in place. Large iron objects associated with the archaeological record should be removed and replaced after the magnetic survey whenever that is archaeologically acceptable.

A single steel pin flag can corrupt a 5-m radius area at a typical prehistoric North American site. A scatter of small (1- or 2-inch-long) iron objects (e.g., nails and other small hardware) on or near the surface, however, are seldom a problem because they are readily removed with appropriate data processing. Larger, more deeply buried, iron and steel objects pose a problem.

Vegetation can be an important consideration in magnetic field gradient survey if its height, density, or distribution across the site prevents the surveyor from carrying the magnetometer at a relatively constant elevation and angular orientation. The associated data defects can limit detection of weak anomalies.

Station Configuration

It is useful to establish a Balance and Alignment Station in a “magnetically uniform” area on the site. To find such an area, select a convenient location and establish a distant horizon feature for magnetic north. Scan ca. 2 m north and south and ca. 2 m east and west from the selected point, noting the data change during the scan. Since the instrument will not yet be well balanced, keep it oriented in a single direction while scanning. If data variations are less than 0.5 nT, a uniform magnetic area has been found. Mark it with a wooden stake. Use this location for balancing and aligning the instrument.

An alternative and generally superior strategy involves the use of a plastic box or stool (with no metal fittings) that is ideally at least 1 m high. Experience teaches that, when the bottom sensor is at least 2 m above the ground surface, a relatively uniform magnetic location has been found. Elevating the magnetometer at least 2 m above the ground is a necessity in high susceptibility and volcanically derived soils.

Instrument Configuration

1. Follow the manufacturer's procedure for balancing the instrument's two sensors.
2. Follow the manufacturer's guidance for angular alignment:
 - in the north-south direction
 - in the east-west direction.
3. Repeat angular alignment:
 - in the north-south direction
 - in the east-west direction.
4. Repeat the manufacturer's procedure for balancing the two sensors.
5. Repeat the manufacturer's guidance for angular alignment:
 - in the north-south direction
 - in the east-west direction.
6. Repeat angular alignment:
 - in the north-south direction
 - in the east-west direction.
7. Validate balance and alignment:
 - balance validation – normal and inverted readings differ by less than 1.0 nT
 - alignment validation – note the instrument reading at all four cardinal directions; the difference between the minimum and maximum data value should be less than 1.0 nT.

Data Collection Protocol

By convention, and to be compatible with data processing software and data file management protocols, it is essential to start surveying each grid in the southwest corner. Data collection proceeds from the southwest corner to the north edge of the grid along the first traverse. On subsequent traverses, data can be collected in the parallel or zigzag mode. Note that magnetic data can be collected along transects oriented in any direction, so long as one begins in the "lower left" corner (if looking at the grid from above). Orienting the data collection traverses to magnetic north is advantageous in that it allows identification of dipole anomalies that may relate to in-situ burning.

All surveys are performed in rectangular grids or units (e.g., 20 x 20 m, 30 x 30 m, 5 x 20 m, etc.). The site is divided into these units by land survey methods. Grid subdivision for data sample location is implemented by means of 1-m marked tapes combined with the automated data logging features in the survey instrument. Each grid data set in these surveys is referenced to the south edge and the southwest corner of the grid unit. By using this standard and preserving the grid corner location, it is possible to relocate a map feature in the field to within a small fraction of a meter.

Quality Control

Data quality control is a field activity. The surveyor must simultaneously minimize the angular, elevation, and data sample location errors. The smaller and weaker the magnetic field associated with the archaeological record, the more carefully the survey must be performed. Good practice will maintain data sample location errors to less than $\pm 10\%$ of the data sample distance. Angular orientation errors will be maintained to less than ± 5 degree in all three angular directions (using aircraft terminology — pitch, yaw, and roll).

7 Checklist of Field Procedures

This chapter presents ATAGS Supplemental Document 4, a Checklist of Field Procedures. This checklist is intended to help surveyors in planning and executing electrical resistance and magnetic field gradient surveys.

Resistivity Survey

The following checklist identifies a number of key issues that should be addressed to ensure a successful survey. This discussion assumes a rudimentary familiarity with Geoscan resistivity and magnetic instruments and Geoplot 3.0.

Pre-Survey

1. Fully charge instrument batteries (8 hours).
2. Inspect wires, cable, plugs, probes and fittings, and PA-X probe array. They should be clean, dry, free of salts, mud, etc.
3. Attach a new plastic-sheet “diaper” to the instrument frame using duct tape.
4. Check laptop. Ensure that Geoplot software has been installed, the battery is fully charged, etc. Test and confirm that data can be transferred by means of the data dump cable from the resistance meter to the laptop computer prior to going to the field. Confirm data transfer by examining data grid files.

Field Survey

1. Clear resistance meter memory of all data.
2. Configure resistance meter for survey.
3. Conduct initial site assessment; finalize sampling strategy.
4. Establish reference/drift/calibration station.
5. Finalize decisions about survey depth/probe separation and data density.
6. Inspect PA-X probe array. Ensure that it is correctly assembled, complete with grommets and mud shields, and that probes are connected to the junction box as required by the intended survey depth and data density. Install plastic “diaper.”
7. Deploy remote probes at an appropriate location, anticipating relocation requirements.
8. Adjust remote probe positions with respect to dynamic range requirements.

Survey Method

1. Begin data collection in accordance with the survey design.
2. Start in southwest corner of each grid (if transects run north-south; see Chapter 4). Collect data along first transect from south to north.
3. Maintain consistent probe placement and orientation with respect to reference tape.
4. Deviation in probe position (data sample location) from the intended location indicated by the tape should not exceed $\pm 10\%$ of probe separation distance.
5. Monitor data quality. Monitor data values for continuity and reasonableness. Delete and resample all questionable values.
6. Transfer data from RM-15 to laptop.
7. Clear memory on RM-15 before resuming data collection.
8. Remove diaper and clean equipment after each field session. Remove dirt, mud, and salt from cables, PA-X probe array frame, probes, grommets, washers, and insulating bushings. Do not reuse plastic sheet diapers.
9. Never store (not even overnight) PA-X probe array with plastic diaper installed.

Post-Survey

1. Clean-up and process data.
2. Use Despiking procedure to remove extreme data values.
3. Use Grid Edge Match as required to remove grid-to-grid mean value differences.
4. Negative readings – edit as required.
5. Use Interpolation to achieve uniform data sample density (i.e., square pixels).
6. Interpret data vis-a-vis absolute values. Note evidence for large-scale trends (geomorphology).
7. Use High-Pass Filter to enhance detection of small-scale low-contrast anomalies.
8. After high-pass filtering, plot the positive data values. Interpret these vis-à-vis local soil and feature types.
9. After high-pass filtering, plot only the negative values. Interpret these vis-à-vis local soil and feature types.
10. Identify and interpret anomalies that represent clutter (see Chapter 5, “Too Many Anomalies”).
11. Identify and interpret anomalies associated with archaeological features.
12. Repeat useful processing sequences and optimize map appearance to enhance interpretability.
13. Interpret survey results in terms of the archaeological research design.
14. Use GIS, Surfer, or other software to graphically integrate geophysical results with other data (air photos, plan maps of excavation units, etc.).
15. Prepare final report.

Magnetic Field Gradient Survey

Pre-Survey

1. Fully charge instrument batteries (8 hours).
2. Check laptop. Ensure that Geoplot software has been installed, the battery is fully charged, etc.
3. Verify that field clothing is free of iron/steel: empty pockets; no glasses, wire bras, zipper flies, jeans rivets, shoes, surgical steel, coins, or paper money. Note that many silver, copper, and brass accessories on clothing are actually plated steel. Gold and silver are okay.
4. Check laptop. Ensure that Geoplot software has been installed, the battery is fully charged, etc. Test and confirm that data can be transferred by means of the data dump cable from the magnetometer to the laptop computer prior to going to the field. Confirm data transfer by examining data grid files.

Field Survey

1. Clear magnetometer memory of all data.
2. Configure magnetometer for survey.
3. Conduct initial site assessment; finalize sampling strategy.
4. Establish a balance and alignment station.
5. Balance and align instrument.

Survey Method

1. Begin data collection in accordance with the survey design.
2. Start in southwest corner of each grid (if transects run north-south; see Chapter 4). Collect data along first transect from south to north.
3. Continue data collection in zigzag or parallel traverses.
4. Maintain consistent gradiometer position and angular orientation with respect to reference tape.
5. Deviation in gradiometer position (data sample location) from the intended location indicated by the tape should not exceed ± 2 cm if data sample interval is 8 samples per meter; ± 4 cm at 4 samples per meter.
6. While surveying the magnetometer's position, angular orientation, and elevation should be monitored by a field assistant.
7. Transfer data from magnetometer to laptop.
8. Clear magnetometer memory before resuming data collection.
9. Clean equipment and wipe dry before storage.

Post-Survey

1. Clean up and process data.
2. Use Zero Mean Traverse to remove bias defects.
3. Use Interpolation to achieve uniform data sample density.

4. Use Low Pass Filter to reduce small-scale variation and enhance the potential for detecting subtle anomalies.
5. Interpret strong high-contrast anomalies; attempt to differentiate features from clutter.
6. Interpret weak low-contrast anomalies; attempt to differentiate feature from clutter (see Chapter 5 “Too Many Anomalies”).
7. Use statistical thresholds to identify statistically significant anomalies in a replicable manner.
8. Repeat useful processing sequences and optimize map appearance to enhance interpretability.
9. Interpret survey results in terms of the archaeological research design.
10. Use GIS, Surfer, or other software to graphically integrate geophysical results with other data (air photographs, plan maps of recent features, excavation units, etc.).
11. Prepare final report.

8 Data Processing Procedures for Resistivity and Magnetic Field Gradient Survey

This chapter (ATAGS Supplemental Document 5) provides concise guidance on the data processing procedures that can be used to clean up, analyze, interpret, and present the data that result from resistivity and magnetic field gradient surveys. This discussion assumes a rudimentary familiarity with Geoplot 3.0.

Resistivity Survey

There are typically two principal stages in resistivity data processing. The first is concerned with large-area and high-contrast anomalies. The second is concerned with the small-area and low-contrast anomalies. The former generally does not require High-Pass filtering of the data; the latter does.

Stage I: Large-Area and/or High-Contrast Anomaly Processing

1. Merge the raw data: Combine data from individual survey grid files into a composite file. This creates a graphic for the entire survey and enables all Geoplot 3.0 analysis and data processing algorithms.
2. Edit or remove defective data: Data obviously inconsistent with soils, sediments, geology and archaeological features should be removed. This is implemented with the Search and Replace processing function. Defective data are usually replaced with Geoplot's dummy data value, 2047.5.
3. Despiking: It is customary to use Despiking, a statistically based quality control process, which removes "spike-like" data that often arise in resistivity surveys.
4. Edge Match: Resistivity grids with slightly different bias levels can be adjusted by means of the Edge Match process.
5. Display and Initial Interpretation: Visually examine the composite map for anomalies and archaeological features of interest. Distinguish between archaeological and geological features and anomalies.
6. Interpolate Data: Interpolate the composite file data to achieve the same data sample density in the N-S and E-W directions. This may or may not be necessary depending on the data sample densities used during the survey. The Interpolation function is used to expand the lower density direction data in steps of x2.

Sin(x)/x interpolations are recommended for the first expansion (x2). Additional expansion should use linear interpolators (an option in the Geoplot Interpolation function). A final data sample density of 2 x 2 per m² is useful for display on the computer screen, hard copy maps, and export to GIS and other software packages. After processing in Geoplot, geophysical data are commonly exported to Surfer to produce final maps.

7. Display and Interpretation: Examine the uniformly sampled data file by means of grayscale, relief, trace, contour, or color plots as required.

At this point in the processing sequence both the high-contrast and large-area anomalies present in the survey will be apparent. Variations in the site soils, sediments, and geology will also be apparent.

Stage II: Small-Area and Low-Contrast Anomaly Processing

1. High-Pass Filtering: The High-Pass Filter routine should be applied to the uniformly sampled data file (i.e., following completion of Stage I Processing). This is implemented with a large, uniformly weighted high-pass filter window (the default High-Pass Filter parameters in Geoplot).

The small-area and the low-contrast anomalies in the survey will now be more visible. The High-Pass Filter operation has effectively subtracted the local average (background) resistivity from the survey data. The result is a new map with both positive and negative values and a mean value of approximately zero. The positive data represent areas where the resistivity is greater than the local average background. Negative data represent areas where the resistivity is less than the local average background.*

There is a very important interpretative consequence of high-pass filtering. Positive values can be confidently interpreted as anomalies with higher resistivity than the surrounding soils, and negative values can be confidently interpreted as anomalies with resistivity that is lower than the surrounding soils. These anomalies should be evaluated as possible cultural features.

* The above procedures and descriptions apply in the absence of high-contrast anomalies. In the presence of high-contrast anomalies, conventional (linear) high- and low-pass filters introduce "processing anomalies," which can obscure the low-contrast anomalies of interest. When high-contrast anomalies are present, it is necessary to (1) replace the high-contrast data with dummy values by means of Search and Replace or (2) process the data with nonlinear high- and low-pass filters.

Stage III: Separating High/Positive and Low/Negative Resistivity Anomalies

The sign (positive=high resistivity, negative=low resistivity) of an anomaly after high-pass filtering is indicative of a feature's resistivity relative to the surrounding soil. Sign can be very useful in archaeological interpretations of anomalies. It is therefore generally useful to separate positive and negative anomalies into different files.

1. Positive vs. negative anomaly separation: To isolate the high resistivity anomalies, use the Clip routine to select all the positive data (specify 0 to 9999) and save the results to a new high resistivity data file. To isolate the low resistivity anomalies, use Clip to select all the negative data (-9999 to 0) and save to a new low resistivity data file.

Stage IV: Improving Anomaly Visibility

1. Noise reduction: A Low-Pass Filter can be applied to the uniformly sampled data file (end of Stage I Processing) or to the high-pass filtered data file. This is best done with a Gaussian weighted low-pass filter. Filter window diameter should be equal to or slightly greater than the anomaly dimension of interest for maximum noise reduction with minimum loss of anomaly detail.

Stage V: Statistically Significant Anomalies

When the signal-to-noise ratio is high, anomalies are easily recognized. As the signal-to-noise ratio approaches zero, it becomes increasingly difficult to recognize anomalies with any confidence because their probability distribution overlaps with the random background probability distribution. Figure 22 depicts data with three different signal-to-noise ratios and their associated probability distribution functions. At the lower signal-to-noise ratios the overlap is evident. Under these circumstances, it is useful to choose a threshold that can be used to statistically select anomalies with a known confidence level.

The standard deviation (STD) of the random background noise can be quantified by examining an anomaly-free region of the survey. Using this value, various thresholds (1 STD, 2 STD, 3 STD) and their associated levels of statistical confidence can be chosen. The Clip routine can then be used to select all anomalies greater than the desired threshold, resulting in a map of statistically significant anomalies at a known confidence level. For example, one can produce a map showing only those values greater than 3 STD above the mean. The statistical threshold approach allows one to detect anomalies in a replicable manner, and to

assign anomalies to categories based on the statistical thresholds. One does not know beforehand whether the strongest anomalies will tend to be associated with archaeological features, or whether the features will be manifested by very weak anomalies. By assigning the anomalies to threshold categories, however, one can develop a stratified sample of the anomalies for ground-truthing investigation.

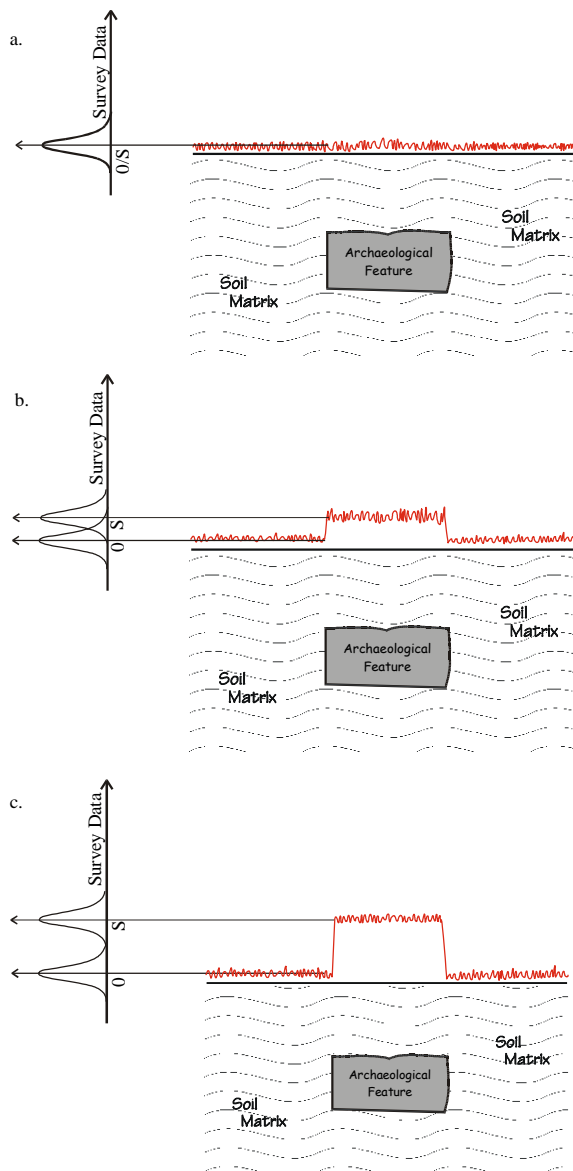


Figure 22. Schematic representation of (a) zero, (b) low, and (c) high signal-to-noise ratios with probability distribution functions shown on the left (S = signal, O = noise).

Magnetic Field Gradient Survey

There are two principal stages in magnetic field gradient data processing. The first stage is concerned with mapping strong magnetic anomalies, and the second is concerned with weak magnetic anomalies. Subsequent stages in processing are concerned with improving the visibility and interpretability of anomalies. Typical magnetic field gradient survey data processing sequences are discussed below. This discussion assumes a rudimentary familiarity with Geoscan magnetic instruments and Geoplot 3.0.

Stage I: Strong Magnetic Anomaly Processing

1. Merge the raw data: The initial step in data processing is to combine the data from individual survey grids into a composite file. This creates a graphic for the entire survey and enables all Geoplot 3.0 processing algorithms.
2. Edit or remove defective data: The major instrument and operator-induced defects are removed by means of the Zero Mean Traverse routine. Other defective data are usually replaced with the Geoplot dummy-value (2047.5) using Search and Replace.
3. Display and initial interpretation: Visually examine the composite map for anomalies and archaeological features of interest. Weak magnetic anomalies, if present in the data, will probably not be visible at this stage. Distinguish between fired soil features (e.g., hearths, burned houses, bricks, sherd concentrations) and the (usually) stronger ferrous-object-related features.

At this point, for high contrast ferrous-object-related features, processing has little more to offer. The objects have been detected and located. A detailed analysis of the strong magnetic anomalies is possible (Bevan 1998).

4. Interpolate the data: Interpolate the composite file to achieve an equal data sample density in the north-south and east-west directions. Interpolation will make it much easier to visually detect anomalies in the data. In Geoplot, the Interpolation function is used for both expansion and contraction. It is usually necessary to shrink the north-south data sample density by a factor of 2 or 4 depending on whether the data were collected at 8 or 16 data samples per linear meter, respectively. The east-west direction data density is usually increased by a factor of 2 using the $\sin(x)/x$ Interpolation option. The goal is to obtain an interpolated map with equal data sample density in both directions, typically 2 x 2 or 4 x 4 per meter.
5. Display and interpretation: Examine the uniformly sampled data file by means of grayscale, relief, trace, contour, or color plots as required.

Ferrous objects, brick clusters, and most historic features will be associated with the strong magnetic anomalies ($> \pm 10$ nT). Variations in the site soils, sediments and geology, as well as most prehistoric archaeological features and artifacts will be associated with the weak anomalies.

Stage II: Weak Magnetic Anomaly Processing

Stage II processing is concerned primarily with detecting very weak magnetic anomalies. Anomalies associated with disturbed soils and most prehistoric features generally have data values ranging from about -10 to +10 nT. To detect these weak anomalies, it is useful to replace all values greater than +15 nT and less than -15 nT with the dummy value (2047.5). This is accomplished using the Search and Replace routine.

The weak anomalies in the data will now be apparent. Weak positive anomalies at prehistoric sites are often associated with hearths, pits, and fire-altered rock. Weak negative magnetic anomalies are often associated with iron oxide-free materials within iron oxide-rich soils, e.g., limestone/rock concentrations, etc.

Stage III: Separating Positive and Negative Magnetic Anomalies

1. Positive vs. negative anomaly separation: To isolate the positive magnetic anomalies, Clip the data from 0 to 9999, and save those (positive) data in a new file. To isolate the negative magnetic anomalies, reload the (unclipped) high-pass filtered data, Clip from -9999 to 0, and save the (negative) data to a new file.

At this point in the processing sequence, positive data will be assembled in one file and negative data will be assembled in another file.

Stage IV: Improving Anomaly Visibility

At this stage, the very weak (-1.5 nT to +1.5 nT) anomalies are of most interest. If the data sample density in the survey was adequate, it will be possible to apply the Low Pass Filter routine with useful effect. Typically, a uniformly weighted low-pass filter with a window of 1-4 m in diameter is used. The result is a significant reduction in random (instrument, geology, operator) data defects. Defects can be reduced by factors of 3 (1/3) to 5 (1/5). By reducing the amplitude of the random component, the signal-to-noise ratio is improved, and the weak anomalies become better defined. Statistically significant values smaller than 0.1 nT can be confidently mapped and interpreted. The Low-Pass Filter reduces the spatial resolution (detail) in the filtered map. It is important to set the Low-Pass Filter window dimension to be the same as the anomaly of interest. For

example, if one hopes to identify weak anomalies associated with pit features that average about 1 meter in diameter, the Low Pass Filter window would be set at 1 meter.

Stage V: Statistical Significance and Thresholds

When the signal-to-noise ratio is high, magnetic anomalies are easily recognized. As the signal-to-noise ratio approaches zero, it becomes increasingly difficult to recognize anomalies with any confidence. This is because their probability distributions overlap with the random background probability distribution. Figure 22 depicts data with three different signal-to-noise ratios and their associated probability distribution functions. The overlap between the distributions is evident. Under these circumstances, it is useful to choose a threshold that can be used to statistically select anomalies with a known confidence level. The approach used with magnetic data is essentially the same as that described above for resistivity data.

9 Annotated Bibliography

De Vore (n.d.) has compiled a very extensive bibliography organized by subtopics relevant to archaeological geophysics. Rather than partially duplicating that effort, this chapter (ATAGS Supplemental Document 6) provides brief annotations of highly selective recent references. All of those included in the **General References** section are good, relatively nontechnical introductions and overviews suitable for ATAGS users. The **Instructional** and **Case Studies** sections should also be of interest to ATAGS users and survey sponsors, as well as to other archaeologists seeking a greater familiarity with geophysical applications. Many of the other sections include references directed at the professional geophysical community. These are included to benefit those who may wish to read more widely and in greater depth. Note that many older books and articles are not listed here. These can be found in the references cited by the **General References**. Many of the older references remain important sources.

Despite an increased use of geophysics by U.S. archaeologists, there continue to be few case studies in the major archaeological journals. Brief summaries with maps of many recent surveys can be found on WWW sites maintained by Archaeo-Physics (2003), Cultural Resource Analysts (2003), and Kvamme (2003), among others.

General References

Bevan, Bruce W. 1998. *Geophysical Exploration for Archaeology: An Introduction to Geophysical Exploration*. Midwest Archeological Center Special Report No. 1, U.S. Department of the Interior, National Park Service, Lincoln, NE.

Bevan provides valuable guidance on magnetic, resistivity, conductivity, GPR, and self-potential surveys. Most examples concern historic (particularly Civil War) sites. The discussion on interpreting magnetic anomalies is particularly useful. Graphical presentation is not state-of-the-art, but content is excellent. All individuals interested in learning to conduct their own surveys, as well as those who want to learn how to work effectively with geophysical consultants should read this volume.

Clark, Anthony. 1996. *Seeing Beneath the Soil: Prospecting Methods in Archaeology*. B.T. Batsford, London.

A standard reference since its initial publication in 1990, with its 1996 revision, this volume continues to be one of the most useful resources for archaeologists interested in geophysics. Resistivity, magnetometry, and magnetic susceptibility are accorded relatively extensive treatment, whereas GPR is covered rather briefly, as are other methods. Sections on site and method selection, data interpretation, and processing are useful.

Conyers, Lawrence B., and Dean Goodman 1997. *Ground-Penetrating Radar, An Introduction for Archaeologists*. Altamira Press, London.

This volume provides a comprehensive but largely nontechnical introduction to GPR for archaeologists. Particularly valuable is the extended treatment of amplitude analysis, which allows production of time-slice (horizontal) maps and 3-D images of survey results. Also valuable is the discussion of the potential for using GPR to detect various types of targets.

David, Andrew. 1995. *Geophysical Survey in Archaeological Field Evaluation*. Research & Professional Services Guideline No. 1, Ancient Monuments Laboratory, English Heritage Society, London.

This monograph is well worth any modest trouble the U.S. resident may have in acquiring a copy. To date, no other brief monograph offers such broad coverage of issues relevant to survey sponsors. Considerable attention is devoted to choosing the appropriate technique. A table that matches survey techniques to types of archaeological features is very useful, as is another table concerned with the response of various geological deposits to magnetic survey. Also valuable are discussions of major processing techniques and recommendations for report content.

Heimmer, Don H., and Steven L. De Vore 1995. *Near-Surface, High Resolution Geophysical Methods for Cultural Resources Management and Archaeological Investigations* (revised edition). U.S. Department of the Interior, National Park Service, Rocky Mountain Regional Office, Interagency Archeological Services, Denver, CO.

This volume provides a very useful, nontechnical overview of the most widely used geophysical techniques (magnetics, electrical resistivity,

GPR, metal detectors), as well as some that are less common and, in some cases, rather specialized (self-potential, gravitational, acoustic). There are separate chapters on topics such as quality control, administrative requirements, and project planning. The appendices include a collection of data sheets and marketing flyers for a variety of instruments. Surveyors and survey sponsors will find this to be a very readable and useful source of information.

Heimmer, Don H., and Steven L. De Vore 1995. "Near-Surface, High Resolution Geophysical Methods for Cultural Resources Management and Archaeological Investigations." In, *Science and Technology in Historic Preservation*, edited by Ray A. Williamson and Paul R. Nickens, pp 53-74. Kluwer Academic / Plenum Publishers, NY.

While this chapter has the same title as the monograph discussed above, it has been revised somewhat. Like the monograph, this chapter provides a useful and nontechnical overview of the leading methods: magnetics, resistivity, conductivity, GPR, and metal detecting. Several maps exemplifying survey results are provided, but the monograph's useful appendices have been omitted. Where the monograph is somewhat more comprehensive, this chapter is highly readable and will prove useful to both surveyors and survey sponsors.

Herz, Norman, and Ervan G. Garrison. 1998. "Archaeogeophysical Exploration," In *Geological Methods for Archaeology*, pp 147-180.

This chapter provides a somewhat more technical overview of the standard techniques in archaeogeophysics, as well as seismic reflection and refraction, microgravity, and thermography. Compared to the others in this section, this source offers a somewhat more thorough discussion of basic principles but less focus on field applications. The graphics are informative but do not reflect the advances that have been made in imaging in recent years.

Kvamme, Kenneth L. 2001. "Current Practices in Archaeogeophysics: Magnetism, Resistivity, Conductivity, and Ground-Penetrating Radar." In *Earth Sciences and Archaeology*, edited by Paul Goldberg, Vance T. Holliday, and C. Reid Ferring, pp 353-382. Kluwer Academic / Plenum Publishers, NY.

This chapter is one of the single-most valuable introductions to the four most commonly used geophysical methods: magnetism, resistivity, electromagnetics, and GPR. Particularly useful is a table that

concisely compares the advantages and disadvantages of these techniques, including costs, coverage rates, and the effects of trees and metal. A group of case studies includes both prehistoric and historic sites. A glossary provides nontechnical definitions for a number of key terms.

Instructional

Hesse, A. 1999. "Multi-Parametric Survey for Archaeology: How and Why, or How and Why Not?," *Journal of Applied Geophysics*, Vol. 41, pp 157-168.

Discusses situations when using multiple geophysical techniques may or may not be necessary, depending on time and cost restraints and knowledge of the site. An example is presented for each of five situations: (1) When little or no a priori knowledge is available concerning the subsurface conditions and features of interest. Multiple methods are often required to adequately characterize the site. (2) With a priori knowledge of features existing at the site and expected response of geophysical measurements. In this case, the use of multiple techniques probably is not necessary and would be strictly complementary. (3) The use of individual methods, when considered independently, will not provide clear answers because it is possible for different features to produce a similar response for a given geophysical instrument. However, by considering a suite of complimentary data sets, it is possible to properly interpret the data and successfully characterize the site. (4) When validating a new method or tool. It is then necessary to compare the experimental results with those acquired using a proven technique. (5) Generally involving large explorations, several methods are tried within a limited area and, based on that data set and on time and cost considerations, the method best suited for surveying a large area in a minimum amount of time is chosen.

Dalan, R.A. and S.K. Banerjee. 1998. "Solving Archaeological Problems Using Techniques of Soil Magnetism," *Geoarchaeology: An International Journal*, Vol. 13, No. 1, pp 3-36.

An introduction to the magnetic properties of soils and techniques to measure these properties is presented. Soil magnetic measurements at archaeological sites have applications regarding (1) site boundaries, activity areas, and features, (2) site morphology, (3) sedimentation

and erosion processes, (4) correlating stratigraphic sequences, and (5) climatic data. Examples of each application and a case study are given.

McNeill, J.D. 1996. *Why Doesn't Geonics Limited Build a Multi-Frequency EM31 or EM38?*, Technical Note TN-30, Geonics Limited, Mississauga, Ontario, Canada.

McNeill discusses why Geonics Limited does not offer a multi-frequency electromagnetic instrument (frequency domain [FD]). First he states two reasons that a multi-frequency instrument is desirable: (1) to allow mapping of a multi-layered earth and (2) for improving discrimination and identification of metallic targets. McNeill proceeds to explain why it is theoretically not feasible to build a multi-frequency FD instrument. To resolve a multi-layer earth, it is necessary that a multi-frequency FD instrument have a frequency range into the megahertz (MHz) and that the skin depth of the highest frequency be significantly less than that of the transmitter-receiver coil spacing. If the frequency range does not span sufficiently high frequencies, then equivalence (different layer models can satisfy the same data) becomes a problem. Also, the task of accurately setting and maintaining the instrument zero becomes more difficult as additional frequencies are added.

A multi-frequency FD instrument also does not enhance the ability to detect buried metal objects. The primary induced field generates both an eddy current response and permeability response in a metal target. These two responses are orthogonal. The received signal is thus a combination of two sets of induced magnetic dipoles, each having a different in-phase / quadrature phase ratio, which complicates the interpretation.

McNeill suggests that a time domain system overcomes the problems inherent with a multi-frequency electromagnetic instrument.

Case Studies

Arnold, Jeanne E., Elizabeth L. Ambos, and Daniel O. Larson. 1997. "Geophysical Surveys of Stratigraphically Complex Island California Sites: New Implications for Household Archaeology." *Antiquity* 71, pp 157-68.

GPR and cesium vapour magnetometer surveys at Chumash sites on the California Channel Islands detected relatively ephemeral house floors despite the rather complex cultural stratigraphy.

Baker, J.A., N.L. Anderson, and P.J. Pilles. 1997. "Ground-Penetrating Radar Surveying in Support of Archaeological Site Investigations," *Computers and Geosciences*, Vol 23, No. 10, pp 1093-1099.

Describes GPR survey in two diverse geologic environments, one containing soils derived from volcanic clastics and limestone bedrock, and the other beach sand. A 500-MHz antenna was used and was successful in imaging the archaeological features of interest in both environments. In the beach environment, the GPR was also able to map the contact between the unsaturated and saturated sands.

Frederick, Charles D., and James T. Abbott. 1992. "Magnetic Prospection of Prehistoric Sites in an Alluvial Environment: Examples from NW and West-central Texas." *Journal of Field Archaeology*, Vol 19 (1992), pp 139-153.

Surveys using two Geometrics G856X proton precession magnetometers demonstrated that prehistoric features and artifacts could be detected in alluvial deposits in Texas. Feature types included hearths, concentrations of burned rocks, and a burned post. The range of variation in anomalies associated with small metal objects was broader but overlapped with those of the prehistoric targets. Use of a metal detector is recommended to remove recent metal objects prior to systematic geophysical surveys. Some prehistoric features were not detected, suggesting that negative findings should be verified by traditional archaeological investigations.

Hargrave, Michael L., Lewis E. Somers, Thomas K. Larson, Richard Shields, and John Dendy. 2002. "The Role of Resistivity Survey in Historic Site Assessment and Management: An Example from Fort Riley, Kansas." *Historical Archaeology* 36(4), pp 89-110.

A large area (9 hectares), low-density electrical resistivity survey was conducted at the World War I era Army City entertainment complex at Fort Riley, KS. This survey is used as a vehicle for discussing the benefits of geophysics in the investigation and management of large and complex historic sites. Some of the widely perceived liabilities (cost and risk) of geophysics are all addressed.

Sambuelli, L., L.V. Socco, and L. Brecciaroli. 1999. "Acquisition and Processing of Electric, Magnetic and GPR data on a Roman Site," *Journal of Applied Geophysics*, vol 41, pp 189-204.

Four geophysical techniques (magnetic, electromagnetic, resistivity and GPR) are used to investigate a Roman archaeological site. The limited contrast in geophysical properties of the soil and targets, and alteration of the soil due to agricultural activities emphasizes the need for multiple geophysical methods for identifying the archaeological features/structures.

Slepek, Z. 1999. "Electromagnetic Sounding and High-Precision Gravimeter Survey Define Ancient Stone Building Remains in the Territory of Kazan Kremlin (Kazan, Republic of Tatarstan, Russia)." *Archaeological Prospection*, Vol. 6, Issue 3, pp 147-160.

Describes successful use of electromagnetic sounding and gravimetry in a high cultural environment. The two geophysical methods proved to be complimentary in detecting remains of stone buildings and discontinuities in the cultural layer. The geophysical investigation allowed mapping of the archaeological features without site damage, whereas subsidence after backfilling of previous archaeological excavations caused changes to groundwater conditions that adversely affected the architecture and walls of the Kremlin.

Lopez-Loera, H., J. Urrutia-Fucugauchi, J.L. Comparan-Elizondo, R. Castillo-Torres, Ponce-Juarez, A.M. Jarquin-Pacheco, and E. Matinez-Vargas. 2000. "Magnetic Study of Archaeological Structures in La Campana, Colima, Western Mesoamerica," *Journal of Applied Geophysics*, Vol. 43, No. 1, pp 101-116.

Vertical magnetic gradient surveys identify numerous anomalous areas. Some of the anomalies correspond to topographic highs and excavations reveal small pyramids and a larger complex. A linear magnetic anomaly reveals part of a water channel network.

Basile, V., M.T. Carrozzo, S. Negri, L. Nuzzo, T. Quarta, and A.V. Villani. 2000. "Ground-Penetrating Radar Survey for Archaeological Investigations in an Urban Area (Leece, Italy)," *Journal of Applied Geophysics*, Vol 44, No. 1, pp 15-32.

A GPR survey was conducted prior to an archaeological investigation to aid in the location of possible subsurface features. The survey was conducted in an urban environment known to contain historical and ancient ruins. The GPR profiles successfully mapped the suspected location of structures and identified previously unknown historically significant features.

Instrumentation

Dalan, Rinita A. 2001. "A Magnetic Susceptibility Logger for Archaeological Application," *Geoarchaeology: An International Journal*, Vol 16, No. 3, pp 263-373.

The measurement and interpretation of magnetic susceptibility values have been used at archaeological sites to aid in defining the site boundaries, identifying features within the site, and the soil and cultural strata. Presently, there are no magnetic susceptibility instruments available for acquiring in-situ data at shallow depths. A prototype magnetic susceptibility instrument has been designed and field-tested for obtaining relatively rapid volume susceptibility measurements to depths of 1.6 m. The prototype is housed in a Bartington Instruments MS2F probe. Field tests have shown the prototype to be stable and provide reproducible readings.

Fiorani, L., M. Bortone, S. Mattei, C. Ruocchio, A. Salome, and S. Vetrella. 2000. "Miniaturized Electro-optical Sensors for Archaeological Prospecting," *Proceedings of SPIE—The International Society for Optical Engineering Subsurface Sensing Technologies and Applications II*, July 31-August 3, San Diego, CA, Vol 4129, pp 442-446.

The GEOSCOPE is a combination coring machine and probe. The parameters measured while coring are bit angle, penetration, draught-push, and torque pressures. Once the soil core and bit have been removed from the hole, the color camera is inserted. Sensors on the camera include a hygrometer, two thermometers, two inclinometers, and an electronic compass. The camera provides high-resolution images.

Silliman, Stephen W., Paul Farnsworth, and Kent G. Lightfoot. 2000. "Magnetometer Prospecting in Historical Archaeology: Evaluating Survey Options at a 19th-Century Rancho Site in California." *Historical Archaeology* 34(2), pp 89-109.

Three types of magnetic sensor were compared: the Geometrics 858 Cesium alkali vapor magnetometer, the Geometrics 858 Cesium alkali vapor gradiometer, and the Geometrics 856AX proton precession gradiometer. The alkali vapor magnetometer and gradiometer were found to be clearly superior to the proton precession magnetometer in terms of speed and efficiency of data collection, potential data density, sensor sensitivity, and data clarity. Tests also suggest that the gradiometer arrangement is superior to total field surveys in terms of anomaly definition and placement. Sensor height, gradiometer configuration, and proper base station correction are important factors in optimizing data quality.

Won, I.J., D.A. Keiswetter, G.R.A. Fields, and L.C. Sutton. 1996. "GEM-2: A New Multifrequency Electromagnetic Sensor," *Journal of Environmental and Engineering Geophysics*, Vol 1, No. 2, pp 129-137.

A bistatic, multifrequency electromagnetic instrument, GEM-2, is introduced. The GEM-2 is capable of collecting data at several frequencies, ranging from 90 Hz to 22 kHz, during a single measurement. This is achieved using the pulse-width modulation technique where the selected frequencies are converted into a digital bit stream and combined to form the desired transmitter waveform. The use of multifrequency surveying allows different depths of investigation to be interrogated simultaneously. The GEM-2 has applications in near-surface geophysical investigations.

Won, I.J., D.A. Keiswetter, D. Hanson, E. Novikova, T. Hall. 1997. "GEM-3: A Monostatic Broadband Electromagnetic Induction Sensor," *Journal of Environmental and Engineering Geophysics*, Vol 2, No. 1, pp 53-64.

A monostatic, multifrequency electromagnetic instrument, GEM-3, is described. The circular sensor uses three concentric coils, two transmitter coils, and one receiver coil. One transmitter coil acts as a bucking coil to create a magnetic cavity in the center where the receiver coil is placed to detect the weak secondary magnetic field. The monostatic design allows for a larger transmitter moment, greater spatial resolution, and no spatial distortion of the anomaly common in bistatic sensors. The GEM-3 is capable of collecting data

at several frequencies during a single measurement. This is achieved using the pulse-width modulation technique where the selected frequencies are converted into a digital bit stream and combined to form the desired transmitter waveform. The use of multifrequency surveying allows different depths of investigation to be interrogated simultaneously. The GEM-3 is suitable for shallow geophysical investigations.

Survey Methods

Bevan, Bruce W. 1992. *Geophysics* 56(9), pp 1310-1319.

Results from surveys of nine historic cemeteries provide a basis for discussing the effectiveness of alternative geophysical techniques. GPR had the greatest success in detecting graves. The best conditions include sites with few underground objects, little or no stratification, and high resistivity. Unfavorable conditions include complex stratigraphy and highly conductive clayey soil. Electrical conductivity was also effective in detecting graves in some situations. Favorable conditions include an absence of metallic debris and the presence of distinct stratification. Magnetic and resistivity techniques were not very useful for these sites.

Dalan, Rinita A., and Subir K. Banerjee. 1996. Soil Magnetism, an Approach for Examining Archaeological Landscapes. *Geophysical Research Letters*, Vol. 23, No. 2, pp 185-188.

At Cahokia, changes in magnetite concentration and grain size provide a basis for differentiating natural soils from clayey swales and sand ridges, culturally produced (midden) soils, and soils that were culturally mixed and transported. This differentiation was based on the ARM/X method. Results included the identification of reclaimed borrow areas and buried ridge and swale features, providing a new appreciation of the nature, scale, and dynamics of human impact on the Cahokia landscape. Magnetic techniques such as this provide a cost-effective, noninvasive approach for investigating cultural landscapes at various spatial scales.

Panissod, D., M. Lajarthe, A. Tabbagh. 1997. "Potential Focusing: a New Multielectrode Array Concept, Simulation Study, and Field Tests in Archaeological Prospecting," *Journal of Applied Geophysics*, Vol 38, No. 1, pp 1-23.

A resistivity array based on the pole-pole array allows focusing of the signal to obtain better definition of subsurface structures. The new array IFMPP (isotropic focused multipole-pole) consists of a central electrode surrounded by four potential electrodes. For ease of use in the field, it is possible to acquire the data implementing two orthogonal pole-pole surveys and averaging the four pole-pole measurements. Both synthetic and field data for Wenner, dipole-dipole, pole-pole, and IFMPP arrays were compared. The IFMPP array was shown to resolve subsurface structures better than the other arrays.

Kampe, A. 1999. "Focused Imaging of Electrical Resistivity Data in Archaeological Prospecting," *Journal of Applied Geophysics*, Vol 41, pp 215-227.

Compares different focused Wenner array arrangements to determine the optimum array for delineating subsurface features. Half-Wenner arrays perform best for identifying anomaly shape and resistivity contrast. Focused image result is similar to inversion image, but recommends performing inversion to obtain more accurate depth, shape, and resistivity contrast.

Luke, B.A. and J.E. Brady. 1998. "Application of Seismic Surface Waves at a Pre-Columbian Settlement in Honduras," *Archaeological Prospection*, Vol 5, Issue 3, pp 139-157.

A surface seismic wave technique, spectral-analysis-of-surface-waves (SASW), is tested at an archaeological site in Honduras to determine its applicability toward locating subsurface burial chambers. In the limited time available for the geophysical investigation, which also included electrical resistivity and magnetic surveys, no burial chambers were discovered. However, other features were detected, including riverine cobbles, a stone monument, and a fill layer at depth. The fill layer was found to be a result of human construction and is the most significant discovery at the site.

Data Processing

Pipan, M., L. Baradello, E. Forte, A. Prizzon, and I. Finetti. 1999. "2-D and 3-D Processing and Interpretation of Multi-Fold Ground Penetrating Radar Data: a Case History from an Archaeological Site," *Journal of Applied Geophysics*, Proceedings of the 1997 1st International Workshop on Electric, Magnetic and Electromagnetic Methods Applied to Cultural Heritage, September 29–October 1, 1997, Ostuni, Italy, Vol. 41, No. 2, pp. 271-292. Elsevier Science Publishers, B.V., Amsterdam, The Netherlands.

Single-fold and multi-fold GPR data were acquired at an archaeological site in northern Italy. The multi-fold data were collected to demonstrate the improvement in subsurface images obtained for a high-resolution study. The signal-to-noise ratio was reduced and both lateral and vertical velocity variations could be determined.

Leckebusch, J. 2000. "Two- and Three-Dimensional Ground-Penetrating Radar Surveys Across a Medieval Choir: a Case Study in Archaeology," *Archaeological Prospection*, Vol 7, Issue 3, pp 189-200.

A GPR survey was undertaken to determine what historical structures existed beneath a church choir. Profiles were performed in orthogonal directions in one area to obtain a high-resolution data set. Velocities of the subsurface materials were evaluated using four techniques: common midpoint, shape of diffraction hyperbolas, time domain reflectometry, and core samples using a network analyzer. Estimation of velocity based on diffraction hyperbolas gave adequate results and was the fastest and easiest technique. Migration of the data allowed the depth and lateral extent of the structures to be resolved.

Moriyama, T., M. Nakamura, Y. Yamaguchi, H. Yamada, and W. Boerner, 1999. "Classification of Target Buried in the Underground by Radar Polarimetry," *IEICE Transactions on Communications*, Vol. E82-B, No. 6, pp 951-957.

The polarimetric images (VH, VV, HH) of FM-CW radar data are used to distinguish between isotropic and anisotropic targets. Plots of the power polarization anisotropy coefficient and polarimetric power signature aid in differentiating the target from clutter and identifying whether the target has an isotropic (plate, sphere) or anisotropic (wire, pipe) signature.

Software

Cooper, G.R.J. 1997. "GravMap and Pfproc: Software for Filtering Geophysical Map Data," *Computers and Geosciences*, Vol. 23, No. 1, pp 91-101.

Describes two DOS-based software programs, GravMap and Pfproc, that are available free of charge via anonymous FTP from ftp.cs.wits.ac.za in directory /pub/general/geophys, or from the server at IAMG.ORG. The programs are designed for small data sets up to 5000 points or for teaching purposes. A variety of frequency domain and spatial domain filters are available. The frequency domain filters include vertical continuation, strike filtering, vertical derivatives, and pole reduction. Spatial domain filters include polynomial surface fitting, edge enhancement, sun-shading, and low-pass and high-pass filters. Other features provided are extraction of a profile from a map and histogram equalization, in which the data are contoured based on an equal number of points within an interval.

Nath, S.K., S. Shahid, and P. Dewangan. 2000. "SEISRES--a Visual C++ Program for the Sequential Inversion of Seismic Refraction and Geoelectric Data," *Computers and Geosciences*, Vol 26, No. 2, pp 177-200.

The SEISRES program is a sequential inversion scheme that first inverts seismic refraction data to obtain subsurface velocity and interface depths and then uses the depth values to iteratively invert resistivity data. The combined inversion presents a more realistic subsurface layer model. Program code is available at <http://www.iamg.org/CGEditor/index.htm>. The seismic inversion utilizes ray inversion for near surface estimation (RINSE), whereas resistivity inversion uses an evolutionary programming technique. SEISRES is also capable of generating forward models and performing separate seismic or resistivity inversion of a data set.

Geoscan Research. 2000. *Geoplot Version 3.00 for Windows, Instruction Manual Version 1.0* March 2000. Geoscan Research, Heather Brae, Chrisharben Park, Clayton, Bradford, BD14 6AE, UK.

The Geoplot 3.0 software was developed for use with Geoscan instruments such as the FM-36 and FM-256 fluxgate gradiometers and RM-15 electrical resistance systems. Geoplot 3.0, like these instruments, is specifically designed for use in archaeological applications. The software can also be used to process data collected

using a wide range of other instruments. Processing routines include low and high pass filters, median and periodic filters, interpolation, despiking, edge matching, zero mean traverse and destagger corrections, etc. Geoplot 3.0 provides a variety of data presentation options, including image and contour maps, data density and pattern plots, and trace profiles.

Algorithms

Huang, H., and I.J. Won. 2000. "Conductivity and Susceptibility Mapping Using Broadband Electromagnetic Sensors," *JEEG*, Vol 5, Issue 4, pp 31-41.

Determination of apparent conductivity and apparent susceptibility from multi-frequency electromagnetic data. These data are generally presented as quadrature and in-phase components in units of parts per thousand (ppt). Five algorithms are applied to the synthetic data sets to determine the optimum method. The five techniques are quadrature, in-phase, phase, amplitude, and phase-amplitude. For determining the apparent conductivity and apparent susceptibility, the phase-amplitude algorithm is the most stable and uses all available data.

Modeling

Bell, T.H., B.J. Barrow, J.T. Miller. 2000. "Subsurface Discrimination Using Electromagnetic Induction Sensors." In *Subsurface Sensing Technologies and Applications II*, edited by Cam Nyugen, Proceedings of SPIE, Vol 4129.

Discrimination of subsurface objects is addressed. Electromagnetic induction sensor data, both time and frequency domain, are modeled using an induced dipole. To quantify an unknown object in the subsurface, multi-axis data are required to begin to differentiate objects of different size, shape, and material composition. Although the paper focuses on the discrimination of unexploded ordnance from clutter, similar techniques could have applications in archaeology.

Keiswetter, D., B. San Filippo, I.J. Won, J. Miller, T. Bell, E. Cespedes, and K. O'Neill. 2000. "Discriminating Capabilities of Multifrequency EMI Data." In *Subsurface Sensing Technologies and Applications II*, edited by Cam Nyugen, Proceedings of SPIE, Vol. 4129.

A multi-frequency electromagnetic instrument (GEM-3, Geophex) is used to demonstrate the differences in response of various unexploded ordnance and non-ordnance items. By modeling the in-phase and quadrature components using parameters related to the target orientation and depth and comparing the response to a library of data collected over known items, it is possible to begin to discriminate between types of targets and eventually to identify the target. These same techniques may be applicable to archaeological investigations.

Tsokas, G.N and R.O. Hansen. 2000. "On the Use of Complex Attributes and Inferred Source Parameter Estimates in the Exploration of Archaeological Sites," *Archaeological Prospection*, Vol 7, Issue 1, pp 17-30.

Uses complex attribute analysis of magnetic data to determine parameters such as dip, azimuth, susceptibility, and depth of buried archaeological features. Models anomalies as 2-D structures using slab and corner models. Slab model produced the best results and the analysis procedure performs best in low noise environments.

Tsokas, G.N., and C.B. Papazachos. 1992. "Two-Dimensional Inversion Filters in Magnetic Prospecting: Application to the Exploration for Buried Antiquities," *Geophysics*, Vol 57, No. 8, pp 1004-1013.

The total magnetic field is modeled as the convolution of an anomaly amplitude function and anomaly shape function. The basic model used for generating these functions is a vertical prism, which is representative of many archaeological targets. The inversion locates the center of the subsurface target and is moderately successful in determining the lateral extent of the feature.

Desvignes, G., A. Tabbagh, and C. Benech. 1999. "The Determination of the Depth of Magnetic Anomaly Sources," *Archaeological Prospection*, Vol 6, Issue 2, pp 85-105.

Four methods are evaluated for determining the depth of a magnetic anomaly. The methods are: (1) determination of the equivalent dipole, (2) Euler deconvolution, (3) location of the center of magnetization and determination of the total magnetic moment of a feature, and (4)

downward continuation of the equivalent stratum magnetization. Euler deconvolution provided the best results and an index of $N=2$ is generally suitable for most archaeological features.

Knight, R., P. Tercier, and H. Jol. 1997. "The Role of Ground Penetrating Radar and Geostatistics in Reservoir Description," *The Leading Edge*, Vol. 16, No. 11.

Ground penetrating radar data are analyzed using geostatistical methods to characterize different depositional environments (deltaic, coastal, and fluvial). Geostatistics is a method for modeling the spatial variability of data. The analysis describes the large-scale sedimentary features, but information on the smaller sub-meter scale that is visible in the radar record was lost. The geostatistical approach is useful for linking geologic point information, such as that obtained from well logs. Future studies will aid in determining if different depositional environments have a characteristic geostatistical signature that could be exploited in areas where little or no geologic information is available.

10 Glossary

Several recent monographs and articles provide useful, nontechnical overviews of the various geophysical methods used in archaeology (Bevan 1998; Conyers and Goodman 1997; Heimner and De Vore 1995; Kvamme 2001). Additional information useful to geophysical practitioners and survey sponsors can be found on several WWW sites (Archaeo-Physics 2003; Kvamme 2003). No attempt is made here to duplicate those sources. Instead, the present chapter provides concise, nontechnical definitions and descriptions of selected instruments, units of measure, types of maps and images, and basic concepts.

Instruments

Magnetometer: An instrument used to measure the localized value of Earth's magnetic field. Proton precession magnetometers were among the earliest magnetic instruments used in archaeological geophysics. Geoscan Research and Geometrics manufacture fluxgate and cesium magnetometers (respectively) that are widely used by archaeologists.

Gradiometer: An instrument used to measure the gradient in Earth's magnetic field. A gradiometer measures the difference in values detected by two magnetometers separated by a small distance. Geoscan Research and Geometrics manufacture gradiometers that are widely used in surveys of archaeological sites.

Ground penetrating radar: An active geophysical method wherein low frequency (80-1000 megaHertz) microwave (radar) energy is transmitted into the Earth by an antenna that is in contact with the surface. The signal is differentially reflected or attenuated by discontinuities associated with changes in soil dielectric properties. The reflected signal is compared to the original input signal. Geophysical Survey Systems, Inc. (GSSI) and Sensors & Software, Inc. manufacture GPR systems popular among archaeologists.

Electrical resistance: An active geophysical survey technique that injects a current into the earth to measure soil resistance. Resistance surveys of archaeological sites are typically conducted using Geoscan RM-15 resistance meters. The

Geoscan MPX-15 multiplexor, when used in conjunction with the RM-15, permits the rapid collection of data for multiple depths and/or multiple readings for a single depth.

Electromagnetic conductivity: In this active geophysical survey technique, radio frequency energy is transmitted into the ground, inducing a current and secondary magnetic field measured by a receiver. Conductivity is measured in milliSiemens/meter (NADAG). The Geonics EM-38 is a widely used instrument.

Units of Measure

NanoTesla: A unit of magnetic intensity, equal to one gamma.

Gamma: A unit of magnetic intensity, equal to one nanoTesla.

Ohms: A unit of electrical resistance.

MilliSiemens: A unit of electrical conductivity

Megahertz: A unit of frequency, equal to one million hertz or one million cycles per second.

Images and Maps

Contour map: A map in which lines are used to demarcate areas characterized by similar geophysical values.

Image map: A continuous scale map in which geophysical values are associated with color or gray-scale gradients. Gray-scale image maps are similar in appearance to coarse-grained black and white photographs.

Time slice: A map based on GPR data that pertains to a particular depth interval. Multiple time slices can be used to create a 3D image of the survey area.

Geoplot 3.0: A software package distributed by the manufacturers of Geoscan Research instruments that is optimized for archaeological applications.

Surfer: Software distributed by Golden Software that is frequently used to produce final maps for data initially processed in Geoplot.

Basic Concepts

Anomaly: A discrete area characterized by geophysical values that differ from those of its surroundings. An anomaly suggests the presence of a localized geological, biological, or archaeological feature with physical properties that differ from the surrounding soils.

Signal: That portion of a geophysical data value that is directly related to the archaeological record/feature.

Noise: Random variation in the geophysical data. Noise typically results from the instrument itself, the surveyor's field technique, and the soil.

Clutter: A nonrandom component to geophysical data that is not related to the archaeological record. Sources of clutter may include tree roots, rodent burrows, rocks, bedrock, clay lens, sand lens, etc.

Signal to noise ratio: The ratio of the geophysical signal value associated with a feature to the magnitude of the random component of the background data, i.e., the standard deviation of the random component of the background data. The signal-to-noise ratio must be greater than 1 (preferably, much greater) for a feature to be detected.

Contrast: The degree to which the geophysical value (e.g., resistivity, susceptibility, etc.) of a feature of interest differs from the geophysical value of the surrounding soil matrix.

Dynamic range: The ratio between the magnitude of the random component of the survey background data (typically the standard deviation of a "quiet area") and maximum data value (signal) present in the survey (typically that associated with a high contrast feature).

Transect: A line defined within a geophysical survey grid along which data are collected at regular intervals.

Block: A square (or rectangular) portion of the survey area. For example, a survey area measuring 100 by 100 meters might be comprised of twenty-five 20 by 20 meter blocks.

Detection: Identification of an anomaly in a geophysical survey.

Recognition: Assignment of an anomaly to a meaningful category, such as “pit,” “house basin,” etc.

Ground truthing: Verification of the nature of the subsurface entity associated with a geophysical anomaly by independent means. Ground truthing typically involves excavation, but it is also possible to ground truth an anomaly using another geophysical technique, historic maps, etc.

Contrast enhancement: Enhancing the detail visible in an image by redistributing the range of gray tones or color values. For example, to increase contrast in a gray tone image, one might reduce the range of data values between mid-range gray and black.

Magnetic susceptibility: A material’s ability to become magnetized. Human occupation can increase the magnetic susceptibility of a site’s soil through the addition of organic material and burning.

Basic Issues

Survey area: The portion of a site subjected to geophysical survey.

Survey design: The strategy used in a geophysical survey, including choices of instrument, instrument configuration and settings, and the density and spatial distribution of data collection points.

Data density: The number of data values collected per unit area (typically, per square meter). Data density is typically positively correlated with signal-to-noise ratio, potential for detecting anomalies, and survey cost.

Survey purpose: The goals of the survey in terms of information return. Goals may range from a determination that at least some large features are present to a very detailed mapping of a wide range of feature types. Survey purpose is a primary determinant of survey design and is closely related to survey cost.

11 Effective Statements of Work

Most archaeologists and Cultural Resources Managers have neither the time nor the inclination to learn to conduct their own geophysical surveys. Such individuals can, however, gain access to the potential benefits of geophysical techniques by learning to make effective use of professional geophysical consultants. In most cases, the services of a consultant are acquired by means of a contractual agreement. In all cases, this should be based on a well-designed SOW. A good SOW is generally quite specific in some ways (e.g., in terms of the information it provides about site conditions), but may be rather general in other areas. For example, it is wise to write a SOW that provides considerable flexibility for the geophysicist, but which nevertheless stipulates the amount and quality of the work to be accomplished.

This chapter begins with general advice on preparing an effective SOW. It then offers two examples of SOWs that were actually used by ERDC/CERL. These examples are certainly not perfect, but their substance has not been altered using the wisdom of hindsight. Certain details (the names of individuals, installations, and sites) have been removed, but the content is essentially intact.

General Guidance

Federal and state agencies have their own format and boilerplate text for SOW. Although the terminology and section headings will vary, the topics addressed below should be addressed in a well-conceived SOW.

- 1. BACKGROUND:** The information provided by the sponsor in this section will help the geophysical consultant design an effective and reasonably priced survey. By taking the time to provide accurate and complete information, the sponsor can reduce the risk of unsatisfactory results and can, in many cases, reduce project costs. A geophysical consultant, like most contractors, is likely to quote a higher price for a survey where there is uncertainty about a key factor, such as the nature of vegetation cover.

a. Site characteristics:

- Location: Provide Universal Transverse Mercator (UTM) or latitude-longitude coordinates. This will allow the consultant to locate the site on U.S. Geological Survey (USGS) maps, U.S. Department of Agriculture (USDA) soil maps, air photographs, etc.
- Access: Indicate the ease or difficulty of access to the site. Can one drive up to the site or must equipment be carried some distance?
- Size: Specify the area to be surveyed in square meters. Be sure to differentiate the area to be surveyed from the total site area.
- Time period: Minimally, specify if the site is prehistoric, historic, or both. If the historic occupation is known to be substantial, be sure to specify that. This is even more important if the primary focus of the survey is the prehistoric occupation.
- Expectations about archaeological features: Provide a realistic summary of the types of features that could reasonably be expected to occur at the site. If small (e.g., less than 0.5 m in diameter) features are likely to be the predominant feature category, convey that in the SOW. If features of any type are rarely encountered at sites in this region or time period, be certain to indicate that. Such conditions may call for a more intensive survey than would otherwise be conducted.
- Vegetation: Most geophysical techniques require the detection instrument to be carried across the site in a controlled manner, along transects spaced at intervals of 1-meter or less. Some instruments are connected to a power source or remote probes by a cable. Vegetation that impedes systematic walking across the site will need to be removed prior to the survey. Thus, the nature of the vegetation cover is an important determinant of survey cost and data quality. If possible, provide the geophysical consultant with photographs that convey typical conditions. Failure to accurately describe vegetation conditions can lead to unsatisfactory results and/or a very disgruntled consultant. If vegetation must be removed, the SOW should specify whether the sponsor or the consultant would do that.
- Ground surface: Indicate whether the site is in an agricultural field, pasture, second growth forest, etc.
- Soil: Identify the soil type using USDA descriptions. Characterize the relative abundance of natural rock. Be sure to indicate whether low portions of the survey area are frequently saturated. Consultants will be particularly interested in the clay content of the soil (if GPR is being considered), and in the presence of historic artifacts or recent metallic debris (if magnetic surveys are being considered).

2. OBJECTIVES: Provide a succinct statement of the project goals focusing on the geophysical consultant's responsibilities. Several examples follow:

Conduct a geophysical survey of the XYZ site using two or more geophysical instruments. The objective of the survey shall be to (specify one):

- a. Determine if subsurface archaeological features are present at the site; or
- b. Produce a map showing the distribution and approximate density of subsurface archaeological features at the site; or
- c. Produce a detailed map showing the distribution and approximate density of a variety of feature types at the site.

In these examples, option a might be the objective if the sponsor is conducting a National Register of Historic Places (NRHP) eligibility assessment and simply needs to determine if some intact subsurface deposits are present. Option b might be specified as the objective if the sponsor wants to secure relatively detailed information about the number and distribution of features. Such information would be important in developing a data recovery plan to mitigate adverse impacts to a site, or if a land manager needs to characterize the nature of cultural resources in a particular area based on a fairly detailed investigation of a representative sample. Option c might be selected as the objective in a situation where the sponsor needed to secure very detailed information about a protected or otherwise important site. For example, the sponsor might need to identify a portion of the site where a new road or utility line would result in the least amount of damage and cost. Similarly, option c might be selected in a research situation, where the objective was to collect as much information about the site as possible while minimizing the amount of excavation to be conducted. Option c might also be appropriate in the case of a politically or culturally sensitive site, such as a Native American cemetery or a site that had played an important role in the history of a particular cultural or ethnic group.

Option a would typically be the least expensive whereas option c would have the highest cost.

In many situations, it might be useful to conduct a survey that combines the objectives. For example, a relatively low data density and low cost survey might be conducted across a large area to identify promising areas for investigation. A high data density and higher cost survey might then be conducted in a small area of particular interest. This is analogous to using a grid of shovel tests and a

few isolated test units to identify a productive area where a large excavation block should be placed.

3. MAJOR REQUIREMENTS: This section should provide detailed information about the contractor's responsibilities. Here the goal should be to ensure that the sponsor would get the information that he/she needs to meet the project goals. The tasks should, however, be written in a manner that gives the geophysical consultant the flexibility needed to achieve the best results given the nature of the site conditions.

a. Task 1: Fieldwork. Specify each of the following:

1) Area (in m²) to be surveyed. Geophysicists typically estimate field costs based on the number of standard-sized blocks to be surveyed. Common block sizes are 20 by 20-m, 30 by 30-m, and 50 by 50-m, although block size can be modified to meet the conditions at a particular site.

Clarify whether the area to be surveyed pertains to each instrument or represents the total. For example, a 20 by 20-m block represents a survey area of 400 m². But if two instruments are to be used, the survey area is obviously 800 m².

2) Instruments to be used. Often the geophysicist will not know which instruments will be most effective until he/she has tried each at the site in question. It is best if the SOW requires the consultant to try several instruments and then to conduct the bulk of the survey using the instrument(s) that appear to yield the most useful data.

At many sites, some features will be detected using one technique whereas other features may best be detected using a second technique. If the objective is simply to determine if some subsurface features are present, the bulk of the survey can be conducted using the single instrument that is found to be most effective. If more detailed results are needed, it will be desirable to use two or more instruments across much of the survey area. Increases in information return will be positively correlated with increased cost.

The sponsor can generally protect his/her interest by requiring the consultant to survey a particular number of blocks, but allowing the consultant to decide which instruments to use. The sponsor and the consultant need to share the same objective: to secure geophysical data that meet the survey goals, as well as the same assumption about the approximate number of days to be devoted to the fieldwork. Unfortunately, the contracting departments of many agencies do not favor contracts that specify the number of days to be spent in the field, but in-

stead favor specifying the area to be covered in the survey. However, consultants can generally provide an estimate of the area they can survey in a day, given certain assumptions about ground cover, etc.

3) Data density. Unless the sponsor is very knowledgeable about geophysics, it is best to not quantify the data density for a particular survey. The sponsor should, however, stipulate realistic criteria to be used by the consultant in selecting data density. For example, the SOW might state that a data density should be used that will, under favorable conditions, permit the detection of features as small as __-m in diameter. Detection of features less than ca 0.3 m in diameter is problematic in all but the most detailed and expensive surveys. Such information will assist the consultant in developing a survey design that will meet the sponsor's needs. Keep in mind that greater data densities generally require more field time and thus increase costs. The sponsor and the consultant should share the same goal: to identify the data density that is adequate to meet project objectives, but to avoid using a data density that is greater than necessary.

4) Additional mapping. In addition to producing maps of the geophysical data, the sponsor may request the consultant to use an optical transit or Electronic Distance Measurement (EDM) instrument to map recent cultural features that may affect the survey results (e.g., roads, ditches, utility lines). In many cases, geophysical surveys of historic cemeteries are far more useful if accompanied by a map of grave markers, visually discernable graves, etc. Not all geophysical consultants have the capability to produce such maps, but many do.

5) Datum points. It is very important to require the geophysicist to mark several corners of his/her survey grid, and/or to secure very accurate GPS coordinates. Require the geophysicist to include in his/her report a list of the controlled datum points, including a description of how they are marked in the field, and their GPS (or other) coordinates.

6) Ground truthing. In many cases, geophysical consultants are not formally trained archaeologists and are not ideally qualified to personally conduct excavations designed to ground truth (verify) the results of a geophysical survey. It is extremely useful, however, for the geophysicist to be present at the site when excavations are conducted. This poses an obvious logistical problem, associated with additional costs, when the excavations occur after the geophysicist has left the project area. In surveys of complex, sensitive sites, it is well worth the additional cost for the geophysicist to spend several days at the site during excavation. The exchange of information that occurs on such occasions will improve the future performance of the geophysicist as well as the field archaeologist.

b. **Task 2: Analysis.** In most cases, it is not productive for the sponsor to attempt to specify in detail how the geophysical consultant should analyze his/her data. Analysis is typically an iterative process that requires substantial experience to yield optimal results. It is useful, however, for the sponsor to request, if appropriate, certain broad approaches to analysis.

1) **Ground Penetrating Radar.** The SOW should require use of time slicing, a technique that yields plan maps of anomaly distributions. This technique is now widely used, although there are still some consultants who rely on simple diagrams that summarize the results of multiple profiles. In most cases, such maps should not be viewed as an acceptable final product. Note, however, that time slicing is labor intensive. If the site is likely to be characterized by large areas of very low feature density, it is advisable to require the consultant to simply use time slicing in selected areas.

2) **Ancillary information.** A geophysical consultant will not automatically seek out previous archaeological reports, air photographs, etc. in order to better interpret his/her geophysical maps. Such information is useful and should be provided to the consultant by the sponsor. If the sponsor wants such ancillary maps to be used as overlays to better interpret the geophysical data, this should be stipulated in the SOW.

c. **Task 3: Report.** In certain situations, the sponsor may simply require a map accompanied by a letter report that concisely explains the results of the geophysical survey. This minimalist approach is not recommended, particularly for sponsors who have little or no understanding of geophysical techniques. To maximize the value of the geophysical study, the SOW should require a complete report. All text and graphics should be submitted in both hard copy and electronic formats. The following information should be included in the report.

1) **Introduction and background:**

- A brief explanation of how the geophysical survey fits into the overall undertaking or research effort
- Background information on the site, particularly the nature of subsurface deposits
- Basic information on site location, setting, and chronology – If the sponsor requires substantial detail in these sections, he/she should provide the consultant with previous reports, site forms, etc.

2) **Methods:**

- A brief explanation of which instruments were used, why those instruments were chosen, and how those methods work

- Clear discussions of the survey design used for each instrument, including instrument settings, data density, and transect spacing
- A discussion of factors (vegetation, soil moisture, modern metal trash, etc.) that affected the results of the survey.

3) Results:

- A map of the entire site showing the areas included in the geophysical surveys – This figure will be based on a map provided to the consultant by the sponsor.
- Maps showing the results from each instrument – Request the consultant to use symbols, labels, etc. to identify anomalies that are discussed individually in the text. Map borders on all sides should display ticks (at 1-m intervals if possible) to make it easy to determine the coordinates of small anomalies.
- Widely used software (e.g., Geoplot 3.0, Surfer 8.0) permit various types of maps, each of which has certain advantages and disadvantages – The SOW should permit the consultant to use the map format he/she feels maximizes the potential for detecting anomalies that may be associated with cultural features. Key maps should be presented using two or more formats (e.g., gray-scale image maps and color-scale image maps). Note that contour maps are often not the best choice for depicting the very low-contrast (subtle) anomalies often associated with prehistoric features.
- The text should include clear descriptions of the data processing steps used for each instrument, and criteria used to identify anomalies as possible cultural features vs. natural phenomena or recent artifacts or impacts.

4) Recommendations:

- The text should identify those anomalies judged most likely to be associated with cultural features. A table should provide the coordinates for these features.

5) References:

- The SOW should request the consultant to cite previous geophysical studies in the area, and sources for additional reading by nonspecialists on geophysical techniques.

The SOW should require the consultant to submit a draft report, including all graphics, for review. The sponsor should be able to request revision of any sections that are poorly written, inaccurate, or needlessly technical.

4. CONTRACTOR RESPONSIBILITIES: SOW for contracts issued by the Federal Government typically state that the consultant's work is open to inspection by properly designated government representatives at any time, and that work found not to be in conformance with the SOW must be corrected at the consultant's expense. The SOW should also stipulate that the consultant must comply with all safety and security practices and protocol required by the installation or facility where the fieldwork will occur.

5. SPONSOR-FURNISHED SUPPORT: The SOW should specify that the sponsor will provide the consultant with:

- Permission to access and conduct work at the site(s) covered by the SOW
- Reports, site forms, maps, photographs, and other materials that provide background information needed by the consultant to conduct his/her work
- The SOW should make it very clear whether the consultant or the sponsor is responsible for clearing vegetation from the site in preparation for the geophysical survey.

6. SPONSOR POINT OF CONTACT: Provide contact information for the person(s) designated to interact with the consultant.

7. TRAVEL REQUIREMENTS: Make it clear who is responsible for travel costs, including travel to and from sites located on Government-owned property.

8. DELIVERABLES AND SCHEDULE:

- Specify the number of copies and date of submission for each deliverable: completion of fieldwork, draft report, final report.
- The SOW should require submission of bound hard copies, an unbound "camera ready" copy suitable for photocopying, and electronic copies of each element of the final report, including all graphics.
- The SOW should also require submission of a copy of the final report in PDF format, since this is often more convenient than photocopying as a means of producing additional copies. In many cases, geophysical maps will not photocopy well.
- In addition to the processed data, the SOW should require the consultant to submit clean electronic files of the raw (totally unprocessed) data.
- For some sites and projects, it is useful to require the consultant to submit one or more large format hard copies of selected maps.

9. QUALIFICATIONS: At present there is no formal system of certifying individuals as qualified to conduct geophysical investigations of archaeological sites. The following general guidelines are offered to assist potential sponsors in identifying qualified consultants:

- Previous experience in conducting geophysical investigations of archaeological sites in the region
- In-depth familiarity with the concepts and methods of archaeological investigation, types of archaeological features and deposits, etc
- A demonstrated ability to produce well-written and well-illustrated reports in a timely manner
- Access to and previous experience in using several geophysical instruments, including electrical resistance, magnetic (gradiometer or total field), electromagnetic, and/or ground penetrating radar
- An ability to explain geophysical instruments and graphics in nontechnical terms
- A familiarity with the concepts and practices of CRM
- Previous experience interacting with archaeologists engaged in ground truthing the results of geophysical surveys.

Example Statement of Work No. 1

Geophysical Surveys of Five Historic Cemetery Sites at Fort XYZ

1. BACKGROUND: Fort XYZ has requested assistance of the Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) in mapping the limits and internal patterning of five historic cemeteries using one or more noninvasive geophysical techniques. The work to be conducted under the present Statement of Work (SOW) will expand upon the geophysical survey approach implemented by Contractor A and Contractor B at Fort XYZ in 1999 and 2001.

2. AUTHORITIES: The Department of Defense (DoD) is the steward of a vast number of historical properties located on millions of acres of public land. Federal regulations require that DoD installations accomplish their military missions in compliance with cultural resources laws. Relevant acts include the Archaeological Resources Protection Act (ARPA) of 1979, the National Historic Preservation Act (NHPA) of 1966 (as amended), the National Environmental Policy Act (NEPA) of 1969, the Native American Graves Protection and Repatriation Act (NAGPRA) of 1990, as well as Army Regulation (AR) 200-4.

The Government and the Contractor agree and understand that the services to be rendered under this contract are nonpersonal services, and the parties recognize and agree that no employer-employee relationships exist or will exist under this contract between the Government and the Contractor's employees.

3. OBJECTIVES: The objectives of this work are to a) conduct geophysical surveys at five historic cemeteries at Fort XYZ; and b) prepare a professional quality report of the survey results.

4. MAJOR REQUIREMENTS: In order for the Contractor to accomplish the work described in this SOW, it shall be necessary for the Contractor to complete the following tasks:

a. Task 1: Conduct geophysical surveys at five historic cemetery sites at Fort XYZ. The cemeteries that shall be surveyed under this SOW are: Site A, Site B, Site C, Site D, and Site E. Maps and descriptive information about these cemeteries can be found at the following web site:

(Note: In this case, an inventory of historic cemeteries was available on the installation's web site. This included sketch maps of each cemetery that provided a basis for accurate estimates of area and number of tombstones, as well as descriptions of vegetation.)

1) At each site, the contractor shall use Ground Penetrating Radar (GPR), magnetic gradiometry, and/or electrical resistance to map the limits and internal distribution of historic graves. The objective of the work is to produce reliable maps of the graves rather than to experiment with the advantages and limitations of the three techniques at each site. Thus, the contractor shall determine which technique provides the best information and then focus primarily on that technique.

(Note: Previous geophysical studies at Fort XYZ conducted by the same consultant had focused on the use of multiple instruments in order to assess the performance of each in the local soils. In this cemetery survey, however, the objective was to quickly determine which instrument would yield the best results, and then to use it to produce the desired maps.)

2) At each site, the Contractor shall use an Electronic Distance Measurement (EDM) instrument to produce a map of the historic grave markers. The map shall also include the cemetery limits, for example, a fence that surrounds the cemetery, and any other prominent landmarks that would make the map readily interpretable. The EDM map of the gravestones shall be used as an overlay for interpretation of the geophysical data.

3) Where GPR is used, the data shall be presented as horizontal maps based on time slicing techniques rather than on data profiles.

4) The Contractor shall make an attempt to completely survey each of the five cemeteries. However, the Government recognizes that, if vegetation or other site conditions are not accurately described in the information referenced above, 100% survey coverage may not be achieved. The Government will identify to the Contractor which of the five sites is of lowest priority and should be surveyed last.

b. Task 2: Submit a written report on the geophysical surveys. This report shall be a professional quality document that can serve as a stand-alone document and would also be suitable for inclusion in an ERDC/CERL monograph or other technical report. The report shall include the usual front matter, including a table of contents, list of figures, etc. The report shall explain the methods and survey design used in the field, as well as the study results and interpretations. Full citations shall be provided for all published references cited in the report. For each site, the report shall include publication-quality maps with data values scaled for presentation in gray-tones as well as versions of the same maps with the data presented in color. The Contractor shall use his/her own judgment in deciding whether to include the gray-scale or the color maps in the body of the report. The maps that are not included in the body of the report shall be included as an appendix. The gray-scale maps and the color maps shall each be presented in two versions: (1) with no labels or symbols to indicate the outlines of graves, and (2) with symbols indicating which anomalies are interpreted as graves, and with the locations of the gravestones mapped using the EDM. Note that there may well be apparent discrepancies in the survey maps, such as gravestones with no anomalies suggestive of graves, and anomalies suggestive of graves with no gravestones. These discrepancies are of particular interest in terms of (1) ascertaining if some graves are present but unmarked, and/or (2) if some gravestones have been placed in the wrong location, and/or (3) if some graves simply are not reliably detected by the geophysical surveys. The report shall quantify and discuss the occurrence of each of these types of discrepancies.

(Note: It is not necessary in all projects for the contractor to provide maps in four versions: gray-scale and color, with and without labels. In this case, the sponsor had a methodological interest in which approach to data display would be most useful, and was also planning ahead for future presentations at professional conferences, etc.)

5. CONTRACTOR RESPONSIBILITIES:

The Contractor shall provide all of the personnel and equipment needed to execute this SOW.

In the event that the Contractor encounters problems in fulfilling performance requirements, or when difficulties are anticipated in complying with the schedule or dates, or whenever the Contractor has knowledge that any actual or potential situation is delaying or threatening to delay timely performance of tasks, the Contractor shall immediately notify the ERDC/CERL Contracting Officer's Technical Representative (COTR) by telephone communication and in writing of all relevant details. However, this material will be informational in character and this provision shall not be construed as a waiver by the U.S. Government of any delivery schedule or date, rights, or remedies provided by law under this task order.

The Contractor can submit invoices to ERDC/CERL for progress payments when significant portions of the work have been completed. The Contractor shall provide ERDC/CERL with accurate descriptions of the nature and amount of work that has been completed at the time of each invoice.

Neither the Contractor nor any of his/her representatives shall release or publish any sketch, photograph, report, or other material of any nature derived or prepared under this SOW without written permission of the ERDC/CERL COTR except as is specifically provided for in this SOW. Copyright shall not be claimed by the Contractor for any materials produced under this SOW. The Contractor shall not include copyrighted material in his/her report. All materials are to remain in the public domain. The Contractor and those in his/her employ may, during the term of this agreement, present reports of research from this project to various professional societies and publications. Abstracts and copies of these reports, presentations, or articles utilizing work sponsored by ERDC/CERL shall be provided to the ERDC/CERL COTR for approval prior to publication or presentation.

It is the intention of the Government to have a second contractor (working under a separate SOW) map one or more of the same five historic cemeteries using a hand-held thermal sensor. If requested by the Government, the Contractor shall submit working draft hard copies and/or electronic files of the EDM maps of the cemeteries so that they can also be used as base maps or overlays by other contractors.

6. GOVERNMENT-FURNISHED MATERIALS AND SUPPORT:

The Government will provide the Contractor with the following:

- a. Access to the sites where the geophysical surveys will be conducted
- b. Available background information, including maps, of the cemetery sites.

7. CONTRACTING OFFICER'S TECHNICAL REPRESENTATIVE (COTR) AND POINT OF CONTACT (POC):

The ERDC/CERL COTR and POC is Dr. Michael L. Hargrave, Telephone 217-352-6511, Fax 217-373-7222, Email Michael.l.hargrave@erdcd.usace.army.mil. The ERDC/CERL COTR is the only contact for direction on technical matters, and the ERDC/CERL Contracting Officer (CO) is the only responsible part for contractual matters. No ERDC/CERL, Fort XYZ, or other government personnel will have the authority to do other than clarify technical points or to supply relevant information. No requirement in this SOW may be altered as a sole result of such verbal clarification.

8. MEETING/REVIEW: The Contractor shall report to the office of the Fort XYZ Cultural Resources Manager (Mr. John Doe) prior to beginning fieldwork. At the conclusion of fieldwork, the Contractor shall present an informal briefing to the CR Manager or one or more of his staff, using preliminary maps to summarize the results of fieldwork.

The Contractor shall provide the ERDC/CERL COTR with monthly progress reports as described in section 10, REPORTS/DELIVERABLES.

The Government reserves the right to periodically inspect all phases of the Contractor's work in progress or after completion of the project, to ensure that the work is being performed in compliance with this SOW. If the ERDC/CERL COTR determines that the work is not being conducted in accordance with these specifications, the ERDC/CERL COTR reserves the right to require that the work be corrected of deficiencies or to be redone if acceptable corrections cannot be made. Time spent making corrections or redoing the work shall be absorbed by the Contractor with no additional expense to the Government. All work-related records shall be available at all times for examination by the ERDC/CERL COTR.

9. TRAVEL REQUIREMENTS: All arrangements and travel and per diem expenses associated with this project are the responsibility of the Contractor. All such expenses shall be included in the Contractor's cost quote. It is anticipated that the work described in this SOW will require the Contractor to make one trip to Fort XYZ. This trip is expected to require approximately two weeks for a crew of two or three individuals.

10. REPORTS/DELIVERABLES: The Contractor shall submit the following deliverables to the ERDC/CERL COTR on or before the dates specified below:

a. The Contractor shall submit to the ERDC/CERL COTR a brief (approximately one page) written report of progress each month, due on the 10th day of each month. In these monthly reports, the Contractor shall specify the task(s) that he/she is working on, and identify any actual or potential problems or delays, and any findings of particular interest. The most recent such progress report shall accompany each invoice. These progress reports shall be submitted by email. Progress payments will not be paid unless these progress reports have been submitted.

b. All fieldwork associated with the geophysical surveys described in the SOW shall be completed not later than (date).

c. Upon completing fieldwork, but prior to departing from Fort XYZ, the Contractor shall visit the Fort XYZ POC and, if requested by the Fort XYZ POC, present an informal discussion of project results.

d. Four hard copies and one electronic copy of a draft report shall be submitted by the contractor to the ERDC/CERL COTR not later than 60 days after the Contractor completes fieldwork at Fort XYZ. The ERDC/CERL COTR will provide written comments on the draft report within 45 days. The draft report shall be a polished, professional-quality document, and shall not be submitted in an incomplete form. The Contractor shall incorporate the changes requested by the Government into the final report.

e. Ten hard copies (including one camera-ready copy) of the final report (revised to include changes requested by the Government) shall be submitted to the ERDC/CERL COTR not later than 30 days after the receipt of Government comments. The final report shall be bound with a tape or plastic spiral binding and shall have laminated covers.

f. Two electronic copies (one copy each on two separate computer disks) of all of the electronic files needed to reproduce all of the text, figures, maps, photographs, drawings, and other graphics included in the final report shall be submitted to the ERDC/CERL COTR along with the final report. All such files shall be in a format readable by Microsoft Word 6.0 or in Surfer Version 7 with no loss of formatting. The contractor shall be responsible for fixing any loss of formatting. Each of these disks shall also include one copy of each Geoplot or other software data file that contains final data from the Fort XYZ surveys. These shall be clean, final data files. No "draft" files shall be submitted. Each disk

shall be neatly labeled with the Contractor's firm, date, contract number, and nature of contents. Each disk shall include a file that explains the names and contents of each of the other files.

g. Two PDF electronic files on separate disks of the assembled final report shall be submitted, so that ERDC/CERL and/or Fort XYZ can easily produce additional copies of the final report.

h. One large format (approximately 24 by 24-inch) hardcopy map showing the results of geophysical surveys at each cemetery shall be provided along with the final report. These maps shall be printed in color, although the Contractor shall decide whether the data should be presented in color or gray-scale tones. The large format maps shall include the locations of gravestones and other features mapped using the EDM, and shall indicate which anomalies are interpreted as graves.

11. PERIOD OF SERVICE: All work shall be completed and all deliverables shall be submitted not later than (date).

Example Statement of Work No. 2

Geophysical Survey of a Prehistoric Cemetery and Habitation Site at Fort ABC

1. BACKGROUND: As the steward of more than 24 million acres of public land, Department of Defense manages a wide array of cultural resources, including prehistoric archaeological sites. Where human remains and/or items of cultural patrimony are present, archaeological sites take on great social, religious, and political significance to living Native American groups. Key legislation defining the historic preservation responsibilities of Federal agencies include the National Historic Preservation Act (NHPA) of 1966, as amended (36CFR800), the Archaeological Resources Protection Act (ARPA) of 1979, the Native American Graves Protection and Repatriation Act (NAGPRA) of 1990, and Executive Order 11593. Army Regulation (AR) 22-4 specifies Army regulations for compliance with these and other relevant laws.

In 1998, the U.S. Army Construction Engineering Research Laboratories (USACERL) is continuing its efforts to identify situations where the use of geophysical survey techniques can improve the performance and cost effectiveness of archaeological site assessments. Geophysical techniques are noninvasive (involve no excavation) and so are particularly useful in the investigation of sites known or suspected to include human burials.

The work described in this Statement of Work (SOW) involves the use of geophysical techniques to identify and map prehistoric human graves and other archaeological features at Site X. This site is a prehistoric cemetery and habitation site complex. The site was initially recorded in 1974; a copy of the site form accompanies this SOW. The site was inspected on 5 February, 1998, by Dr. John Doe 1 (MACOM), Dr. John Doe 2 (Fort ABC, and Dr. Michael Hargrave (USACERL). At that time, a number (probably less than 20, but no exact count was made) of depressions and stone slab features interpreted as the remains of prehistoric stone box graves were visible on the surface. Some of these features represented shallow depressions surrounded by in-situ vertical stone slabs. Other features were marked by depressions and/or displaced stone slabs. Open looter holes and/or small back dirt piles suggested the presence of additional features. It is assumed that all of the graves that are readily apparent have long since been thoroughly looted. However, it is highly likely that additional, more deeply buried graves are also present, and these may contain human remains and/or associated artifactual materials.

The project objective is to secure information needed to develop a management plan for this site. Maximum site boundaries are suggested by local topography. However, it is necessary to accurately map all graves and other features discernable on the surface, and to attempt to identify the distribution of additional subsurface features. This SOW involves detailed mapping of the site area using an EDM (electronic distance measurement) instrument, and use of one or more geophysical techniques to map subsurface cultural features.

Fort ABC occupies an upland setting characterized by gently rolling to nearly level upland plains dissected by numerous small tributaries of the Unnamed River. Site X is situated on a fairly level upland ridge overlooking Little West Fork. Access to the site is provided by an unimproved (dirt) fire road. The site area was presumably under cultivation during the early 20th century, but is now in second growth timber. The graves visible on the surface are on the edge of a clearing characterized by rather dense undergrowth but no trees. Substantial clearing of undergrowth will be required to conduct the geophysical survey.

2. OBJECTIVES: The objectives of this work are (1) to produce a detailed and accurate map of the site area, (2) to use geophysical survey techniques to map the distribution of subsurface prehistoric features, and (3) to produce a written and well-illustrated report on the methods, results, and conclusions of the mapping and geophysical survey.

3. MAJOR REQUIREMENTS: In order to accomplish these objectives, the Contractor shall perform the following tasks.

a. Task 1: Establish a grid at the site.

The grid shall consist of a series of wood stakes accurately set at intervals of 20 meters (or other intervals representing multiples of 10 meters) across the entire site area. The grid coordinates shall be marked on each stake using permanent black ink. All grid coordinates shall be in positive numbers relative to an arbitrary off-site datum to be established by the Contractor. The UTM (Universal Transverse Mercator) location of the datum stake as well as that of at least four other grid stakes shall be determined using a GPS (Global Positioning System) instrument. These five stakes (the off-site datum and four others) shall be set with particular care so that they are likely to remain in place for a number of years after the conclusion of the work described in this SOW. The four non-datum stakes described here shall be located at or near the most north, south, east, and west extremes of the gridded area.

b. Task 2: Produce an accurate horizontal map of the project area.

This map shall be produced using an EDM instrument so that an electronic file of the data comprising the map is available for use in future projects. It is not necessary for the Contractor to produce a contour map showing differences in elevation, since elevation data already exist for the project area. The Contractor shall reference his/her map to the GIS (Geographic Information System) contour map maintained by the Fort ABC Cultural Resource Management staff. The Contractor shall produce hard copies of his/her map at a scale between 1:100 and 1:300. The exact scale at which hard copies shall be produced shall be determined through consultation between the Contractor and the USACERL and Fort ABC Points of Contact (POCs, named in section 6). The map shall show and clearly label the grid system, all actual grid stakes, all fire roads, cleared areas, prehistoric features visible on the surface (as indicated by discrete depressions and stone slabs), all large dirt piles resulting from earlier clearing, the extent of vegetation clearing by the Contractor, the extent of the geophysical surveys by the Contractor, previous test units at the site (only one is known), and other areas of disturbance (e.g., old agricultural terraces and fire breaks). Because this map will be used to document future looting and/or other impacts to the site, it is essential that the Contractor's map shows all looter holes and back dirt piles that may be associated with looting. Although the map produced by the Contractor need not show contour lines, the Contractor shall collect sufficient elevation data to allow his/her map to be referenced to existing USGS maps. Similarly, the Contractor's map shall show the location of abrupt changes in slope, such as those that mark the edge of the relatively level site area. The Contractor's map shall include key landmarks located beyond the limits of the site area, so that the site can readily be viewed in broader context.

- c. Task 3: Clear vegetation from the site area sufficiently to allow geophysical surveys.

Most of the site area to be surveyed using geophysical techniques is in second growth timber (see attached map). Most of the graves that are visible on the surface are located within or at the edges of a cleared area characterized by weeds and briars but very few or no trees. At the Contractor's discretion, this area can be cleared of undergrowth using a small tractor with attached brush hog. However, such work shall be done only when a member of the Fort ABC CRM staff is present to monitor the work. Monitoring is required in order to keep the machine from damaging prehistoric graves and other features. Within the wooded portions of the survey area, the Contractor shall use hand tools and/or chain saws, hedge trimmers, weed eaters, or similar hand-held power tools to clear undergrowth and small trees. The objective of the vegetation clearing shall be to allow an effective geophysical survey of the site area. Requirements as to the spatial extent of the geophysical survey (and thus, of the vegetation clearing) are specified in Task 4.

- d. Task 4: Conduct resistivity and/or magnetic surveys of the site area.

The resistivity survey shall be conducted using a Geoscan Research RM-15 resistance system. The magnetic survey shall be conducted using a Geoscan Research Fluxgate Gradiometer. The Contractor can include in his/her response to this SOW a written proposal to use alternative instruments. If such a proposal is made, the Contractor shall explain in writing the advantages and disadvantages of the alternative instruments relative to those specified herein.

Before beginning the geophysical fieldwork, the Contractor shall review archaeological site forms, reports, and other information provided by USACERL. Information about the probable size and depth of cultural deposits shall be used to determine optimal instrument settings and survey design. Before systematically undertaking the overall surveys, the Contractor shall survey several small areas using each instrument, as well as a Ground Penetrating Radar (GPR) instrument. The Contractor shall use the results of this initial work to decide which instrument offers the greatest potential for realizing the project objective of mapping subsurface prehistoric features. The Contractor shall conduct the bulk of the survey work using the technique judged to be most productive.

Data plot maps of preliminary results shall be generated while the field team is at Fort ABC, so as to ensure that the instruments are working properly, geophysical data are viable, and that work is being conducted in that portion of the site where cultural deposits are most likely to be present. The Contractor shall

show a representative selection of these preliminary maps to the USACERL and Fort ABC POCs during the course of the fieldwork. It is conceivable that decisions will be made in the field to shift the focus of the survey (within the project area as defined in this SOW) so as to increase the likelihood of detecting cultural deposits. Such actions shall not, however, obligate the Contractor to survey a larger total area than was specified in writing in his/her response to this SOW.

Filtering and other data enhancement techniques (for example, high pass filtering, clipping, etc.) shall be used as necessary to maximize the interpretability of the magnetic and resistance data vis-à-vis the presence and nature of subsurface cultural deposits.

e. Task 5: Inspect the ground surface to account for geophysical anomalies.

Following completion of the geophysical surveys and inspection of the preliminary data plots, the Contractor shall systematically walk over the surveyed area. He/she shall make detailed and accurate written record of factors that may account for the presence of geophysical anomalies. Examples of such factors include but are not limited to vehicle ruts, shallow depressions, large tree roots, animal burrows, wet spots, etc. This walk over inspection shall include the systematic use of a metal detector to assess whether magnetic anomalies are likely to represent recent metallic debris rather than prehistoric features. Tables or edited narrative notes of this walkover inspection shall be included in the final report.

f. Task 6: Use Ground Penetrating Radar (GPR) to further investigate possible subsurface cultural features.

The goal of the GPR survey shall be to better define the nature, size, and shape of possible cultural features detected by other means. In view of this goal, the GPR survey shall be conducted after the site mapping and other geophysical surveys have been completed. The GPR shall focus on loci where the resistivity and/or magnetic surveys detect anomalies interpreted as possible cultural features, or where graves and other features visible on the surface or in a previously excavated test unit suggest that additional subsurface features may be present.

The Contractor shall experiment with the GPR instrument during the early stages of the fieldwork (as described in Task 4), in order to determine if local soil conditions will allow it to be used effectively. (It is very possible that local soils will prove to be too clayey.) If the Contractor finds that the GPR is more effective at locating possible cultural deposits than the other techniques, he/she may request permission from USACERL to expand the GPR survey and to do propor-

tionately less (as measured in person-days) resistivity and magnetic survey. This change in strategy shall be acceptable if the Contractor can demonstrate that it will increase the likelihood of identifying cultural features and it involves a comparable level of effort on the part of the Contractor.

g. Task 7: Provide written tables and hard copies of scaled maps locating resistivity, magnetic, and GPR geophysical anomalies which may correspond to cultural deposits.

The Contractor shall categorize all of the major anomalies based on their geophysical data value, size, shape, and/or other relevant characteristics. The Contractor shall then prioritize the anomalies in terms of which ones are most likely to represent cultural features. For each anomaly, the Contractor shall specify the following:

- 1) Anomaly number. Anomalies shall be numbered consecutively, 1 through n.
- 2) Grid coordinates. Anomaly locations shall be expressed to the nearest 0.25 m.
- 3) Anomaly category
- 4) Predictions about the kind of cultural feature that may be associated with the anomaly (e.g., earth pit, stone slab, hearth, etc.). The goal shall be to clearly describe to the archaeologists the kind of phenomena that he/she would look for if ground truthing excavations are conducted in the future.

h. Task 8: Produce a written report detailing the methods, results, and conclusions of the geophysical study. The final report shall include but need not be limited to the following:

- 1) Written discussions of the following topics:
 - equipment used
 - a brief explanation of how each technique works and how data are interpreted
 - site characteristics and other conditions (soils, bedrock, vegetation, weather, etc.) affecting the results
 - sampling strategy, including data density, decisions about which site areas to grid and survey, etc
 - amount of time (in person-hours) devoted to each aspect of the fieldwork, including vegetation clearing, gridding, survey, preliminary data processing, data enhancement processing, and report preparation. These data

shall be based on written records maintained during the fieldwork.

Rough estimates made at the end of the project are not acceptable.

- recommendations about how cost effectiveness, survey quality, etc. might be improved in future studies.

2) Tables

- tables listing the number, location, category, and interpretation of the anomalies as specified in Task 7.

3) Maps

- for each surveyed area and each technique used, a publication quality map showing survey results. Clearly labeled on each map shall be the grid coordinates of the surveyed area, and the anomalies interpreted as possible cultural features. These maps shall be based on the enhanced data, if data enhancement techniques are used. These maps shall be produced in gray tones rather than color, so as to permit subsequent photocopying. One or several maps showing an enlarged view of site areas where possible subsurface cultural features are located shall also be produced in color and included in the report.

The report shall be suitable for inclusion in a larger report that will be completed by USACERL. Thus, it is not necessary for the geophysical report to include background information on regional prehistory or history, nor on the natural setting of the Fort ABC study area. Site-specific characteristics that affected the outcome of the survey shall be discussed.

4. GOVERNMENT-FURNISHED EQUIPMENT AND INFORMATION: USA-CERL will arrange for the contractor's permission to work at Fort ABC. USACERL will provide the Contractor with copies of extant archaeological site forms, reports, maps, and other information directly relevant to the Contractors work at the site.

5. CONTRACTOR RESPONSIBILITIES: The Contractor shall provide full cooperation with the Fort ABC POCs and other officials appointed by Fort ABC and/or USACERL. The Contractor shall follow all standard procedures and protocol required of Contractors by Fort ABC.

The Contractor shall participate in interaction concerning Fort ABC with the State Historic Preservation Office (SHPO) and the Advisory Council for Historic Preservation (ACHP) only upon the direction of the Fort ABC and USACERL POCs.

The Contractor shall conduct his/her work at Fort ABC in close coordination with the Fort ABC Cultural Resources Manager, Range Control Office, and USACERL POC. The Fort ABC POC will provide the Contractor with the appropriate telephone numbers and address of the Range Control Office.

Although there are no active firing ranges within the project area at Fort ABC, the potential exists for live small caliber ammunition, razor wire, and other personnel hazards throughout the installation. The Contractor should be aware of this and exercise reasonable caution during the field investigations.

In the event that the Contractor encounters problems in fulfilling performance requirements, or when difficulties are anticipated in complying with the schedule or dates, or when the Contractor has knowledge that any actual or potential situation is delaying or threatening to delay timely performance of tasks, the Contractor shall immediately notify the USACERL technical POC by telephone communication and in writing of all relevant details. However, this material will be informational in character, and this provision shall not be construed as a waiver by the U.S. Government of any delivery schedule or date, rights, or remedies provided by law or under this statement of work.

The Contractor shall notify the Fort ABC and USACERL POCs at least one week before the date he/she begins fieldwork.

6. POINT OF CONTACT: The USACERL technical POC is Dr. Michael L. Hargrave (217-352-6511, fax 217-373-7222; email m-hargrave@cecer.army.mil). The USACERL POC is the only contact for direction on technical matters, and the USACERL Contracting Officer (CO) is the only responsible party for contractual matters. No USACERL, Fort ABC, or other government personnel other than the Contracting Officer will have the authority to do other than clarify technical points or to supply relevant information. No requirement in this statement of work may be altered as a sole result of such verbal clarification.

7. MEETINGS/REVIEW: The Contractor shall provide the USACERL POC with a brief written progress report following the completion of fieldwork and preliminary analysis, but before the preparation of the draft report. The USACERL POC will be present during portions of the fieldwork in order to ascertain that work proceeds in accordance with this SOW.

8. TRAVEL REQUIREMENTS: The Contractor shall be responsible for all of his/her own travel and per diem costs and arrangements.

9. REPORTS/DELIVERABLES: The Contractor shall submit the following deliverables to the USACERL POC on or before the dates specified:

a. All vegetation clearing, gridding, site mapping, and geophysical survey work conducted as described in Tasks 1, 2, 3, 4, 5, and 6 shall be completed not later than __ days after award of the contract.

b. A brief written progress report shall be submitted to USACERL following completion of fieldwork and preliminary data processing (as described in Tasks 1, 2, 3, 4, 5, and 6) but prior to commencement of the draft report. This progress report shall be submitted not later than __ days after the completion of fieldwork.

c. Five copies of a draft report (as described in Task 8) shall be submitted not later than __ days after the award of the contract. The draft report shall be a complete, polished document. The maps included in the draft report shall be based on data enhancements (if data enhancements are used) and shall be labeled as described in Task 7. The Government will provide comments on the draft report within __ days of submission.

d. Three hard copies of a large format map of the site area showing all indications of looting and other relevant features as described in Task 2 shall be submitted along with the draft report. Government comments on this map will be provided along with those on the draft report.

e. One unbound camera-ready original copy and five bound photocopies of the final report printed on acid free paper and including changes made in response to Government comments shall be submitted not later than __ days after receipt of Government comments on the draft.

f. Three hard copies of the large format map of the site area as described above in item (d) including changes made in response to Government comments shall be submitted along with the final report.

g. Two copies on computer disks of all files used to produce maps, figures, tables, and text included in the final report (as described in Tasks 7 and 8) shall be submitted along with the final report. All text files and tables shall be in Microsoft Word 6.0. The Contractor may request permission from USACERL to submit the map files on tape, so long as the format and type of the tape submitted is approved by CERL.

h. Two copies on computer disks of the file(s) used to produce the large format map of the site area as described above in item f shall be submitted in a format specified by the Fort ABC GIS manager.

10. PERIOD OF SERVICE: All work shall be completed and all deliverables shall be submitted not later than 200 days after the award of the contract.

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