A Guide to Incorporating Geophysical Remote Sensing In Transportation Archeological Investigations

Requested by:

American Association of State Highway
and Transportation Officials (AASHTO)

Standing Committee on the Environment

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Table of Contents

1. Introduction

Transportation agencies interested in surveying cultural resources within a project area have a suite of commonly used archaeological methods available to discover buried features. Geophysical remote sensing (GRS) technologies offer state departments of transportation (state DOTs) additional means by which to determine an area's sensitivity for archaeological resources. GRS technologies, combined with other context related information, may help determine an area's sensitivity in a non-invasive manner, but may also require ground truthing in the absence of other data.

> **A Note on Terminology**
>
> Much debate has occurred regarding the use of the term 'remote sensing' to describe technologies such as ground penetrating radar, resistivity, conductivity and gradiometry. While gathering data about subsurface features from above the ground is remote, it is a different method than other 'remote sensing' applications such as aerial photography or satellite imaging. Thus, we have chosen to use the term 'geophysical remote sensing' both to capture the unique nature of these methods and to differentiate them from other well known technologies used to gather data today.

This guidebook is intended to provide a high-level introduction to the available technologies, a discussion of potential uses and site considerations, and some suggestions for incorporating GRS into the archeological investigation framework at state DOTs in the future. This document provides information on the most common survey techniques and does not attempt to fully describe the technical complexities of each of these methods. It should be used to provide an overview of GRS, but it is not designed to provide all the information that users would need to design and execute surveys themselves. In order to assist those interested in pursuing additional information on this rapidly expanding field, a description of additional sources of information on these technologies is provided. Throughout the pages of this guidebook are textboxes with real world examples of GRS successfully applied to DOT projects. These mini case studies highlight the variety of situations in which GRS has been used and suggest the potential it holds for the future.

GRS technologies can provide capabilities that are of great utility to state DOTs. State DOTs are responsible for ensuring the constructability of planned highways in addition to minimizing environmental effects of agency construction projects. This effort, usually conducted by the environmental sections of the departments, includes assessing the extent to which potential transportation projects may affect historic structures, other cultural features, and archaeological sites, in order to provide recommendations and guidance to the project managers on how to avoid, minimize or mitigate any such impacts to these resources.

Archeological investigations at state DOTs must also satisfy the requirements of many Federal and State laws and regulations regarding historic preservation, some of which have been in place for more than 30 years. Perhaps the most well known and influential regulation, 36 CFR 800, implements Section 106 of the National Historic Preservation Act, which requires that the impact to significant historical and archeological resources from activities conducted with federal money, on federal land, or involving federal permits be considered in project development. The Advisory Council on Historic

Preservation (ACHP) has published an expanded interpretation of Section 106 in its *Protection of Historic Properties* (2000), which provides for "nondestructive project planning activities before completing compliance with section 106, provided that such actions do not restrict the subsequent consideration of alternatives to avoid, minimize or mitigate the undertaking's adverse effects on historic properties." The Secretary of the Interior's Archeological and Historic Preservation: Standards and Guidelines notes that remote sensing techniques may be the most effective way to gather background environmental data, and that ordinarily the results of remote sensing should be verified through independent field inspection. Clearly GRS fits within the established regulatory framework developed over the past 30 years, which has encouraged the use of methods which are non-destructive and preserve cultural resources for future generations.

1.1 Technology Overview

This section provides an overview of available GRS technologies, their individual capabilities, and common applications at DOTs. It focuses on ground penetrating radar, magnetometry, conductivity and resistivity since these are the most common GRS technologies. Useful results in any form of remote sensing, including geophysical methods, are obtained from contrasts between archeological features and the natural background of the surrounding soil. Such contrasts are identified as anomalies until ground truthing excavations, pattern recognition, or post-processing can present the data as unambiguous cultural resource features.

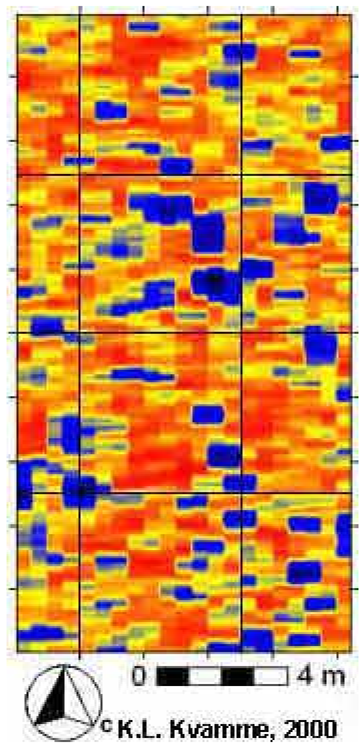
Technologies have improved in recent years, especially with computer-aided collection and post-processing of data. This is particularly important for cultural resource management (CRM) archeologists interested in identifying significant features in a given project area from the tens of thousands of individual measurements at varying densities and depths that are collected. In such cases, the interpretation and post processing techniques become just as important for a successful GRS investigation as the data collection procedures. While some of these GRS methods have been used with varying success for decades, recent improvements have dramatically increased their capabilities for identifying and mapping potential near-surface buried cultural remains.

For each of the four major technologies, a brief description is provided to explain what the technology is, how it works and, perhaps most importantly, how it can be helpful in locating archeological resources for state DOTs. It should be noted that several GRS methods are not discussed here, notably the use of metal detectors and side scanning sonar for under water GRS.

1.1.1. Ground Penetrating Radar

Perhaps the most well known GRS technology, ground penetrating radar (GPR) has gained widespread use as one of the first technologies offering a reliable means for gathering data below the surface of the soil. GPR technologies transmit a radar wave into the ground. When the wave strikes buried objects or surfaces, part of the signal is transmitted back and picked up by the receiver. The depth of buried features may be determined through the amount of change in the radar velocity as the wave travels through various layers of the soil between the GPR unit and the object. As with many GRS technologies, a GPR survey is usually conducted at a site in a grid pattern. Using this approach, a large number of periodic reflections can be correlated and used to develop an accurate, three dimensional picture of buried features.

Because reflections are received from buried features with physical and chemical properties that contrast with the surrounding medium, targets which are fairly large, hollow, or linear are often the most identifiable. A wide variety of features have been found using GPR. These include caskets in cemeteries, tunnels, buried pipe or conduits, house pits, storage pits and stone foundations to name few.



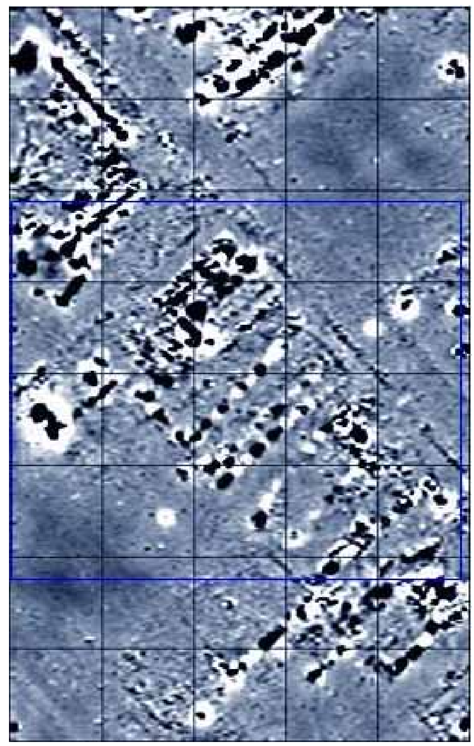
GPR results showing known and probable graves and other anomalies at Bozeman Cemetery, AR. Image courtesv of Kenneth Kvamme.

In addition to the types of subsurface features, the reception of radar reflections is also affected by the distance that the waves must travel to the feature and then back to the surface. This is controlled both by the intended depth of the survey and the frequency of the radar waves emitted. GPR methods have been most successfully applied to sediments and soils between 20 cm and 5 m below the surface. DOT users with a large area of potential affect should be aware of this limitation and choose a GPR antenna with the appropriate operating frequency for the desired depth and resolution of the target features. In general, lower frequency antennae are better suited to deeper projects, and higher frequency antennae are better suited to shallow surveys. The resolution of subsurface features also varies with radar frequency. Higher frequency antennae can resolve features down to a few centimeters, but are limited in depth penetration. Finally, the successful detection of subsurface features using GPR methods is also determined by the soil composition and moisture condition of the site at the time of the survey. GPR methods calculate the location of subsurface features by detecting the velocity of energy moving through the ground. Ground that has a higher electrical conductivity, such as wet clay, will remove the electrical portion of the radar wave and any useful reflections. Dry quartz sand is an example of a low conductivity soil that will readily allow radar waves to pass through. For a gross GPR suitability index by state, one can go to the following web site: (http://soils.usda.gov/survey/geography/maps/gpr/index.html).

DOTs have found GPR methods to be most effective when used as one element among several in larger site investigations. While cemeteries and foundations are often quite distinct in GPR results, the data by themselves may not allow conclusive decisions regarding the nature or significance of identified features. At this point, archeologists must use ground truthing to supplement the GPR results. However, once some excavation is completed, the results may be integrated with GPR results into a mapping process to refocus or reduce the amount of additional excavation required. DOTs should anticipate the need for this data calibration and verification process, but recognize the potential for GPR methods to save time and money on project investigations, in addition to increasing the variety of data collected at any given location.

1.1.2. Magnetometry

Magnetometry is a method used to map local variations of the earth's magnetic field in the near surface. This GRS method has been used successfully to detect small and varied cultural features over broad landscapes through a process of pattern recognition and geometric interpretation. Magnetometry represents a passive GRS method, meaning that the technology detects contrasts in the existing properties of the earth and does not generate or induce artificial fields into the ground.



Army City, KS. Magnetic image showing metallic anomalies such as pipes, nails, bolts. etc., which reveal outlines of structures. Image courtesy of Eileen Erenwein.

Magnetometry methods are a particularly good GRS tool for archeologists because they allow large project areas to be surveyed in relatively small amounts of time. This is a particular advantage for DOTs when analyzing long corridor improvements and/or large capital improvement projects. In addition, magnetometry has the ability to collect very high resolution details about potential features. These elements, taken together, may allow a DOT archeologist to identify whole cultural features with regular interpretable geometric shapes within a single GRS survey. This technique, which relies on pattern recognition and identification of non-natural geometric figures, is similar to those which have been used in the analysis of aerial photography and satellite data.

Magnetometers measure the local magnetic susceptibility of a given location, including both human activities and natural processes which result in magnetic variations. Evidence of human behavior occurring on a given site may include:

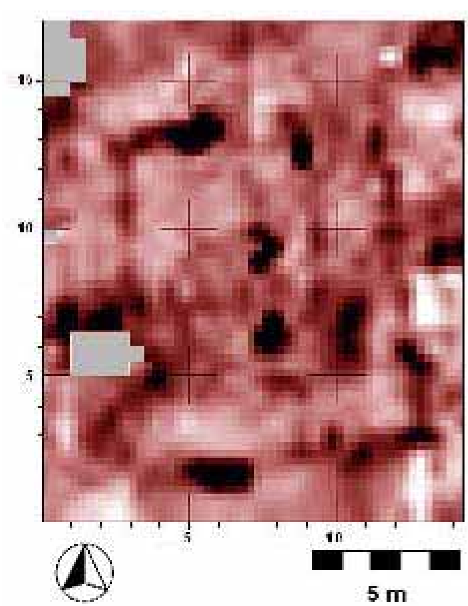
1. Remnants of hearths
2. Fire affected rock and ceramics
3. Middens

4. Changes in the level and composition of topsoil caused by prior human agriculture
5. Imported stone and other materials that have magnetic signatures
6. Iron artifacts
7. Storage pits and trails

Archeologists have successfully used magnetometry, particularly to detect small and varied cultural features over broad landscapes that would be difficult or impossible to analyze through traditional methods.

1.1.3. Resistivity

Resistivity technologies are some of the oldest GRS methods, having been in use for over 40 years. Resistivity surveys introduce a known electrical current into the ground and measure the resistance of the soil to the current flow through the soil by a voltage measurement. The most common technology configuration consists of a mobile current-voltage probe attached by a wire to a second stationary current-voltage probe at some distance. This twin-electrode array configuration provides a return path for the injected current and a reference voltage for the voltmeter. The distance between the two probes determines the depth of the survey. Introducing a number of voltage electrodes allows multidepth surveys to be performed with greater time and cost savings.



Mount Comfort Church, AR. Detailed resistivity examination of the church area shows its outline and interior support piers, all probably more resistant brick. Image courtesy of Kenneth Kvamme

Resistivity methods collect data on features, activity areas, and settlement locations with respect to resistivity. Archaeological remains are divided into two distinct categories. Some locations contain brick, stone, cement, or highly compacted soils. These constituents have their own intrinsic resistivity and contrast highly with the surrounding soils. These features are termed 'positive contrast.' There are also earthen or 'disturbed soil' features such as filled pits, house pits, middens, post molds, field boundaries, which have varying degrees of developed resistivity unique to the feature. These 'negative contrast' features are common in the archaeology of the United States and can be more difficult to detect.

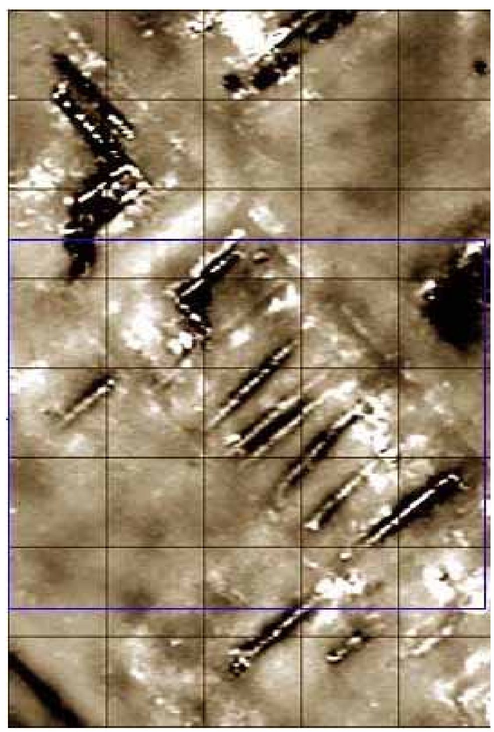
Data processing procedures can be used to enhance feature detection and separate the high contrast features from the low contrast features. The first stage of the post-processing procedure is concerned with mapping the large features and high-contrast features. The second uses high pass filtering of the data to map small and low-contrast features. Finally, the last stage of data processing separates high and low resistivity features using a low pass filter to remove random noise. While this final step will result in less spatial resolution, an experienced archeologist will be able to adjust the filter to the appropriate size in order to facilitate the interpretation of anomalies. Interpretation of resistivity data (anomaly diameter, depth, and high/low resistivity) will be most effective when taken within the context of the anticipated archeological record.

DOTs have found resistivity methods particularly useful for projects with difficult site conditions, such as surface obstruction, which prevents ground penetrating radar (GPR) from continuous antenna contact with the soil (e.g., late fall, dense vegetation). In addition, resistivity surveys are not as affected by metal located on the site, and do not require as extensive a preliminary site investigation as some other methods. Both conductivity and magnetic surveys will require additional manipulation of the dataset to generate meaningful results if scattered iron or other metal is located in the project area.[1]

When multiple GRS technologies are used on an archeological site, resistivity is often conducted first because it is relatively simple to use, inexpensive, and applicable across a broad spectrum of historic and prehistoric sites.

1.1.4. Conductivity

Conductivity surveys measure the ability of the soil to conduct an electric current, the reciprocal of resistivity. Unlike resistivity methods, however, there is no electrical connection between the survey instrument and the ground. The induction meter uses a coil near the surface of the ground to broadcast a low frequency signal which is detected by the receiver (located in the same instrument package). Conductivity methods thus have the potential for significant savings in the amount of time required for data collection over GRS methods that require the insertion of a probe into the ground.



Army City Conductivity survey.
Image courtesy of Eileen Erenwein

While time savings are perhaps the most significant benefit offered by conductivity methods; other advantages include the ability to:

- Conduct surveys in a variety of ground conditions (where other GRS techniques may fail),
- Measure some vertical separation of features when using multiple receivers, multiple frequencies, and/or running in

[1] The text box to the right is adapted from Remote Sensing in Archaeology: An Explicitly North American Perspective. Edited by Jay Johnson, Forthcoming

both horizontal and vertical dipole modes, and
- Collect data using both magnetic susceptibility and conductivity measures in a single instrument.

At the same time, the incredible sensitivity of conductivity methods sometimes requires users to conduct a preliminary investigation using a local soil map and/or systematic shovel tests to gather some knowledge of local soil conditions and the type of cultural resources expected.

If the presence of the following site characteristics is revealed in the preliminary investigation, conductivity methods will have limited potential to generate meaningful results.

- non-significant metal features, particularly in the near surface
- electrical interference from certain external electromagnetic frequencies (such as overhead power lines)

Taken together, these considerations in densely built-up modern environments require an experienced GRS operator in surveying near-surface urban settings. It is helpful to be able to use geographic information systems (GIS) to georeference utility maps and historic Sanborn maps with geophysical survey results. With this capability, certain anomalies that can be correlated with modern infrastructure can be distinguished from those associated with historic foundations, wells, and privies.

Archeologists have used earth conductivity methods to successfully gather information on the presence of earthworks, such as mounds, ditches, and banks, particularly when there is significant contrast between the fill and non-fill. Conductivity can also record low-conductivity features like buried stone and masonry foundations and fired clay features such as central hearths in late prehistoric Native American structures.

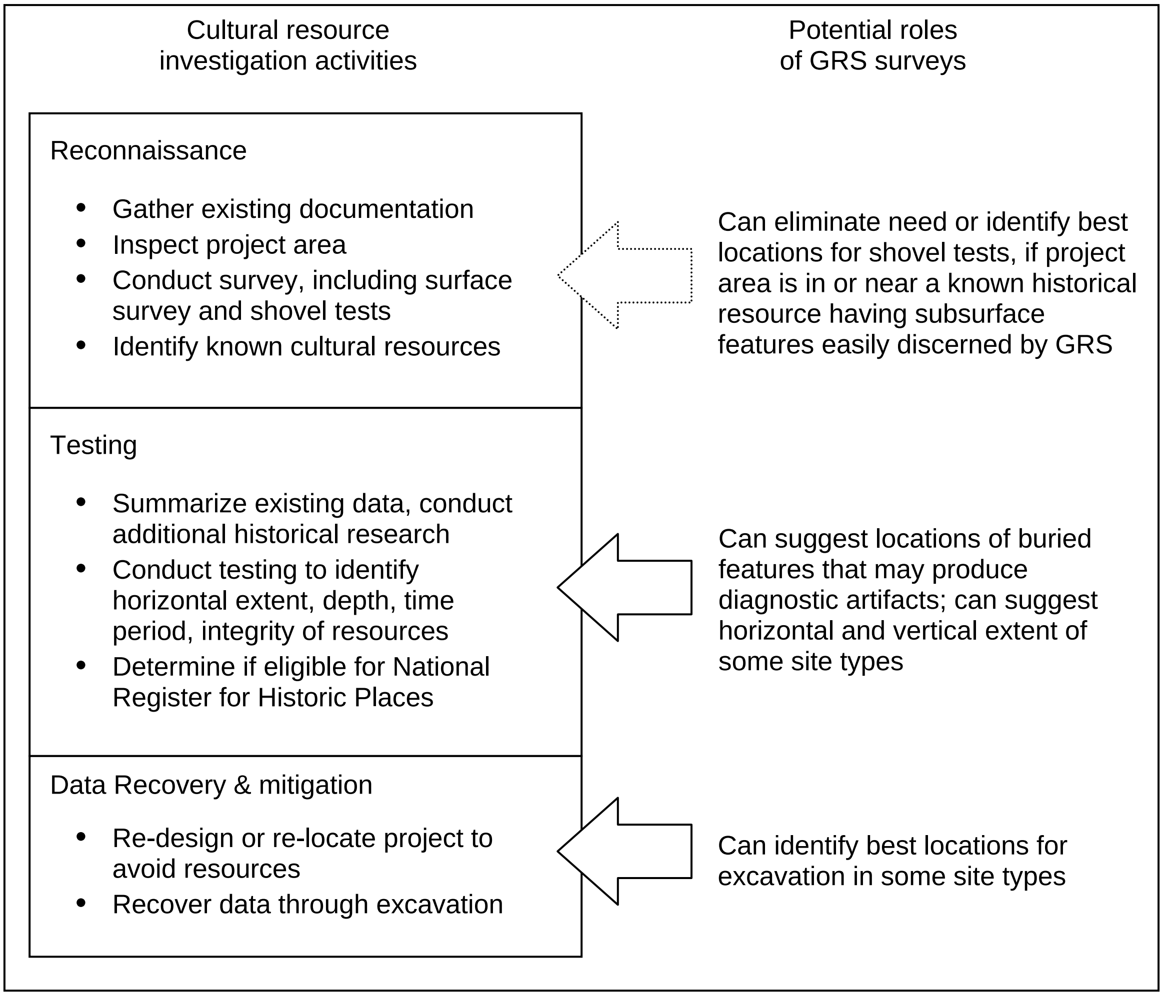
> Some DOTs have found that conductivity offers the most robust results when combined with other methods, such as a magnetometry or GPR in order to provide additional information on the depth of targets.

1.2. GRS within CRM Investigations

GRS technologies encompass a wide range of capabilities, analysis techniques, and data needs that will determine their relative effectiveness for DOT archeological investigations. Taken together, the complete set of GRS technologies offer capabilities that can be applied to all categories of archeological investigation.

The following figure lists three categories of archeological investigation and suggests the potential role of GRS within each.

Figure 1. GRS roles within the phases of an archeological investigation



1.2.1. Reconnaissance and Survey

In reconnaissance or survey, inventory information is collected about the area of potential effect that may be altered by a transportation project. This phase includes the identification of sites, preliminary assessment of site boundaries, and data categories, through a series of increasingly targeted information gathering activities. First, archeologists review state site files, anecdotal evidence, and local recorded history to collect background information on the potential for cultural resources. A preliminary assessment of the soil and geologic conditions is made. Next, a thorough field survey is conducted by observing ground surface and sometimes conducting periodic shovel tests at fixed intervals.

GRS technologies offer agencies the ability to augment traditional data collection procedures in the survey with information that would not normally be gathered at this point in an investigation. The potential cost and time savings for an entire project may be enormous if GRS surveys locate potential buried sites and landscape features very early in the planning process. Background research on a project located in northeastern Texas showed preliminary evidence of Caddo house features. Because the project was so large, magnetometry was chosen by TxDOT to locate signature features and patterns associated with the prehistoric architecture, including post holes and fire pits. The surveys provided additional data on the site prior to subsurface testing efforts. In addition, the data collected on visual patterns and feature types will be used regularly as a baseline whenever Caddo culture is involved in future DOT projects.

> Project Success:
> Batavia Township, Ohio
>
> Phase I of a project to re-align 0.25 miles of existing highway and replace an adjoining culvert identified the likely existence of buried archeological deposits. GRS was chosen to direct Phase II work as a timely and cost-effective means of surveying the entire area prior to excavation. Results from magnetometry and conductivity surveys located a cluster of early woodland roasting pits and other anomalies, which were ranked and evaluated. The GRS findings were integrated with results from shovel testing and pedestrian surveys for a more complete understanding of the artifact distribution at the site. Subsequent ground-truthing efforts were targeted and able to focus in more detail on artifact evaluation.

GRS may be used to identify the best locations for shovel tests as part of an initial site examination. While a commonly accepted interval for inventory survey is usually excavating shovel test pits every 30 m in high-probability areas, a GRS survey can indicate areas within the site to target shovel tests and offer an initial assessment of the characteristics of potential features. This is particularly true if the project area is in or near a known historic entity having subsurface features easily discerned by GRS.

1.2.2. Testing

Archeological testing programs are used to evaluate the eligibility of properties within a project’s area of potential effects for National Register listing. Testing often uses closer interval shovel tests than initial surveys to better establish the boundaries of a cultural resource and to determine whether buried features are present. Test pits are often employed to collect preliminary data on stratigraphic integrity and acquire additional data on artifacts.

By suggesting the locations of buried features that contain diagnostic artifacts, GRS technologies may expedite the recovery of data that contribute to the determination of National Register eligibility. In addition, GRS methods can suggest the horizontal and vertical boundaries of some site types, assisting in future project work.

1.2.3. Archeological Data Recovery

When an agency has determined that its project may adversely affect an archeological site, the agency works to resolve this adverse effect. This may involve redesigning a project to minimize impacts to historic properties, or if this is not possible, taking actions to mitigate project effects through archeological data recovery. Data recovery relies on a research design that reviews the state of knowledge relevant to the site, and specifies the questions, methods, and analyses to be applied in the investigation. GRS technologies can be identified in the research design as contributing to methodological research questions or analytical approaches to answer other research questions.

GRS technologies offer archeologists the ability to identify specific site boundaries within a project area; useful regardless of the mitigation activity chosen at the location. If the project is redesigned, the GRS results can be used to ensure that new plans do not also affect the site's cultural resources. If the agency chooses to mitigate impacts through archaeological data recovery, GRS technologies may be used to locate excavation units in portions of a site most likely to contain data pertinent to the research design. This can reduce the number of excavation units needed, with consequent time and cost savings.

2. The Choice to Use GRS

Cultural resource management professionals should consider using GRS when conducting archaeological investigations. Whether GRS is the right technology for any particular investigation will depend on a variety of site and project specific factors. Because of recent advances in technology, such as improvements in information processing, GRS has become a more powerful tool for collecting site information.

There are a number of benefits of using GRS technologies in conjunction with traditional methods of site investigation. GRS can provide better data, or data that would not otherwise be available, in many instances. Employing GRS can allow for the more precise location of cultural resources. GRS can locate sites that would be missed by traditional methods.

There can be significant monetary savings from employing GRS technologies. The lower cost of GRS can make possible the survey of larger areas, allowing archaeologists to see cultural features that may not be detectable in studies of smaller areas. The use of GRS can help to focus shovel probes and test units into smaller areas, limiting the costs of locating and excavating significant features. Utilizing GRS can allow boundaries and features within a site to be rapidly mapped. When information on cultural resources can be provided early in the design process, it can allow for cost savings through the avoidance of areas that are culturally sensitive. (See text box) By definition, GRS is non-destructive of the resource being investigated. It can allow for the effective investigation of sensitive sites, such as Native American burial grounds or cemeteries.

> **Project Success: Wilsonville, AL**
>
> Plans to widen a state highway through Wilsonville, AL required the purchase of land adjacent to a local cemetery. Though there were no marked or known unmarked interments, the likelihood of gravesites in the affected property area appeared to be high. Consultants used GPR as a preliminary survey tool to explore the project area and found signatures indicative of old grave shafts. The consequent redesign of the roadway to avoid this parcel resulted in significant cost savings to the DOT as further Phase II and Phase III efforts were avoided.

GRS technologies have improved significantly in recent years. New information technologies allow for the enhancement of images and the ability to screen out noise in the data. When used by professionals in tandem with traditional methods, GRS can improve the quality of archaeological investigations.

A case study comparing the cost of GRS to traditional investigation methods for the Parchman Place site in Mississippi is shown below[2]. When used effectively for the right types of projects, the value of employing GRS is easily apparent. Even greater benefits of GRS can be achieved if the use of the technology can provide higher confidence that all significant cultural features at a site have been found before construction. Uncovering unexpected cultural resources during construction can result in higher recovery costs, cost overruns and schedule slippage. Employing GRS can help to manage these risks.

[2] Adapted from Remote Sensing in Archaeology: An Explicitly North American Perspective. Jay Johnson

Cost Benefit Analysis of GRS vs. Traditional Data Collection
Application at the Parchman Place Site Conducted Jay Johnson and Bryan Haley

Geophysical Remote Sensing

Data were collected using multiple technologies on a 5.6 hectare site at Parchman Place site in northwestern Mississippi in 2002. This study employed the following technologies.

- Broad Scale Magnetic Survey required 30 person days for data collection
- Conductivity Survey required 15 person days for data collection
- Ground Penetrating Radar required 15 person days for data collection

The survey mapped a large number of structures and historic features, and provided a clear idea where they were. Ground truth excavations were undertaken on a 40 x 40 meter area. The remains of three houses and one prehistoric pit were uncovered.

Traditional Data Collection

The cost of collecting data at the site using traditional methods was estimated. In order to produce a map of the subsurface features of comparable quality to the GRS analysis above, the following activities would have been required.

- A controlled surface collection would be used. The correlation of the surface distribution of artifacts with subsurface features is often weak, especially in areas where the surface soil has been farmed for an extended period of time. Based on prior studies, research on 5.6 hectares would require 269 person days.
- Excavation of 1 M test pits where artifact density is high would be necessary to determine subsurface features. A one percent sample would require 183 pits in areas of high artifact density. This would require 488 person days in the field and 976 days in the lab to process the artifacts.
- In order to obtain comprehensive feature documentation, road graders would be used to strip the plow zone. A field crew would record and clean the exposed features. This would take approximately 20 days of machine time and 111 person days.

Cost Comparison

Based on these assumptions, the site map produced using traditional means would cost approximately $196,000 if it were to obtain and exceed the level of accuracy provided by GRS. The same mapping task was accomplished with GRS and limited ground truthing in two weeks at a cost of $6,000. These GRS cost estimates do not include overhead, and costs may also vary significantly between states.

2.1 Local Considerations

Determining if GRS should be used and which GRS technology should be employed are decisions that require consideration of a range of factors. The types of resources likely to be found at the site and the depth of these features are important. Surface characteristics such as local development, structures, terrain and ground cover may affect the choice of technology. Subsurface features, including geology, soil type and bedrock depth, also need to be considered. If possible, it is desirable to employ multiple technologies to obtain the best understanding of subsurface features. Review of previous local surveys can help to identify the technologies that work best in a given area. Generally speaking, remote sensing works by illuminating the contrast between cultural features of interest and the surrounding non-cultural matrix. Which technologies will work best depends on how host matrix characteristics interact with cultural resource features. Characteristics that produce noise or attenuate the instrument signal will affect technology choice. A number of the most important decision factors are considered below in more detail.

Type of Resource

The types of cultural resources that one expects to find will determine what GRS technology is likely to be most useful. Resources that consist of larger structures, such as foundations or walls, can easily be detected with GPR. GPR can be highly effective at locating these types of resources because they provide significant contrast to the surrounding subsurface features and pattern recognition can be used to identify features of interest. Empty spaces underground, such as caskets, tunnels and pipes, also generate significant radar reflections and can be detected using GPR.

Where cultural resources are likely to be smaller and lacking in structural remains, such as a prehistoric camp site, magnetometry is often best, since prehistoric burning can be detected through its magnetic signature. Magnetometry is also effective at locating metal artifacts. Near surface pits or other negative features that are typical of prehistoric sites can also be found with magnetometry. Resistivity and conductivity can detect historical ditches or pits if the fill material is substantially different and retains moisture in a different way.

For smaller, irregular and less prominent subsurface features, visual pattern recognition of GRS outputs may be insufficient to detect features of interest. In these cases, it is often necessary to perform more detailed analysis based on multiple instruments to identify key features.

Depth of Subsurface Resources

Magnetometry, conductivity and resistivity are most effective at depths of 1-2 meters. Ground penetrating radar can be effective at depths of up to 5 meters.

Geology

If bedrock is igneous and close to the surface, it can produce magnetic interference that will prevent magnetometry from effectively mapping features. The presence of igneous boulders in the ground can also have this effect. Magnetometry works well in many southern states because bedrock is generally deeply buried and there is little igneous rock.

Soils

The presence of highly conductive clay materials in concentrations over 10 percent can limit the use of ground penetrating radar by attenuating the signal. Fine grained soils or high water saturation generally tend to limit the penetration of GPR signals.

Fine grained soils are better for resistivity and conductivity, since these soils retain moisture. These techniques can detect differences in moisture levels between soils.

There is a higher magnetic susceptibility in the top soil horizon. Because of this, magnetometry can be used most effectively in areas where soil layers have not been intermixed due to farming. Differences can be used to spot specific cuts in the soil layer, such as grave sites. Glacial soils with igneous gravels will prevent effective measurements using magnetometry because of the interference associated with igneous rocks previously mentioned.

The application of fertilizers may alter resistivity and conductivity characteristics of soil, affecting readings. This may be particularly important if the researcher is conducting multiple readings at a specific site over time.

Surface Features

For sites with dense brush growth, extensive clearing may be necessary to ensure access to make straight line measurements with some GRS technologies. The long term effect of this activity on the study area may be of concern if the site is not ultimately chosen for development.

Surface features can affect the choice of GRS technology. Magnetometry and conductivity are less effective in urban areas where metal objects such as light poles, cars, or buried metal objects create noise that prevents effective measurements. Resistivity or GPR can work better on sites with such extraneous metal interference.

Overhead wires can affect GPR, resistivity and conductivity measurements. Trees can affect GPR measurements by creating above ground reflections that create instrument noise. Exposed tree roots or rocky surfaces can make some GRS measurements difficult. If surface conditions are rough, it may prevent a GPR antenna from maintaining contact with the ground. The antenna can be elevated above ground but this requires additional post processing of the data collected. On rough terrain, conductivity measurements are easier since the instrument is designed to be held above ground.

Weather conditions such as electrical storm activity can affect resistivity and conductivity measurements. For magnetometry, solar winds and solar magnetic storms can create disturbances that interrupt data collection for extended periods of time.

Figure 2. GRS Technologies by Resource Type and Site Characteristics

Site Types and Characteristics	Resistivity	Electromagnetic Conductivity	Ground Penetrating Radar	Magnetometry
	GRS Technology			
Type of Cultural Resource				
Structures, foundations, walls	○	○	●	○
Caskets, tunnels and pipes	○	○	●	○
Prehistoric pitches and ditches	●	●	○	○
Prehistoric burning	○	○	○	●
Metallic cultural resources	x	○	○	○
Soils				
Conductive clays (> than 10%)	○	○	x	○
Fine grained soils	●	●	○	○
Soils saturated with water	○	○	x	○
Very dry sites	○	●	○	○
Glacial soils with igneous gravels	○	○	○	x
Geology				
Igneous rocks (metallic deposits)	○	○	○	x
Igneous bedrock near the surface	○	○	○	x
Surface Features				
Trees and large bushes	○	●	○	○
Interfering metal (cars, light poles)	●	x	●	x
Rough terrain	○	●	○	○
Tree roots on surface	○	●	○	○
Electrical storms	x	x	●	●
Solar magnetic storms	●	●	●	x
Depth of Investigation				
Near surface resources (1- 2 M)	●	●	●	●
Beyond 2 meter depth	○	○	●	○

● Most Applicable
○ Applicable
x Not applicable

2.2 Choosing a Method

Which GRS technology should be employed depends on what cultural resources are located in the project area, the characteristics of the local geology, ground cover, terrain, subsurface features and soils. The table above shows a range of decision factors and how each instrument compares to others with regard to each factor. Technologies that are most applicable are marked with a solid bullet, while those technologies that are applicable are marked with an empty bullet. Technologies that may not perform well, or at all, in the presence of a certain site characteristic are marked with an X.

Generally, the researcher should gather as much information about the project area beforehand as possible. Characteristics such as terrain, ground cover and other above ground features can be assessed by walking the site. Secondary research regarding local history and any prior investigations can identify the types of cultural resources that are likely to be found, as well as information about prior use of geophysical remote sensing technologies in the area.

Another tool available to researchers is the Automated Tool for Archaeo-Geophysical Survey (ATAGS) which was developed by the Construction Engineering Research Laboratory. The software is a decision support tool that allows the user to enter characteristics of the likely cultural resources, information on soil conditions, geology, surface features and other factors. Based on this data, ATAGS recommends an effective survey design, including the type of technology to employ, recommendations on data sample density, distribution requirements and estimates of the number of hours required to perform the work.

ATAGS distinguishes between three different survey types:

- detection
- mapping
- integrity

Detection surveys seek to identify the presence of larger, high contrast features common at historic sites and thus the sampling density employed may be lower. Fewer measurements are required to produce a lower cost image with less resolution.

Mapping is used when a survey is needed to identify smaller features that exist at prehistoric sites. This type of survey would obtain a greater level of feature identification and image resolution, but at a higher cost.

Integrity surveys seek to maximize the likelihood of detecting small, widely spaced, low contrast features. By taking a large number of measurements, integrity surveys yield a map with a greater reliability and cost. Integrity surveys provide information on the state of preservation of the identified resources. ATAGS is designed for use in the Midwest, but has general applicability to other parts of the U.S.

2.3 Employing Multiple Methods

In most cases researchers do not have all the information they need to assess what type of instrument or survey type would be best. In these cases, it is often recommended to employ multiple instruments so that if one instrument is compromised by unexpected site features, data are still available from another. Additionally, unexpected cultural resource features can be missed if only a single instrument is used. Employing multiple methods increases the amount of information obtained from the site, but raises the cost of conducting the survey. This is justified if the enhanced quality of the information reduces site investigation costs later, or yields substantial new information that would not have been obtained otherwise.

To detect the greatest variety of features, researchers should employ GRS technologies that differ substantially in the way they detect features. Resistivity and conductivity tend to identify the same types of features, and provide a more comprehensive survey when combined with GPR. Many researchers have found that magnetometry and GPR used together tend to detect the greatest variety of features.

Having several different GRS technologies at the site allows researchers to identify the best instrument through trial and error if initial technology selection proves to be unreliable. It also allows a survey team to focus additional GRS technologies on particular anomalies if more information is needed.

When using multiple survey technologies, the results can either be interpreted separately, or overlaid onto each other. GIS software can allow the information to be displayed in map layers. Some researchers combine the results of several GRS technologies into a single display to allow complementary and different anomalies to be seen at the same time. A variety of techniques are available for this. Red-green-blue color compositing assigns primary colors to map layers and combines these into an image containing all of the colors. Other techniques allow each of the GRS maps to be made translucent and viewed simultaneously. Data from statistical analysis techniques, such as principle components analysis, can also be mapped to provide CRM professionals with a fuller view of the site.

> **Caltrans: Meeting Project Deadlines with GRS**
>
> Caltrans prefers to use multiple technologies at each site. For example, at a recent project in Napa Valley on a tight schedule, multiple GRS technologies, combined with standard records search and knowledge of site types within the region, were used to gather information. Magnetometry, resistivity, conductivity, and GPR were used to identify potential subsurface targets, depths, and the extent of deposits. Due to the wealth of information from multiple sources, the project was able to move forward with treatment plans more quickly than would have otherwise been possible.

Analyzing data from multiple GRS technologies can allow researchers to combine different types of information that are available from each technology. For instance, GPR might identify structures, while magnetometry would be able to provide information on the location of burning within the site.

GRS is not a replacement for traditional archaeological investigation methods. Like traditional methods, GRS may suggest the presence of cultural resources where there are none. In some cases, it may fail to locate the resources that are there. Neither GRS nor traditional methods can provide 100 percent confidence that there are no resources on the site. What GRS can do is to provide a tool that allows researchers to rapidly identify potential resources that can be verified using more traditional methods. GRS and traditional methods should be used in tandem to increase the efficiency of the location and identification of cultural resources.

3. Accessing GRS Technologies

Once a decision has been made to use one or more GRS technologies, cultural resource management professionals need to consider how they will access these technologies. For professionals working in a public agency, there are at least three options. They can purchase the equipment and conduct the surveys with trained in-house personnel, they can share or borrow equipment from another related office, or they can contract for services with outside professionals. This section describes factors that should be considered when pursuing each of these options.

3.1 Contracting GRS

With limited resources, many public agencies find that staff time is better spent managing contracts for archeological services, rather than conducting the work outright. Agencies looking to contract out services should first consider whether GRS expertise exists in their area and then aim to become savvy consumers of GRS services by clearly specifying expectations in detailed scopes of work.

State DOTs using consultants to conduct the GRS surveys vary in the way they secure outside services. While some states have written general scopes of work for GRS services internally before making solicitations, others have either worked with trusted and knowledgeable consultants to develop scopes of work or relied on these consultants to develop the detailed scopes of work. Still others have not written formal scopes of work, opting instead to rely on consultants to define and carry out the work informally. It is also common for public agencies to use large environmental service firms to purchase GRS services for them in subcontracts.

Significant knowledge of GRS may be required to effectively purchase and manage services from outside consultants. In order to be a good consumer of GRS services, cultural resource management professionals need to know enough about GRS to assess the quality of the work performed and use the results to inform their analysis.

If a public agency directly contracts out for GRS services, a well written scope of work will ensure that the services needed are procured. When contractors are uncertain as to the exact nature of the service required, they will often quote a higher price so that they are able to cover any contingency. By providing sufficient information to allow the contractor to develop an accurate price estimate, public agencies can often enable the service to be provided at lower cost as well.

Contracting out for GRS services entails two issues, (1) clearly specifying what expertise and technology you need and (2) ensuring that the contractors who deliver that technology are “expert” in the use and interpretation of that technology. Ways to address each are discussed in separate sections below.

3.1.1 The Scope of Work

Purchasers of GRS services should seek to provide as much information as possible in a scope of work requesting services, while at the same time allowing the consultant to propose the approach he/she believes is best. Scope of work should thus provide detailed information on the characteristics of the project area and the types of cultural resources that might be encountered. Purchasers of GRS services should consider including the following items in their scopes of work to describe the project area characteristics:

- Latitude-longitude or UTM coordinates for the project area
- Desired data density
- Access (Can one drive to the location?)
- Area that must be surveyed in square meters
- Most likely time period of cultural resources (prehistoric, historic)
- Expected archaeological features and their size (Are expected resources likely to be less than .5 M in diameter?)
- Vegetation on the area to be surveyed
- Specify who is responsible for removing vegetation if needed
- Land use (agricultural field, pasture, second growth forest)
- Soil type (use USDA descriptions, clay content of the soil is important)
- Other soil characteristics (prevalence of natural rocks, water saturation of soil, recent metallic debris)
- Local geology
- Anomalies of interest (modern features, prehistoric features, natural features, etc.)

It is often good practice to include a picture of the area so that consultants can see its general characteristics. The location of objects that may interfere with the survey should be described if possible. For instance, are there overhead power lines at the site, buried utilities, vehicles or other metal structures that might interfere with GRS measurements?

The scope of work should state the objective of the work in terms of what type of results are desired (detection, mapping, integrity). For instance, the goal may be merely to determine the presence or absence of a large feature, in which case, a less costly detection survey would be conducted. More expensive and detailed data collection would be required to compile a comprehensive map of the density of cultural resources at a site. An even more detailed survey would be conducted to determine the integrity of the cultural resources contained there, and provide enough information to determine how an excavation could be conducted so as to have the least impact.

The scope of work should allow the consultant flexibility to employ the best methods given the site conditions. At the same time, the scope of work needs to specify the objectives in enough detail so that the service meets the needs of the sponsor. Thus it may be desirable to suggest a GRS technology, but allow other methods to be employed if site conditions suggest that this is desirable. Some scopes of work allow consultants to employ multiple GRS methods on site and then select the best technology.

Another important variable is the survey grid block size. The smaller the block size, the greater the density of the data collection and the greater the precision (quality) of the subsurface image produced. Smaller block sizes increase the labor hours and cost required to conduct the survey. Typical block sizes include 20 by 20M, 30 by 30M and 50 by 50M. The scope of work can suggest a block size, or it may also be desirable to instead describe the minimum size of the features that the survey will need to detect, and allow the contractor to suggest a block size that is appropriate. Detection of feature sizes less than .3 meters require the most expensive surveys and are not common.

If the goal of the survey is to merely detect whether a particular feature is at the site, it may not be necessary to use multiple methods. If more detailed information is needed on a range of features, it is often desirable to employ multiple methods. If the scope of work specifies multiple GRS technologies are to be used, clarify in the scope of work if the description of the area to be surveyed is for each instrument, or is the total area combining all the instruments.

The research sponsor will want to request that the consultant use accurate GPS measurements to mark several corners of the survey grid. The consultant should include a list of controlled data points and how they were marked in their report.

The research sponsor may want to request that the geophysical consultant map other features that will affect the survey. Some consultants have the capability to use an optical transit or electronic distance measurement instrument to map site features. Features mapped might include the location of visible headstones in a graveyard or power lines at the site. Mapping and referencing features such as these can help with the interpretation of the final results.

It may be desirable to specify follow-up treatment for any found anomalies. This might include employing additional GRS technologies to collect more information, or conducting a survey of the area where the anomaly was found with a greater sample density.

The RFP should specify what format the results will be reported in. Particularly if the sponsor does not have extensive experience with GRS, it will be useful to obtain the results in a report that describes the survey in some detail and explains the findings. This report should include the following items.

- Management summary of report and results
- Goals of the geophysical survey
- Background information on the site
- Site location
- Explanation of which survey instruments were used and why
- Description of the survey design (instrument settings, data density, transect spacing)
- Sources of potential noise that could affect the results
- Findings and interpretations

3.1.2 Evaluating Outside Expertise

It is extremely important to hire a professional with demonstrated experience and education in archaeology and geophysical applications. The field of geophysics is complex and experience can be critical to achieving project success. The vast majority of professional geophysicists in the United States work in areas such as geology, mineral prospection, hazardous waste management, unexploded ordnance, and land mine detection. In general these subfields are concerned with the detection of large-scale and/or high-contrast targets, while prehistoric archeological features tend to be small, often less than 1 meter in greatest dimension and exhibit very subtle contrast with the surrounding soil. Thus, geophysicists with expertise with a variety of instruments, modeling, and imaging techniques may lack an understanding of the subtle nature of the archaeological record and a familiarity with appropriate processing methods and algorithms. There is currently no formal system for certifying individuals as qualified to conduct geophysical investigations of archaeological sites.

In addition, the success of geophysical applications varies significantly between regions. For this reason, obtaining the services of someone who has local survey experience is desirable. Finally, it is important to hire a consultant who is not wedded to a particular geophysical technology, but who can employ multiple technologies and use the one that is most suited to the job.

Since geophysical applications in archaeology are significantly different than in other fields, the research sponsor should stress the subtle nature of the features sought, the possible feature types, and surface conditions so that the geophysicist conducts the most appropriate survey, analyses, and data processing procedures. When evaluating the experience of consultants, the following factors should be considered.

- Experience conducting geophysical investigations of archeological sites in the region
- Familiarity with the concepts of archaeological investigation
- Experience with multiple geophysical instruments and technologies
- Ability to produce well written research products
- Knowledge of cultural resource management
- Participation in formal geophysical training and education

In California, one must be a licensed geophysicist to conduct geophysics (with the exception of applications in archaeology). Where states issue geophysical licenses, the license status of consultants should also be considered as a factor of evaluation. Hiring a professional may not be sufficient to ensure that the GRS results are adequate, especially if the GRS professional is not an archeologist. Some states have found it effective to have a DOT archeologist work with the hired GRS professional both in the field data collection stage and when the GRS data is analyzed and interpreted.

3.2 Sharing GRS Equipment

Cultural resource management professionals at some DOTs have utilized GRS equipment available in other departments. Other departments within DOTs often maintain this equipment to locate utility lines in urban areas or for other purposes. Departments that may maintain GRS equipment include utility maintenance departments, materials and testing departments, and geotechnical departments. While others in the DOT may already have GRS equipment and expertise, archeo-geophysics is distinct from other kinds of geophysics. It requires additional skills in using GRS to find archeological objects. Existing DOT expertise in GRS will likely need to be augmented with expertise specifically in archeo-geophysics in order to conduct successful GRS archaeological surveys.

The Alabama DOT (AlDOT) has successfully worked across departments to utilize agency GRS experience. Because few firms in Alabama own GRS equipment, some investigations requiring GRS are sub-contracted to out-of-state vendors. The Materials and Testing Section (MTS) at AlDOT headquarters in Montgomery owns a GPR unit, which the Environmental Testing Section (ETS) has used occasionally. While MTS dispatches the equipment and a staff technologist to conduct the survey, a member of ETS staff who has archeology-related GRS expertise accompanies them on the field survey.

AlDOT is expected to procure GPR units in each of nine geographic divisions so that in-house equipment will be readily available in the future. Given the potential for cost savings from owning the equipment, ETS is considering the purchase of additional GRS units specifically for archeological applications, as well as additional training. Beyond increasing ETS' ability to perform in-house surveys, the training would increase the staff's ability to prepare survey designs and review contractor reports presenting the results from GRS surveys.

3.3 Purchasing GRS Equipment

Some states have found it to be cost effective to purchase GRS equipment and establish in-house analysis capabilities. There are many good reasons to develop in-house capacity in GRS though purchasing equipment. Some agencies have staff availability to conduct investigations and significant GRS education and expertise. In addition, some state DOTs also have other groups in the agency with a need for GRS equipment, such as geophysical design groups, maintenance groups, or transportation labs.

In order to determine if purchasing GRS equipment makes sense, one needs to assess how often the equipment will be used, how much maintenance will cost, how long the equipment is expected to last, and what kind of training will be necessary. Sharing GRS technologies with other departments can help to defray some of these costs. Training costs can be substantial though. In addition, interpretation of data on GRS investigations of archaeological sites is a skill that requires significant experience and professional judgment. Effective use of the technology requires an investment in staff for training and use of the equipment.

The Georgia DOT (GaDOT) recently purchased GRS equipment and has used it with success on many projects. Three factors contributed to Georgia DOT's decision to purchase a GPR machine for $25,000 in 2001. These were: 1.) the success of Georgia DOT with a University GRS project, 2.) a Georgia state law requiring that investigations near cemeteries use minimally invasive survey techniques and 3.) a lack of GRS consultants in the state.

GaDOT chose to use GPR because of its 3D capabilities and widespread use as reported at conferences and in literature. Staff was trained to conduct GRS surveys and interpret results in a two-day course sponsored by the manufacturer. The agency uses GPR to augment traditional pedestrian surveys and provide additional data at the start of projects. GPR has also been used to target excavations once features have been identified. The department is now in the process of purchasing a gradiometer. GaDOT uses the GPR machine one to three times each month on large projects. The agency has found the most important aspects of GRS use to be effective field design and data presentation, both of which require prior GRS experience.

4. Data Processing and Presentation

Once GRS technologies have been evaluated and the survey completed, the data processing and presentation occurs. This section provides an introduction to the information gathering and data processing procedures that can be used to clean up, analyze, interpret, and present the data that result from GRS surveys. The amount of resources devoted to ground-truthing and documenting survey results will depend on the objective of the work in terms of the type of survey (detection, mapping, integrity).

4.1 Ground-truthing

While spectacular images of easily recognizable resources are sometimes produced from a GRS survey, even well executed surveys can require some additional information in order to interpret the results map. Ground truthing is perhaps the most misunderstood element of GRS surveys, as even the term truthing implies that GRS results in spurious data which must be validated by traditional excavation techniques. Indeed, many DOTs have cited the potential costs of ground truthing activities as the primary deterrent to the use of GRS.

Ground truthing refers to efforts to classify the results of a GRS survey through the use of independent evidence. This evidence may include non-archeological evidence gathered in the preliminary literature review (such as historic maps, site histories, and anecdotal evidence) and/or field excavations (such as soil coring and shovel tests). While there is no single approach to determining a ground truthing plan, there are at least five common issues to consider.

> Magnetic anomalies present a particular challenge to simple interpretation. Anomalies might be natural phenomena, highly magnetic materials, or small pieces of iron commonly found at occupied sites

- Information return
- Cost
- Invasiveness
- Social and political issues
- Risks to personnel

In most transportation archeological investigations, the more extensive excavations will be invasive and should result in a greater information return. It is the relative importance of these factors that will decide the level of effort required. Selecting anomalies for ground truthing may require an ongoing dialogue between contractors, the SHPO, and DOT staff to ensure adequate categorizing and prioritizing of anomalies. Further, some ground truthing may be accomplished using a multi-staged approach that systematically evaluates the anomalies using a series of increasingly invasive and expensive techniques.

As ground truthing efforts often require coordination between people with varying degrees of geophysical knowledge, the following list is designed to provide practitioners with a way to avoid common mistakes[3].

- Expect an archaeo-geophysicist specialist to provide substantial input into the prioritization of anomalies and be available for consultation as the results of ground truthing are interpreted. Include this expectation in the scope of work to allow for ample time and budget.
- Do not expect all cultural resources to be presented with sharp visual contrasts. In addition to providing information about anomalies, ground truthing can also reveal soil characteristics that will aid in the interpretation of other anomalies.
- Expect the approach and results of a ground truthing survey to be different from standard excavation approaches.
- Expect to focus limited ground truthing toward areas without the presence of any anomalies to ensure that the GRS survey was completed correctly.
- Expect the archaeo-geophysical specialist to assist in the preparation of draft and final reports. He or she may be able to ensure a proper presentation of the GRS methods and findings, increasing their integration into the broader site survey.

4.2 Documenting GRS Surveys

State DOTs pursuing the use of GRS in archeological investigations must consider the presentation of the information within the broader project report. While some agencies have described GRS investigations as part of their discussions of other archeological activities, some state DOTs prefer to isolate GRS results into a distinct document that is then referenced in the final report. Agencies should be consistent documenting the results of GRS surveys and ensure that the presentation methods and documentation are clear and concise. In either format, there are usually several common sections to include when presenting the results of a transportation archeological survey which has used GRS. These include:

- An introduction to the field of GRS,
- Operating methods of the technologies employed,
- Survey area and its potential for cultural resources,
- GRS and ground truthing survey techniques,
- Any data post processing, interpolation, and/or enhancement activities, and
- Summary of findings.

The introductory sections that describe the state of the practice and available technologies may also serve to advance interest in GRS within the state. Documenting successful GRS applications provides additional information for other state agencies and practitioners to develop their expertise. DOTs with limited GRS capacity in their states

[3] Adapted from Remote Sensing in Archaeology: An Explicitly North American Perspective. Edited by Jay Johnson, Forthcoming

would do well to emphasize the agency's successful projects in order to build that capacity.

Some reports provide details of the data processing methods, while almost all reports show the survey area overlaid with key anomalies interpreted for archeological features. The evidence accumulated from GRS surveys, once post processed and interpreted into geophysical maps and charts, must be accurately displayed and organized to maximize its usefulness within the broader investigation. The choice of the display form will also depend on the outcome of the investigation and the goals of the presentation.

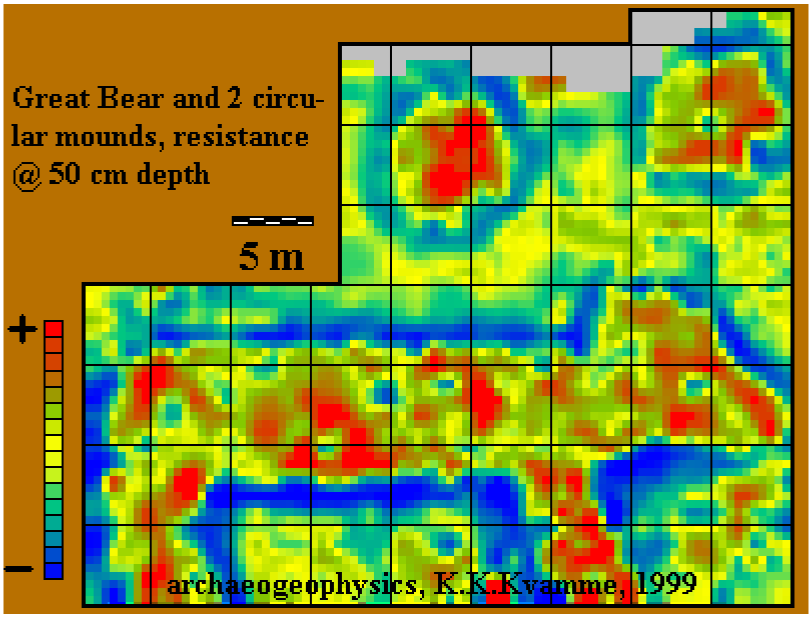


Image courtesy of Kenneth Kvamme,

A continuous gray or color scale will reveal subtle details, which are often suited to the kind of cultural anomalies found in the United States. This presentation image is best used to illustrate systematic patterns across a region.

The figure above shows the results of a resistivity scan near Prairie du Chien, Wisconsin managed by the U.S. National Park Service. It was surveyed by students of a workshop sponsored by the NPS entitled: "Recent Advances in Archeological Prospection Techniques." The Great Bear Mound shown here also includes two circular mounds. The low resistances shown surrounding each figure are probably due to water pooling and drainage from the mound. The use of color scale here clearly outlines the figure and makes identification easy.

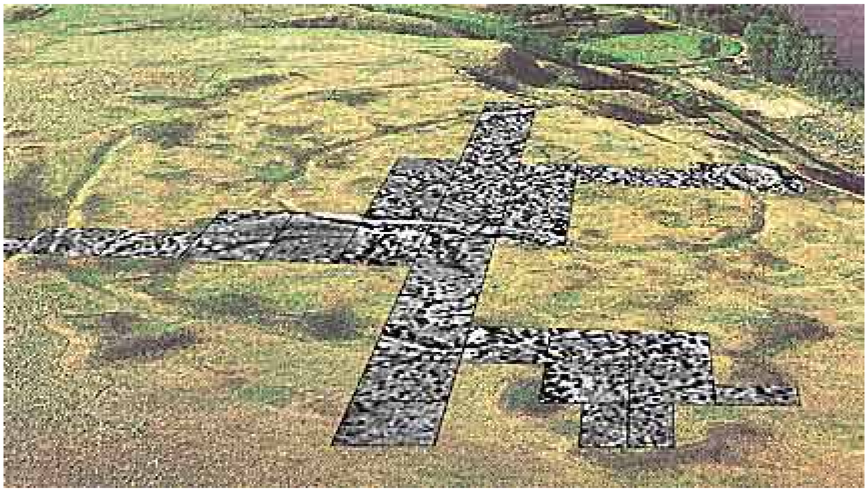


Image courtesy of Kenneth Kvamme

Another GRS presentation feature uses contouring and pseudo-three-dimensional views to highlight particularly large density or size contours. These may be lost in scaled maps which hide extremes within large categories. In the image above, the results of a resistivity and magnetic susceptibility survey at Double Ditch Village near Bismarck, ND are located within a three-dimensional photo of the site topography.

The image below shows the results of a resistivity scan which reveals a pioneer cabin. The feature's cut stone foundation blocks show up as highly resistant in the image, revealing a rectangular foundation split into two rooms. One room (left) has a resistant stone floor; the other (right), a less resistant earthen floor which was verified with coring.

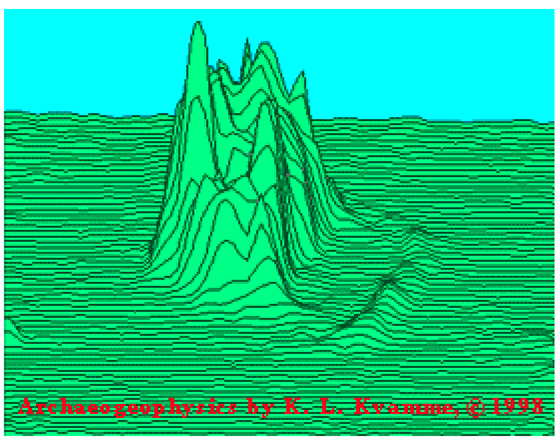


Image courtesy of Kenneth Kvamme

Perhaps the most well known GRS data presentation device is an "end-image" which portrays subsurface features found through GRS surveys overlaid onto accepted cartographic maps. These interpreted maps are perhaps most useful to archeologists as an aid in targeting excavations and to site managers for documenting site content. However, producing these images requires significant processing technical skill, experience with the local soil and feature types, and a successful GRS survey. A processed image integrated into an interpretable map is shown here.

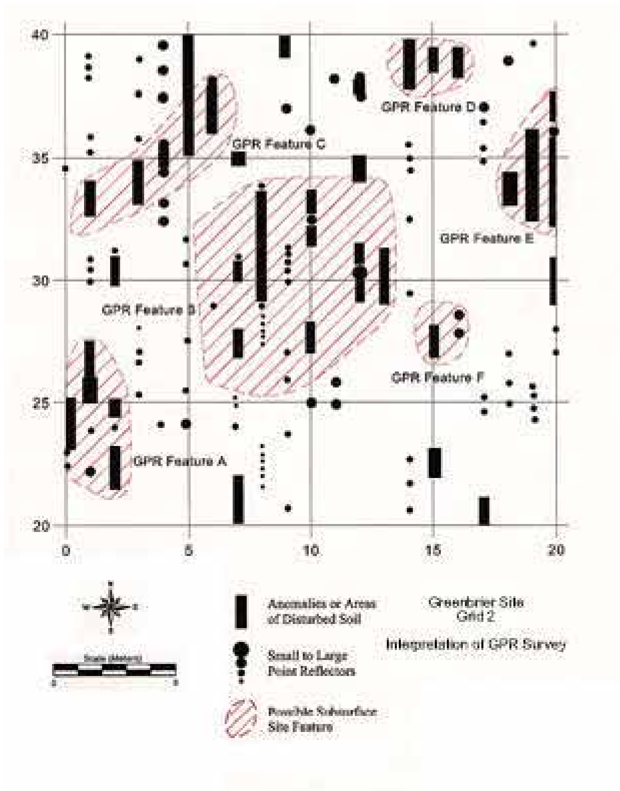


Image courtesy of Kenneth Kvamme

Following the presentation of the GRS data and results, a report should identify the importance of subsurface features given the project plans and nature of the site. It is desirable to link the background research, GRS survey data, and ground truthing results into a complete assessment of the site that can be captured in the summary section of the report.

5. Moving Forward

Creating a dialogue between practitioners and DOT management is necessary to advance GRS applications in each state. Integration of GRS into the standard operating procedures of state DOTs is a desirable goal. Obtaining information on the experiences of other DOTs with GRS can help states assess whether to expand their use of GRS. The following sections describe several implementation issues.

5.1 Internal Procedures and Protocols

Developing policies and procedures that incorporate GRS is one way to institutionalize GRS into transportation archeological investigations. These could include protocols to consider GRS alongside traditional methods as well as operating procedures to select GRS techniques for investigation. In some cases, both cultural resource staff and DOT management have had earlier experiences with older GRS technologies that were unsuccessful, and this early experience has deterred staff and management from pursuing newer GRS technologies for expanded application.

Most states have accessed GRS technology by contracting with outside consultants. States have typically used a pre-qualification process to select consultants for archeological services. States seeking to implement a GRS practice may consider developing an additional pre-qualification specification for GRS capabilities. Agencies that have conducted a pre-qualification process for archeology contractors report that the process has allowed them to deploy GRS capability to projects faster relative to a regular contracting process. This speed has been important on projects with tight timelines, where a regular contracting process for GRS services would have added significant time to the schedule.

> **MnDOT Deep Site Testing Protocol**
>
> Following a statewide predictive modeling effort, a suite of GRS technologies were evaluated alongside traditional methods at several locations. Results indicated that both trenching and coring were more reliable than GRS for detecting the presence of deeply buried sites. In the future, MnDOT may use GRS to identify site boundaries and subsurface patterns once some other Phase I survey method has indicated the presence of historic features.

Many DOTs have identified cost and time savings as principal factors in determining whether to pursue the use of GRS. Studies that illustrate the applicability and feasibility of GRS technologies go a long way toward increasing its acceptance. The Minnesota Deep Site Testing Protocols provides an excellent example of a state that systematically explored the capability of GRS to locate features in local conditions. (See text box). Other states may want to consider development of similar research into the suitability of GRS technologies in other areas.

5.2 SHPO Interactions

DOTs have experienced a variety of SHPO attitudes toward GRS. The SHPOs play a critical role in carrying out the National Historic Preservation Act. Most GRS work is conducted within the context of inventory, evaluation, or effect considerations under Section 106 where the SHPO is consulted regarding (1) 'reasonable and good faith effort' in the identification and evaluation of historic properties, and (2) in approaches to resolve adverse effects to historic properties. SHPO attitudes vary greatly depending on individual preferences and earlier experiences with older GRS technologies that may have been unsuccessful. Most states report using informal agreements between the SHPO and DOT concerning the appropriate use and application of GRS technology.

Implementation of a GRS practice in states that are not currently employing it requires a common understanding between DOTs and SHPOs. DOTs that apply GRS successfully have reported interacting with the SHPO at the earliest stages of an investigation in order to obtain support for the survey methodology. In Arkansas, the SHPO has been very supportive of using GRS applications, in part because both SHPO and DOT staff attended the same GRS workshop. Using this common background, the two agencies have been able to communicate informally regarding the use of GRS on DOT projects. In addition, the SHPO is using the workshop information to raise the profile of GRS within the state, by encouraging other agencies to consider it and working with local consultants to develop their expertise. While this current situation is effective, both agencies recognize that formal written guidance will be needed in the future, particularly if there are personnel or political changes in the state.

The Nebraska SHPO has been not only supportive of GRS technology for archeology, but an enthusiastic practitioner as well. He has assembled a resistivity device on his own and has offered its use for investigations. The SHPO's perspective is that GRS is an effective tool for refining the understanding of known sites. The understanding between Nebraska State Historical Society (NSHS) investigations staff and the SHPO regarding use of GRS has been informal; no written guidance about GRS is used.

6. Sources for Further Information

There are many information resources describing the field of GRS, best practices, and technical assistance which may be helpful to transportation agencies. Figure 3 shows selected GRS information resources that may offer particularly relevant information.

Figure 3. Selected GRS Information Resources

Center of Expertise	Relevant Content
Society for American Archaeology	Annual association conferences, Articles, links to resources
Society for Historical Archeology	Upcoming events and meetings, Links to ongoing research, Technical briefs
University of Arkansas	Center for Advanced Spatial Technologies; Dr. Kvamme leads workshops
University of Mississippi	Center for Archeological Research; Dr. Johnson leads workshops
California State University – Long Beach	Program in Archaeological Science
North American Database of Archeological Geophysics (NADAG)	Bibliographic materials, Information on instruments and contractors, Upcoming events, and a Project Database
U.S. Army Engineer Research and Development Center	Geotechnical Laboratory contains cultural resource project reports and published findings
U.S. Department of Defense	Defense Environmental Network and Information Exchange (DENIX) contains planning tools, handbooks, and guidelines for cultural resources
National Park Service	National Center for Preservation Technology and Training offers an 'Archeological Prospection' workshop taught by Steve DeVore
NASA Remote Sensing Tutorial	Available online and by CD, offers an introduction to remote sensing across a wide variety of applications

A number of the information resources are professional associations and university research centers that can provide access to expertise. While this list is not meant to be comprehensive, the academic programs included here offer ongoing technical workshops and hands-on training sessions that may be particularly useful to DOT practitioners. Other institutions in addition to these may also have the capability to conduct field surveys or offer training. State DOTs may wish to contact local universities in their region concerning training, workshops, and/or their technological capabilities. In addition, academic centers with archeological or anthropological expertise can provide regional knowledge bases concerning local historic considerations, soil conditions, and interdisciplinary research capabilities. Partnerships between Federal agencies, state agencies, and universities can be a cost effective means by which to begin using GRS in regions where it may not already have been demonstrated.

Similarly, professional associations offer an avenue for GRS practitioners and consumers of GRS results to further educate themselves. Membership in these groups provides an additional means to locate technical expertise. Information sessions, annual conventions, and panel discussions sponsored by these organizations can provide valuable information on GRS capabilities.

Workshops and hands-on technical training represent an important source of knowledge regarding GRS capabilities. Technical training also provides the opportunity to test applications in a variety of soil conditions and obtain first-hand experience interpreting results. A workshop sponsored by the National Park Service was noted by many state DOTs as their primary resource tool. The course provides attendees with background materials and experience collecting data and interpreting results. Additional workshops presented through the University of Mississippi and the University of Arkansas were offered less regularly, but also provide an introduction to GRS and the opportunity to operate several technologies.

Finally, a wide range of research materials and academic resources are available, providing information on general GRS issues, including case studies of successful projects, best practices guidance, and documentation of emerging technical applications. NADAG and the Defense Environmental Network websites both offer a comprehensive list of bibliographic materials, including books, articles, and journals which can be referenced. An upcoming book, *Remote Sensing in Archeology: An Explicitly North American Perspective,* edited by Jay K. Johnson, will address the special considerations of DOT archeologists in particular. The text draws lessons learned from his experience working with DOTs and includes chapters with detailed case studies and issues surrounding ground-truthing efforts, and will be available in 2006. Finally, the NCHRP-IDEA Project 107- Mobile Geophysical Technology: A Subsurface Scoping Tool for Reducing Unforeseen Roadblocks in Project Delivery is currently demonstrating the application of new mobile geophysical methods based on electromagnetic induction to improve the constructability of highway-related projects. The project seeks to integrate the technology into a DOT's Project Development Procedures, assisting in streamlining and enhancing project management, design, environmental review (*including archaeological*), right-of-way, and construction phases. By identifying potential problems during the planning and design phase, rather than "down the road", the "unforeseen" may be avoided, reducing design errors and omissions, schedule slippage, scope creep, and cost overruns.

While these resources do not represent a comprehensive list of available sources for information, they may provide a starting point with which to begin research into the suitability of GRS technologies in different soil types and survey situations.

7. Glossary of Terms

Active Methods
GRS technologies which emit a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object.

Anomaly
A discrete area characterized by geophysical values that differ from those of its surroundings and suggests the presence of localized geological, biological, or archaeological features.

Archeogeophysics
A range of noninvasive methods for delineation and analysis of subsurface archaeological and cultural features.

Conductivity Survey
Conductivity measures the ground's ability to conduct an electric current in order to measure differences in soil composition and formation.

Contrast
The degree to which the geophysical value of a feature of interest differs from the geophysical value of the surround soil matrix. Positive contrast features, such as those containing brick, stone, cement, or highly compacted soils have their own intrinsic properties and contrast highly with the surrounding soils. Negative contrast features are earthen or 'disturbed soil' features such as filled pits, house pits, middens, post molds, and field boundaries, which have varying degrees of geophysical values.

Cultural Resource Management (CRM)
The management of prehistoric and historic properties within the context of modern research, preservation, and land use planning laws, standards and practices.

Drift
A gradual and unintentional change in the reference value with respect to which measurements are made.

Geophysics
The study of earth using quantitative measurements of its physical properties. Measurements include seismic, gravity, magnetic, electrical, electromagnetic, and radioactivity methods.

Ground Penetrating Radar
The transmission of high frequency radar pulses from a surface antenna into the ground. The elapsed time between when this energy is transmitted, reflected from buried materials or sediment and soil changes in the ground, and then received back at the surface is then measured.

Ground Truthing
The process by which anomalies in GRS results are systematically investigated in order to verify and enhance information on their distribution and cultural significance.

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.

Magnetometry
A passive method, which maps local variations of the earth's magnetic field to distinguish anomalies and potential archeological features.

Noise
Random variation in the geophysical data value that is directly related to the archaeological record/feature.

Passive Methods
Methods that detect natural properties of the ground or energy emitted by objects other than the instrument. Passive survey techniques include magnetometry and gradiometry.

Remote sensing
The measurement or acquisition of information about an object or phenomenon by a recording device that is not in physical contact with the object. The measurement may be from a considerable distance. Common examples of modern remote sensing include aerial photography, sonar aboard marine ships, and radar used in airplanes.

Resistivity Survey
A technique that measures the ground's resistance to the passage of an electrical current; variations in resistance may be due to either soil variation or archeological features.

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 for a feature to even be detected.