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SELECTING ARCHAEOLOGICAL SITES FOR GEOPHYSICAL SURVEY

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SELECTING ARCHAEOLOGICAL SITES FOR GEOPHYSICAL SURVEY

1. Purpose. This Public Works Technical Bulletin (PWTB) presents practical guidance on how to identify terrestrial archaeological sites that are good candidates for investigation (including an evaluation of their eligibility for the National Register of Historic Places) using geophysical survey techniques. Geophysical techniques have many applications for marine archaeological sites, but these are not included here. This PWTB also provides guidance on selecting geophysical techniques that are appropriate for use at particular sites. It is designed for use by cultural resource managers, other land managers, and archaeologists who have little or no previous experience in the use of geophysical techniques. The emphasis here is on helping such individuals avoid wasting time and money on surveys that have relatively little probability of success because of unfavorable site conditions or the use of inappropriate methods.

2. Applicability. This PWTB applies to all continental U.S. (CONUS) Army facilities and lands managed by the Corps of Engineers, other federal and state agencies, and civilian lands.

3. References.

a. Army Regulation (AR) 200-4, “Cultural Resources Management,” 1 October 1998.

b. Appendix I lists additional references.

4. Discussion.

a. The National Historic Preservation Act of 1966 as amended (Public Law 89-665; 16 U.S.C. 470 et seq.) requires federal agencies to take into account the effect of their undertakings on any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register of Historic Places. AR 200-4 prescribes Army policies, procedures, and responsibilities for meeting cultural resources compliance and management requirements. AR 200-4's scope includes the National Historic Preservation Act (NHPA); American Indian Religious Freedom Act (AIRFA) and Executive Order (EO) 13007; Native American Graves Protection and Repatriation Act (NAGPRA) Archaeological Resources Protection Act (ARPA), 36 CFR 79; and other requirements and policies affecting cultural resources management.

b. Compliance with the NHPA and AR 200-4 typically requires the agency to identify historic properties within an area that may be impacted by an undertaking and to evaluate those properties' eligibility for nomination to the National Register of Historic Places (NRHP). In the case of archaeological sites, this evaluation often includes excavations designed to define a site's boundaries and to assess its integrity and historical and cultural significance relative to one or more historic contexts.

c. Evaluations of a site's NRHP eligibility based on hand excavation are highly invasive, expensive, and (because only a tiny portion of each site is excavated) potentially unreliable. In the eastern United States, for example, many prehistoric sites that have been plowed have no intact cultural stratum, but the preserved lower portions of pit features may contain scientifically important deposits. A site assessment program based on a grid of shovel tests and a small number of hand-excavated test units can easily fail to discover any of the pits. In many cases, such a failure could lead to the inappropriate recommendation that the site is not eligible for the NRHP.

d. Geophysical techniques can be used to search for subsurface features across a large portion of a site. Excavation units can then be targeted directly on possible features, thereby improving the likelihood of detecting intact, culturally and historically significant archaeological deposits. Such targeted excavation can reduce the volume of excavation required to evaluate a site's NRHP status and may thus reduce costs associated with fieldwork, analysis, and curation. The potential benefits of geophysics can easily be lost, however, if surveys are conducted at sites that do not offer favorable conditions, or if the geophysical techniques used are inappropriate for a particular site. This Bulletin provides recommendations that will reduce the likelihood of disappointing or misleading results from geophysical investigations. Misleading results include situations where the geophysical data have so much noise and/or clutter as to complicate or preclude the detection of features, or where the use of an inappropriate sensor simply fails to detect features that are present. Misleading results can also occur in the absence of adequate ground truthing excavations if anomalies that are associated with clutter are erroneously interpreted as features. In these examples, recognition that the geophysical data are unreliable might require the expenditure of additional funds. Failure to recognize that the geophysical results are unreliable may lead to inappropriate decisions about site management.

e. Appendix A outlines the history and current status of geophysics in Cultural Resources Management in the United States.

f. Appendix B provides nontechnical definitions of a few important geophysical concepts (contrast, anomaly, noise, clutter, and data density). It is essential that all individuals who sponsor, conduct, or desire to understand the results of a geophysical survey be familiar with these concepts.

g. Appendix C describes the four categories of geophysical instruments (magnetic, ground penetrating radar, electrical resistance, conductivity) that are commonly used to investigate archaeological sites in the United States.

h. Appendix D identifies the factors that play an important role in selecting sites for geophysical survey: vegetation, near surface disturbance, metallic clutter, rocks, multi-component sites, and moisture and drainage.

i. Appendix E presents a decision tree to assist in determining whether a site is a good candidate for geophysical survey.

j. Appendix F provides guidance on selecting geophysical techniques appropriate for use at a particular site.

k. Appendix G contains the Conclusions.

l. Appendix H presents figures that exemplify problems posed by noise, clutter, and seasonal variation in contrast.

m. Appendix I lists references for this PWTB.

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Appendix A: The Status of Geophysics in Cultural Resources Management

Introduction

Geophysics is a suite of techniques (including magnetics, electrical resistance, conductivity, and ground penetrating radar) that can be used to detect, map, and characterize subsurface phenomena including archaeological deposits. An effective use of geophysics can improve the reliability, reduce the invasiveness and, in some cases, lower the overall costs of archaeological investigations. Despite these potential advantages, the adoption of geophysics by resource managers in the United States has been very gradual. Equipment costs and a significant learning curve are contributing factors. Perhaps the primary reason for the relatively slow adoption of geophysics by archaeologists in the United States is the perception that it is a risky venture (Hargrave et al. 2002:89, 106). Although a number of successful surveys have been reported in the literature (Arnold et al. 1997; Bevan 1998; Conyers and Cameron 1998; Dalan 1991; Hargrave et al. 2002; Kvamme 2001, 2003; Sternberg and McGill 1995), most Cultural Resources Management (CRM) professionals in the United States still have little or no first-hand experience in using geophysics. Such individuals are likely to make some very basic mistakes that can result in a disappointing survey. Fortunately, most of the mistakes that plague first-time users of geophysics can easily be avoided.

This document provides basic, nontechnical guidance to CRM professionals and other resource managers who want to use geophysics to investigate a particular site. This guidance should also be useful to those who wish to incorporate geophysics into their overall CRM or research program. The focus here is on two of the first and most important decisions the novice user will confront: (1) deciding whether a particular site is a good candidate for geophysical survey, and (2) deciding which instruments are most likely to be effective. The goal is to reduce the risk of disappointing or misleading results from a geophysical survey, and thus, to help readers learn how to best benefit from the potential advantages of geophysics.

Brief History of Geophysics

Although many archaeologists in the United States still view the use of geophysical techniques as “high-tech,” none of the methods discussed in this PWTB are new. The first systematic geophysical survey on a U.S. archaeological site was conducted at Williamsburg, VA, in 1938. Mark Malamphy used equipotential (a method that is not widely used) to search for a stone vault suspected to be associated with an early church. A promising anomalous area was identified, but excavation revealed no archaeological features. The area was resurveyed some 50 years later and subsequent ground truthing suggested that the geophysical anomaly was associated with differential leaching of small fossil shells (Bevan 2000:56; Gaffney and Gater 2003:13-14).

Electrical resistance was first used at an archaeological site in 1946 by Richard Atkinson. With a Megger Earth Tester (then widely used in civil engineering) and a switching system of his own design, Atkinson was able to detect moist, silt-filled ditches that had been excavated into dry natural gravel at Dorchester-on-Thames, UK (Atkinson 1953; Clark 2001; Gaffney and Gater 2003:14). In the United States, Christopher Carr (1982) was an early advocate for the use of resistance survey in archaeological research.

Another milestone application of geophysics occurred in 1958, when Martin Aitken used a proton magnetometer to detect an early kiln near Peterborough, UK (Aitken 1958, 1974; Gaffney and Gater 2003:16-17). Aitken also detected earth-filled pits — a capability that would have important implications for the widespread use of magnetic techniques in the United States.

During the 1970s, geophysics began to be integrated into archaeology in Great Britain and parts of Europe. Roman and late prehistoric sites in those areas often include metal artifacts, stone and masonry architecture, and fired clay roofing tiles. Such materials contrast sharply with their surroundings and could be identified in pre-computer era maps that were characterized by relatively few, widely spaced data points (Hargrave et al. 2002:89; Isaacson et al. 1999; Scollar et al. 1990:371).

John Weymouth (Weymouth 1976, 1985, 1986; Weymouth and Nickel 1977; Weymouth and Woods 1984) and Bruce Bevan (Bevan 1977, 1983; Bevan and Kenyon 1975) conducted a number of early surveys in the United States that demonstrated the usefulness of geophysics, particularly at sites characterized by relatively high-contrast features. In the United States, however, the single-most common type of prehistoric feature is the earth-filled pit. Ferrous metal artifacts are absent in the prehistoric record and stone architecture is found only in restricted areas. It was not until the revolution in information technology allowed the collection, processing, and mapping of thousands of data values that relatively subtle features like earth-filled pits could consistently be detected in magnetic surveys (Hargrave et al. 2002:89; Kvamme 2001:354).

Ground penetrating radar (GPR) was a somewhat later addition to the geophysical arsenal. GPR was initially developed to locate subsurface cavities such as mine shafts and tunnels. It was quickly adopted by geology, civil engineering, and many other disciplines (Conyers and Goodman 1997). In 1975, one of the first archaeological applications of GPR was an effort to map buried walls at Chaco Canyon, NM (Vickers et al. 1976). Other early U.S. GPR surveys focused on historic features such as cellars and buried stone walls (Bevan and Kenyon 1975; Kenyon 1977). Use of GPR in the United States continued through the 1980s and 1990s, demonstrating the technique’s potential for detecting a wide variety of feature types (Conyers and Goodman 1997:20).

Although geophysics is not yet thoroughly integrated into CRM in the United States, it is being used more frequently than ever before (Johnson 2006; Kvamme 2001, 2003; NADAG 2004; Silliman 2000; University of Mississippi 2004a, 2004b). A number of large area surveys – many of them unpublished but reported at professional conferences – have demonstrated geophysics’ potential contributions to archaeological investigations of late prehistoric and historic occupations (Butler et al. 2004; Clay 2001; Hargrave 2004; Hargrave et al. 2002; Hargrave et al. 2004; NADAG 2004; Peterson 2003). Geophysics is now an area of specialization in archaeological graduate programs at several universities (e.g., University of Mississippi-Oxford, University of Arkansas-Fayetteville), and in-house geophysical capabilities exist at university-affiliated research units such as the Arkansas Archaeological Survey, Glenn Black Laboratory at Indiana University-Bloomington, and Indiana University and Purdue University-Fort Wayne. Federal agencies including the National Park Service (Midwestern Archaeological Center), U.S. Army Corps of Engineers (Engineer Research and Development Center, Construction Engineering Research Laboratory); and a number of Districts including New England, Savannah, St. Louis, and Vicksburg), and several Army installations (Fort Riley, KS;

Fort Drum, NY) have in-house geophysical capabilities for terrestrial sites; (Mobile and New York Districts have in-house capabilities for marine geophysics). A number of small geophysical consulting firms focus almost exclusively on archaeological applications.

Trends suggesting an increased use of geophysics by U.S. archaeologists in the future include the gradually increasing labor costs of hand excavation (with no corresponding increase in rates of excavation), versus significant improvements in the performance of geophysical instruments relative to their cost (Kvamme 2001:354). Social and legislative changes in CRM, including an increased role for Native American groups in the management of prehistoric cultural resources on tribal and federal lands, suggest the need for noninvasive or, at least, minimally invasive approaches for evaluating the NRHP eligibility status of some sites. On balance, CRM personnel in the U.S. Army Corps of Engineers, other federal and state agencies, and the private sector will find it increasingly useful to be aware of the potential benefits – and the limitations – of geophysical techniques.

Appendix B: Important Geophysical Concepts

In keeping with its goal of providing nontechnical guidance, relatively few technical concepts are discussed in this Bulletin (see Clark 2001 and Scollar et al. 1990 for detailed technical over-views). It is essential, however, for those who plan to use geophysics or simply to work with a geophysical consultant to have a firm understanding of several key concepts.

Contrast

Contrast refers to a difference in geophysical properties between a subsurface archaeological deposit and the surrounding soil (Somers and Hargrave 2003:92). During excavation, archaeologists rely on visual (color) and textural contrasts to differentiate a pit from the surrounding soil matrix. Features also often contrast with their surroundings in terms of characteristics such as soil compaction, moisture retention, artifact contents, and relative abundance of organic and burned materials. These characteristics – familiar to all archaeologists – are correlated with several geophysical properties (including magnetism, resistance to the passage of an electrical current, and ability to reflect radar energy) that can be measured with great precision (Kvamme 2003:440; Scollar et al. 1990:20). Features that contrast sufficiently with their surroundings in one or more of these properties can be detected in a geophysical survey conducted using an appropriate sensor. Note, however, that the strength of the contrast can be highly variable from site to site. This variability depends upon such factors as the local soils, moisture, bedrock and rock inclusions in the soil, as well as the nature of the archaeological features.

Anomaly

Geophysical surveys of archaeological sites generally result in maps that show the locations of anomalies. Anomalies are simply localized areas that exhibit geophysical data values distinct from those of their immediate surroundings (see, for example, the discrete black and white magnetic anomalies in Figure 1) (Clark 2001:168; Kvamme 2001:380; Somers and Hargrave 2003:92). This distinction is a manifestation of contrast in the property measured by the geophysical instrument. Anomalies may be associated with subsurface archaeological deposits such as pits, hearths, house floors, and so forth. Unfortunately, natural and recent cultural phenomena such as plow furrows, looter pits, military fighting positions (“foxholes”), unexploded ordnance (UXO), tree roots, rodent burrows, and large rocks are also often the source of geophysical anomalies.

Noise

Noise is a seemingly random component of geophysical data values related to characteristics of the instrument, soil, vegetation, or rock inclusions, or flaws in the surveyor’s data collection techniques (Clark 2001:169; Heimmer and De Vore 1995:76; Somers and Hargrave 2003:92). Noise is important because it diminishes the likelihood of detecting subtle (low contrast) anomalies. For example, on a magnetically quiet site, data defects (noise) associated with the manner in which a surveyor carries a gradiometer instrument can introduce a random component to the data that is greater than the contrast between many features and their surroundings (Figure 2). Irregular walking can also cause periodic errors that, while not really random, have the same effects as noise. Using proper survey techniques can reduce some sources of noise and this will increase the chances of detecting subtle features.

Clutter

Clutter refers to nonrandom variation in the geophysical data that is not related to the phenomena of interest (that is, archaeological deposits) (Conyers and Goodman 1997:50; Somers and Hargrave 2003:92). Recent metal is one of the most commonly encountered sources of clutter. In a magnetic survey, recent ferrous metal objects on or near the surface will be manifest by relatively strong anomalies that make it much more difficult to detect lower contrast anomalies associated with prehistoric features (Figures 1, 3, 4). Other common sources of clutter include rocks, plow furrows and tree roots. Note also that historic artifacts and features can act as clutter if the primary objective of a geophysical survey is to detect anomalies related to prehistoric features.

Data Density

Data density — the number of data values collected per square meter — is important in geophysical survey because it affects image resolution, noise, and survey cost (Somers and Hargrave 2003:93). For example, if only one data value is collected per square meter, each pixel on the resultant map of the raw data will represent one square meter. For some techniques, features less than 1 meter in diameter are unlikely to be detected. This is particularly true for relatively low-contrast features. Even if a small feature is detected, it will appear to fill the entire pixel in a map of the raw data. Data processing and display techniques such as contouring and the interpolation of additional data points can produce a map that appears to have finer resolution, but the true spatial resolution of the map will never be better than the limitations imposed by the actual data density.

Unfortunately, the advantages of high data density surveys are offset by higher costs. In practical terms, it often takes nearly twice as long to collect twice as many data values, and this obviously increases time in the field and project costs. In most cases, one should use a data density that is adequate to meet survey goals given the conditions encountered at a particular site, but one should not exceed that data density level (Somers and Hargrave 2003).

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Appendix C: Geophysical Sensors

Geophysical instruments are generally categorized in terms of the properties they measure. The four instrument categories that are most widely used to investigate U.S. archaeological sites are magnetic, electrical resistance, ground penetrating radar (GPR), and conductivity (Bevan 1998; Clark 2001; Gaffney and Gater 2003; Kvamme 2001; Heimmer and De Vore 1995; Scollar et al. 1990). Only these four categories are discussed here. For most of the categories, one can choose between instruments from several manufacturers.

Magnetic Instruments

Magnetic surveys of archaeological sites can be conducted in several ways. The earth's total magnetic field can be measured using a single moving sensor, or the magnetic field gradient can be measured by moving a pair of sensors (Bevan 1998; Clark 2001; Gaffney and Gater 2003; Kvamme 2001, 2005; Heimmer and De Vore 1995; Scollar et al. 1990). In fact, both approaches require the use of two sensors. If a single total field sensor is systematically moved across the survey area, a second sensor must be kept in a stationary position to record diurnal variation in the earth's magnetic field. Diurnal variation — which is generally far more substantial than that associated with archaeological deposits — is removed by using only the difference between the values recorded by the two instruments (Clark 2001:67; Kvamme 2001:358). This difference represents the spatial component of variation in the magnetic values. One disadvantage of using a single scanning (moving) sensor is that data values are more strongly influenced by nearby large metal objects such as fences, signs, utility poles, and pipes, as well as by materials that occur well below the near-surface cultural strata.

Magnetic surveys can also be conducted using gradiometers. These are instruments that consist of two magnetic sensors separated by a fixed distance, typically 0.5 to 1 meter. When the two sensors are in vertical alignment the uppermost sensor, being further from the ground, records a weaker signal. The difference between the two readings is a measure of the magnetic field gradient (Gaffney and Gater 2003:40). Advantages associated with use of a gradiometer include fewer problems with extraneous metal in and near the survey area, and better resolution of near-surface anomalies (Breiner 1999). Using a gradiometer also obviates the need to remove diurnal variation in the magnetic data.

Gradiometers can consist of a pair of total field sensors or a pair of fluxgate sensors. The latter are much more sensitive to variation in their orientation relative to the earth's magnetic field. A disadvantage of the fluxgate gradiometer is the need to keep the paired sensors in proper balance and alignment. If this is not done, slight (and essentially unavoidable) deviations in the instrument's horizontal and vertical orientation while the survey is underway will introduce noise into the data (Figure 2). Advantages of fluxgate gradiometers can include their small size and light weight. Competent surveys can be done with all of the widely used gradiometers, and those sponsoring a geophysical survey for the first time should work with an experienced specialist, and allow him or her to decide on the type of magnetic sensor to use.

Electrical Resistance

Electrical resistance is probably the most widely applicable technique for archaeology in the United States. Resistance instruments measure localized variation in the soil's resistance to the passage of an electrical current (Bevan 1998; Clark 2001; Gaffney and Gater 2003; Kvamme 2001; Heimmer and De Vore 1995; Scollar et al. 1990). Variation in electrical resistance is closely correlated with the amount of moisture in the soil. Coarse grained, well-drained soils (gravels, sands) exhibit a relatively high resistance; whereas fine grained soils (clays, silts) that hold more moisture exhibit lower resistance. Compared to soil, rocks are characterized by very high resistance. Electrical resistance is useful on archaeological sites because cultural features represent localized disturbances to natural soil strata, and often include concentrations of organic materials, rocks, and other artifacts. These disruptions to the natural soils are associated with a localized contrast in moisture retention and electrical resistance.

The electrical resistance instruments most widely used in archaeology consist of two or more probe electrodes and a resistance meter mounted on a light-weight frame (Gaffney and Gater 2003; Kvamme 2001:359). Two stationary remote probes placed in the ground some distance from the survey area are also connected to the resistance meter. At each data collection position, a weak electrical current is introduced into the ground through one probe, and the voltage is measured by an adjacent probe. Because data are collected only when the mobile probes are inserted into the ground, collection of resistance data is slow relative to other types of sensors. One result of this is that fewer (typically 1 to 4) data points per square meter are collected, and this results in poorer resolution and less ability to detect low contrast anomalies associated with relatively small features (such as small pits) (Gaffney and Gater 2003:95). Another disadvantage of electrical resistance is that feature contrast can vary significantly depending on soil moisture. Surveys results are less likely to be reliable when the soil is extremely dry or highly saturated (Figure 1) (Clark 2001:125; Kvamme 2001:361). Under normal conditions, however, resistance instruments are very well-suited for detection of larger features based on contrasts in soil type. Examples include ditches, trenches, house basins, mounds, and historic architectural remains.

Electrical resistance offers several advantages. It is perhaps the most widely applicable technique. By altering the spacing between the mobile probes one can, to some extent, control the depth of survey. Another important advantage of electrical resistance is that it is not influenced by metallic objects, and so can be used at sites that are littered with recent metallic debris (Kvamme 2001:358-363).

Ground Penetrating Radar

GPR instruments work by transmitting electromagnetic energy (very high frequency [VHF] radio pulses) into the ground and measuring the amount of energy that is reflected back and the time it takes to reach the surface (Bevan 1998; Conyers and Goodman 1997; Gaffney and Gater 2003:47; Kvamme 2001:363-365). Soils, rocks, and buried objects and features differ in the degree to which they absorb or reflect the energy. Energy is reflected back to the surface more quickly from shallow objects than from those that are deeper. The time required for reflectance can thus be used to estimate the depths of objects and surfaces, so this technique has great benefits for archaeology. GPR is particularly useful as a means of mapping the interfaces between soil strata and detecting voids. Soil moisture increases conductivity, and saturation can cause much of the electromagnetic energy to be attenuated rather than reflected (Conyers and Goodman 1997:28, 53). In other words, soil moisture reduces the amount of energy that reflects back to the surface. Sites characterized by clayey soils that tend to hold moisture are generally not good candidates for GPR, whereas dry sandy soils are very favorable.

The GPR instruments commonly used in archaeology consist of a transmitter and an antenna that are systematically moved across the ground surface. Some systems are pulled at a constant speed along the survey transect, whereas others use a wheel to measure distance, permitting the instrument to be moved at varying speeds (Conyers and Goodman 1997:25). The moving portion of the system is linked to a laptop computer and battery by a heavy cable. GPR systems now being manufactured can collect data at rates comparable to electrical resistance.

Earlier GPR surveys produced only a series of profile maps that were difficult for nonspecialists to interpret. Horizontal maps (‘time slices’) of GPR anomalies are now produced for potentially thin ranges in depth (Conyers and Goodman 1997:172). While interpretation still requires an understanding of how archaeological features and other subsurface phenomena can be manifest by anomalies, time slice maps have greatly increased the usefulness of GPR to archaeologists who do not specialize in geophysical survey. Processing of GPR data is significantly more time consuming than for magnetics and electrical resistance data (Conyers and Goodman 1997; Kvamme 2001:360).

Conductivity

Although conductivity is simply the reciprocal of resistance, conductivity surveys of archaeological sites are conducted using electromagnetic induction instruments (e.g., the Geonics EM38) that work quite differently than the probe resistance system described above (Bevan 1998:30; Clay 2001, 2005). A magnetic field generated by the EM38 causes electrical currents in the soil that in turn create a magnetic field that is measured by the instrument (Bevan 1998:30; Clark 2001:34). The EM38 thus responds to both the conductivity and the magnetic properties of the soil. Conductivity data can be collected much more quickly than electrical resistance because there is no need to insert probes into the ground, or to occasionally relocate any remote probes. Disadvantages of conductivity surveys include the EM38’s sensitivity to metal artifacts and electrical interference (e.g., lighting, power lines) (Bevan 1998:39; Clark 2001:171; Clay 2006). Aside from a response to metal, conductivity maps tend to resemble maps of resistance data, although image quality is typically somewhat poorer. Like resistance, conductivity is a good method for detecting anomalies that are based on contrasts in soil type. Small pits are generally not detected, but larger pit features, ditches, and the plowed-down remains of earthworks can be detected very effectively. EM38 instruments are affected by large increases in temperature, and data processing is more time consuming than is the case with resistance or magnetics (Clay 2006).

Other Methods

Magnetic susceptibility, self potential, gravity, thermal, and seismic techniques are sometimes used to investigate archaeological sites. At present, however, they are not appropriate choices where the survey objective is to reliably identify a wide range of potentially low contrast subsurface archaeological features across a relatively large area. Magnetic susceptibility may, however, soon be more widely useful in the form of hand-held and/or “down-hole” sensors used to detect buried cultural strata, distinguish cultural features from natural deposits, and to detect discrete deposits that have little or no visual expression in the floors and walls of excavation units and trenches (Dalan 2006).

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Appendix D: Site Selection Issues

Site characteristics strongly affect the likelihood of a successful geophysical survey. In most cases, the effects of these characteristics are related to the concepts discussed above (i.e., contrast, noise, and clutter).

All of the geophysical techniques commonly used to investigate archaeological sites (magnetic, electrical resistance, GPR, and conductivity) require a sensor to be moved systematically across the site’s surface. In most cases, data are collected in 20 by 20-meter squares, although 30 by 30 and 50 by 50-m squares are frequently used, particularly in GPR surveys. Most surveyors use nonmagnetic tapes or ropes to temporarily define the squares and data collection transects. While some instruments are now equipped with GPS units that could hypothetically allow one to wander across the site almost at random and later use the locational data to assemble a coherent map, this approach is not recommended, particularly for prehistoric sites that are likely to have very low contrast features.

Vegetation

Vegetation can affect a geophysical survey in several ways, including the rate of survey coverage and the amount of noise and clutter in the data and its effect on the reliability of survey results (Gaffney and Gater 2003:78; Kvamme 2001:360). The mowed grass found at many state and federally managed archaeological sites represents the ideal situation for geophysical survey. Unfortunately, this is rarely encountered in surveys associated with CRM projects. Agricultural fields where the crops have either not yet been planted or not yet grown high enough to make walking difficult can also represent excellent conditions for geophysical survey. One exception to this, however, is a situation where the survey grids have been laid out in such a way that they cross-cut the crop rows. The constant need to step across crop rows or plow furrows can result in much slower rates of survey. In the case of magnetic gradient surveys, inconsistent walking often causes one to carry the instrument improperly, resulting in data that include a substantial noise component (Gaffney and Gater 2003:80) (Figure 2). Some of the periodic defects associated with irregular walking can be corrected during data processing. However, deep plow furrows that run at an angle to the data collection transects often cannot be removed. The presence of such pervasive clutter may dramatically lessen the potential for detecting smaller, lower contrast anomalies (Figure 3). In short, data collection traverses should always be oriented parallel to deep furrows.

Many archaeological sites in the eastern United States are located in wooded areas, and here vegetation can pose serious limitations on the effectiveness of geophysical surveys. Most surveys are conducted with instruments that automatically collect data at fixed time or distance intervals. Such instruments can be manually triggered, but this dramatically slows the pace of data collection. Trees and undergrowth frequently make it impossible for the surveyor to walk directly down the data collection transect. One reading may need to be taken 20 cm to the left of the tape, whereas a few meters later the surveyor may be forced to shift 50 cm to the right of the tape. Unfortunately, when the data are processed, the software plots the values as if they were collected precisely along the traverse. The effect of dodging around obstacles is to introduce a potentially substantial amount of noise into the data. Maps made using such data may simply not be very accurate in terms of anomaly locations and shapes.

The extensive root systems associated with large trees pose additional problems for geophysical survey. In a magnetic survey, large roots that displace very iron-rich soils might be detected as weak positive or negative anomalies. In most magnetic surveys, however, tree roots would be invisible (Kvamme 2001:360). In resistance and conductivity surveys, a large tree’s root system may absorb much of the local moisture, causing large high resistance or low conductivity anomalies. Roots can be directly detected (due to differential reflectance of electromagnetic energy) by GPR (Kvamme 2001:360).

It is difficult to predict the extent to which tree roots and above-ground vegetation may compromise a geophysical survey. Sites characterized by relatively large, high contrast features (such as historic habitation sites) may be less problematic, whereas ephemeral prehistoric sites that include small, low contrast features may be highly compromised.

Near Surface Disturbance

Agricultural activities (plowing, disking) represent the most common type of near surface disturbance in the eastern United States (Figure 3). The problems posed by plowing are, in many cases, relatively minor. As explained above, survey grids should be oriented so that the surveyor can walk with the furrows rather than across them. It is usually preferable to survey fields long after their most recent plowing, as a well weathered and compacted surface permits more consistent walking. Very recently plowed fields have many small voids between the soil clods, and these will increase noise (Gaffney and Gater 2003:84).

Cattle can disturb the uppermost soil layer and the effects of their hooves are less homogeneous than plowing. Well established trails are likely to be visible as clutter in the geophysical data.

The effects of heavy construction equipment on a geophysical survey are variable. Sites where heavy equipment has been used extensively are very poor candidates for survey. Repeatedly used haul roads are likely to be highly visible in a geophysical map, as are the effects of sporadic cuts by a bulldozer or front-end loader (Hargrave et al. 2002) (Figures 6 and 7). On the other hand, the author has (for experimental purposes) done a magnetic survey on a prehistoric habitation site where a track hoe had recently been used to carefully remove the plow zone in preparation for excavation of the exposed features. Although the survey results were somewhat different from those of a survey conducted prior to stripping, few negative effects of stripping were apparent. It is likely that the actions of heavy equipment are most detrimental to geophysical survey in situations where equipment use has been heavy but uneven, with some areas having been cut and others filled.

Metallic Clutter

Recent metallic trash is one of the most common and frustrating site conditions that can adversely affect a geophysical survey (Gaffney and Gater 2003:83; Kvamme 2003:360). Metal is particularly common on military installations and sites near modern or historic habitations. Clutter associated with ferrous metal is obviously most troublesome for magnetic surveys but it can also affect conductivity data (Clay 2006). Small bits of metal near the surface or larger, deeper pieces are often manifest by strong (often dipole) anomalies that make it difficult or impossible to detect the far weaker indications of prehistoric features (Figure 1). During data processing values that exceed a selected threshold can be deleted. This can reduce the effects of strong values associated with metal on the data set’s mean and standard deviation, but it does little to minimize the obfuscation of weak anomalies.

The size, shape, and amplitude (data value) of an anomaly associated with metal depends on the object's depth, mass, shape, the relative amounts of permanent and induced magnetization, and orientation relative to earth's magnetic field (Breiner 1999:18). Archaeologists generally have little control over the metal trash that is present at a site. Wire pin flags used by archaeologists are particularly troublesome and should not be used at sites where future geophysical surveys may occur. Similarly, nails or spikes used as reference points should not be left in or near excavation units, particularly if the remaining portions of features are present in the unit walls (Figure 6). Metal associated with fences, underground pipes, and utility poles also poses problems for magnetic surveys (Figure 4). In most cases, however, the effects of such objects are highly localized (Gaffney and Gater 2003:81-83).

Rocks

Rocks can represent a significant source of clutter in a geophysical survey. In some areas, igneous and iron-rich rocks can pose problems similar to those associated with metallic trash. Abundant rocks and near-surface bedrock can also represent a significant source of clutter in resistance and GPR surveys (Kvamme 2001:360). Unless rocks are both magnetic and abundant, the use of geophysics should not be decided against simply because they are present. If a magnetic survey is being considered, a sample of rocks from the site should be sent to a geophysicist, who can easily determine if they are sufficiently magnetic to pose a problem.

Multi-Component Sites

Throughout much of the United States, it is common to find that prehistoric archaeological sites often have historic occupations as well. This is particularly true for sites located on high ridges on the floodplain in rural areas, and at many locations near modern population centers. First-time users of geophysics may not anticipate the extent to which metal artifacts and high-contrast historic era features and architectural debris can obfuscate the more subtle anomalies associated with prehistoric features. Magnetic and conductivity surveys will be the most severely affected, and the presence of a historic habitation is an excellent reason to use a nonmagnetic technique if primary interest is in the prehistoric occupation. If the historic occupation is of equal interest, of course, a magnetic survey may be very informative.

Moisture and Drainage

Excessive moisture is generally a temporary condition, since most sites that exhibit evidence of significant past occupation were not located in very poorly drained areas. Areas that are dry enough for careful walking are suitable for magnetic survey. The potential for success of a resistance survey is greatly diminished under extreme moisture conditions (Figure 5). Extremely dry soil can make it very difficult to measure resistance. Both extreme dryness and saturation can greatly reduce a feature’s contrast with its surroundings, and this will affect both resistance and (to a lesser extent) conductivity survey results. Soil saturation can greatly decrease the depth of penetration and effectiveness of a GPR survey (Clark 2001:51-56; Kvamme 2001:361).

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Appendix E: A Decision Tree for Site Selection

The most certain way to prevent disappointing or misleading results from a geophysical survey is to avoid using geophysics at inappropriate sites. Most areas have many sites where geophysics can be used in a productive, cost-effective way. Rarely is there any reason to conduct a geophysical survey at a site where conditions do not favor that approach.

Earlier discussion provided basic information needed to avoid sites highly inappropriate for geophysical survey. This appendix reiterates much of the same information in the form of a decision tree (Figure E1). When considering a geophysical survey at a particular site, the user should address each of the numbered topics (in the order given) and select the appropriate ‘yes’ or ‘no’ answer. The user will be directed to continue through the decision tree, to take some required action (for example, clear vegetation prior to a survey), or simply be advised to not use geophysics. Note that a careful use of the decision tree should also help in deciding whether to incorporate a frequent use of geophysics into one’s CRM or research program. In that case, the decision tree should be applied to a group of sites that is representative of the overall site population for the region under consideration.

There will, of course, be exceptions to each of the recommendations included in the decision tree. Recognizing when such exceptions occur is a benefit of practical experience. The goal here is to help those who do not have much experience in using geophysics avoid disappointing results. To achieve this goal, it is necessary to err on the side of caution, and recommend against using geophysics at sites where it might (but might *not*) work well. Additional information that may clarify many aspects of the decision tree’s logic and recommendations is provided in the following section. Figure E2 is a simplified decision tree.

---

1. Consider the archaeological record:

a) Is it likely that discrete subsurface deposits are present?

Yes: Continue

No: Do not use geophysics.

2. Consider vegetation:

a) Can you walk one-meter traverses across the survey area without dodging around obstacles?

Yes: Continue

No: Clear vegetation (a potentially significant cost issue) or do not use geophysics.

3. Consider clutter:

a) Is there a substantial historic artifact scatter on a site where the primary interest is the prehistoric occupation?

Yes: Focus on nonmagnetic methods. If possible, choose electrical resistance over conductivity.

No: Continue.

b) Does the site have a substantial amount of recent metallic trash?

Yes: Focus on nonmagnetic methods. If possible, choose resistance over conductivity.

No: Continue

c) Does the site contain a substantial amount of magnetic rocks?

Yes: Focus on nonmagnetic methods. If possible, choose resistance over conductivity.

No: Continue

d) Is a large percentage of the survey area near large metal objects (poles, pipes, fences, buildings)?

Yes: Focus on nonmagnetic methods. If possible, choose resistance over conductivity.

No: Continue

Figure E1: Decision tree for identifying suitability of sites for geophysical survey (Continued).

4. Consider near-surface disturbances:

a) Has the site been under recent or historic cultivation?

Yes: Continue

No: Continue

b) Has a significant portion of the site been impacted by other heavy equipment?

Yes: Do not use geophysics.

No: Continue

5. Consider moisture and soil conditions:

a) Is the survey area water-saturated?

Yes: Do not use resistance or GPR. Reconsider your answer to 1a. Conductivity may also be problematic. Use magnetic methods if the area is dry enough for careful walking.

No: Continue

b) Is the survey area devoid of moisture (drought conditions)?

Yes: Do not use resistance (until more moisture is present). Conductivity may also be problematic. Use magnetic methods. Use GPR if the soil is sandy.

No: Continue

c) Do the cultural deposits occur in a clayey soil?

Yes: Do not use GPR. Use magnetic, resistance, or conductivity methods.

No: Continue

d) Do the cultural deposits occur in a sandy soil?

Yes: Focus on techniques other than resistance, especially GPR.

No: Continue

Figure E1 (Concluded): Decision tree for identifying suitability of sites for geophysical survey.

Decision tree notes

1a: In general, do not use geophysics unless there is reason to assume that discrete subsurface deposits are present. These may include features (e.g., pits, hearths, architectural remains) or larger deposits like midden lenses. Features with maximum dimensions smaller than about 30 cm are very unlikely to be detected unless they are strongly magnetic or otherwise very high contrast. Features less than about 50 cm will be under-represented (many will not be detected) unless they are strongly magnetic or otherwise high contrast. Features in this size range will rarely be detected by resistance surveys.

2a: For all methods it is very important to move the instrument directly along the data collection transect. The need to dodge around obstacles such as trees will introduce spatial errors (noise) that will dramatically reduce the reliability of the resultant maps. Resistance instruments can be used in wooded areas but clutter associated with roots can pose a significant problem (Gaffney and Gater 2003:80; Kvamme 2001:360).

The best way to clear vegetation in preparation for a geophysical survey is to cut brush and small trees right at ground level. It is not desirable to pull small plants out by the roots, as this is likely to disturb the soil far more than cutting. For larger trees, remove branches sufficiently to permit unobstructed walking.

3a: Magnetic clutter (such as anomalies associated with relatively small ferrous metal artifacts) makes it very difficult to detect the lower contrast anomalies related to prehistoric features. If historic metal is abundant, one should focus on nonmagnetic geophysical methods (Gaffney and Gater 2003:83; Kvamme 2001:360). Evaluate the abundance of magnetic clutter using a metal detector set to detect ferrous metals. An exception to this rule might be a site characterized by exceptionally high-contrast prehistoric features (e.g., heavily burned house floors, large deep pits, or house basins with rich fill). Magnetic rocks are encountered less commonly than metallic trash in many regions, but their effects can be similar. In some areas, however, magnetic rock may have been brought to the site for use as tools or building materials. If this is known to be the case, a magnetic survey may be particularly informative (Kvamme 2006).

Metal objects such as fences, utility poles, pipes, vehicles, and building components will greatly complicate or preclude the detection of most archaeological features. Do not, however, hesitate to use magnetic instruments if a relatively small portion of the survey area will be affected by such objects (Gaffney and Gater 2003:81-83).

4a: Do not decide against the use of geophysics simply because a site is or has been under cultivation unless standing crops prevent one from moving the instrument properly along data collection traverses. Data collection traverses should be parallel to crop rows and furrows. This orientation will (in some cases) permit anomalies associated with plow furrows and wheel ruts to be removed during data processing (Gaffney and Gater 2003:84). An exception to this advice would include sites where linear features (house walls, fences, roads, etc.) have the same orientation as the plow furrows. In such cases, anomalies associated with the features might well be removed along with the clutter during data processing.

In general, sites that have been impacted by earth-moving activities of heavy equipment are not good candidates for geophysical survey. Similarly, sites that have been heavily impacted by vehicle traffic or heavily used by livestock are also likely to yield disappointing results.

5a and b: Electrical resistance surveys should not be conducted when the soil is saturated or extremely dry (Clark 2001:51-56; Kvamme 2001:361). Conductivity surveys under such conditions should also be avoided (Clay 2006). Similarly, saturation is likely to preclude good GPR results. Variation in moisture is not relevant to magnetic methods.

5c and d: Clayey soils typically hold moisture and are thus not favorable for GPR survey; sandy soils are ideal for GPR. In contrast, sandy soils are characterized by very high resistance values, and natural variation can make it difficult or impossible to detect low-contrast cultural features. The organic contents of features in sandy soil may have leached out, reducing feature contrast for magnetic, conductivity, and resistance techniques.

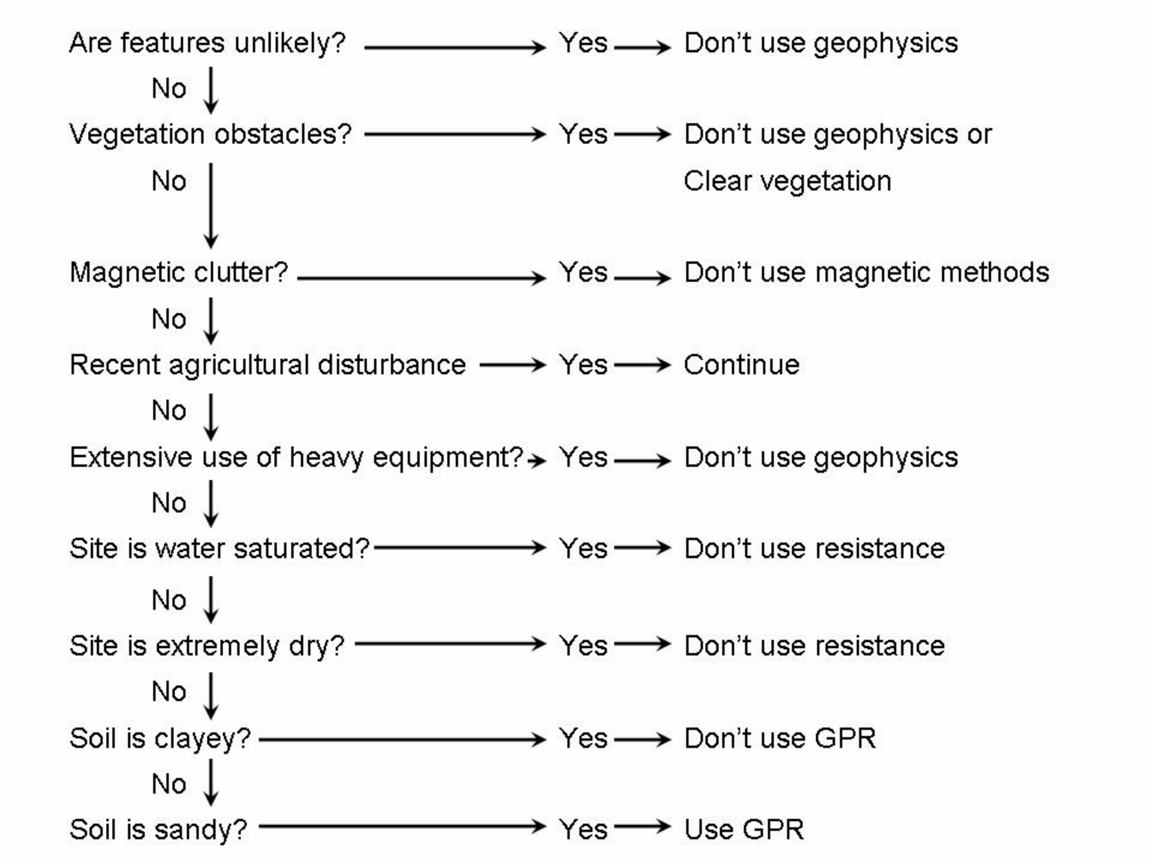

Figure E2: Simplified decision tree for site selection. See Figure E1 and its accompanying notes for details.

Appendix F: Selecting Geophysical Techniques

When it has been determined that a particular site is a good candidate for geophysical survey (or at least is not a poor candidate), one must next select appropriate geophysical techniques. Selecting a technique involves the evaluation of most of the same factors as were considered when evaluating a site’s suitability for geophysical survey. There are, of course, exceptions to all generalizations, and a highly experienced geophysical practitioner will make better selections than a novice. When working with a geophysical consultant, one should be ready to provide information about the factors identified below, and then follow the consultant’s recommendations. Table F1 will help the novice user make his or her selection of instruments when no expert advice is available. For that reason, Table F1 tends to err on the side of caution, recommending against the use of instruments under certain conditions when a more experienced user might recognize some chance for success. The focus here is on helping inexperienced geophysical users avoid disappointing results. To further reduce the risk of disappointment, observations of ‘maybe’ in Table F1 can be read as ‘no’.

Four types of geophysical sensors are commonly used to investigate terrestrial archaeological sites in the U.S.: magnetic, ground penetrating radar (GPR), electrical resistance, and conductivity (Bevan 1998; Clark 2001; Conyers and Goodman 1997; Gaffney and Gater 2003; Heimmer and De Vore 1995; Kvamme 2001, 2005; Scollar et al. 1990). Although a growing number of specialized techniques also exist (e.g., seismic, magnetic susceptibility, self potential), these will not be considered here (Gaffney and Gater 2003:26). While the focus here is on selecting the most appropriate technique, it is almost always desirable to use at least two techniques (Clay 2001). Some feature types may be detected by only one type of sensor, whereas other features may be detected only by a second type. Use of multiple sensors will increase the likelihood of detecting at least some features, and may permit detection of a wider range of feature types. Using multiple sensors will, however, increase survey cost (Clay 2001; Somers and Hargrave 2003).

Table F1. Criteria for selecting geophysical techniques

Site Condition:	**Magnetic**	**GPR**	**Resistance**	**Conductivity**
1) Unlikely that features are present	no	no	no	no
2) Very small (<30 cm diameter)features only	no[1]	no	no	no[1]
3) Features originate >1 m below surface	no[1]	yes	no	no[1]
4) Historic occupation present but focus is on prehistoric component	no	yes	yes	maybe[4]
5) Tall dense weeds[5]	no	no	yes	no
6) Widely spaced trees (park-like)	yes	yes	yes	yes
7) Abundant trees and brush[5]	no	no	maybe[6]	maybe[6]
8) Metal clutter is abundant	no	yes	yes	maybe
9) Magnetic rocks are abundant	no	maybe[8]	yes	maybe
10) Prominent plow furrows	yes[3]	yes[3]	yes	yes[3]
11) Very rocky soil	yes[7]	maybe[8]	maybe	yes[7]
12) Very isolated heavy equipment impacts	yes	yes	yes	yes
13) Generalized heavy equipment impacts	no	no	no	no
14) Sandy soils	yes	yes	maybe	yes
15) Clayey soils	yes	no	yes	maybe
16) Very wet soils	yes	no	no	maybe
17) Very dry soils	yes	yes	no	maybe
18) Large survey area	yes	maybe	no	yes

Notes:

1 Not suitable unless features are very high contrast.

2 Many features of this size are likely to be missed.

3 Align data collection transects parallel to furrows.

4 Ability to identify anomalies associated with metal can be useful.

5 Assumes vegetation will not be cut. Acceptable vegetation height depends on the sensor used. Although instruments can be carried higher, this will substantially reduce the potential for detecting low-contrast anomalies.

6 Rate of coverage will be slow, clutter from tree roots may be a problem.

7 Assumes rocks are nonmagnetic.

8 Rocks will appear as clutter.

Comments on Selecting Geophysical Techniques

This section provides additional explanation of the guidance summarized in Table F1. Numbers refer to the site conditions listed in the first column.

1) and 2): In most cases there is little reason to do a geophysical survey if the site is expected to include no discrete subsurface features (pits, hearths, architectural remains, etc.) or only features less than about 30 cm in diameter (e.g., post holes). Exceptions to this suggestion would include sites where features less than 30 cm in diameter could be expected to have fill that includes a very high density of rock, burned material, or highly organic contents. Such high contrast features might be detected in a magnetic survey or high data density survey using the other techniques.

3) Magnetic, conductivity, and resistance surveys can sometimes detect features at depths greater than a meter, but only if the features are relatively large and/or very high contrast. Typical (less than 1-m in diameter) prehistoric pits would generally not be detected at that depth. In favorable (sandy) soil, GPR surveys can consistently detect features at depths greater than 1 meter (Conyers and Goodman 1997).

4) The magnetic clutter associated with metal artifacts and bricks makes it more difficult to detect relatively low-contrast prehistoric features. If the focus is on a prehistoric occupation, a nonmagnetic technique should be used instead of (or in addition to) a gradiometer or magnetometer. Conductivity should also be avoided if magnetic clutter is abundant (Clay 2006). GPR will also be affected by metallic clutter, although not as severely as magnetics and conductivity. Electrical resistance will be unaffected by the presence of metal. However, resisitivity and conductivity are more likely to detect large areas that have been compacted, plowed, or otherwise disturbed.

5) The presence of tall dense weeds will pose a serious problem for magnetics, GPR, and conductivity. Carrying a magnetic or conductivity instrument high off the ground will greatly reduce the potential for detecting low-contrast features. Resistance surveys can be conducted in such vegetation, although it is advisable to have an additional person available to help clear the cable connecting the instrument to the remote probes.

6) Widely spaced trees without low-hanging (face-level) branches generally pose only a minor annoyance and should not preclude use of any of the techniques. Large tree roots may well be detected as clutter.

7) Abundant trees and brush pose serious problems for magnetic and GPR surveys, and may also preclude resistance and conductivity surveys. If surveys can be conducted, the rate of data collection will be greatly slowed and tree roots may create a great deal of clutter. Such conditions will decrease the likelihood of detecting low and moderate-contrast features.

8) and 9) If metallic trash or magnetic rock is abundant, magnetic surveys should be avoided unless a second, nonmagnetic sensor is also used. GPR and resistance can be used under such conditions, although clutter associated with very abundant rocks may diminish the potential for detecting small and low-contrast features. Conductivity surveys may also be productive unless there is a great deal of magnetic clutter.

10) Prominent (particularly deep and/or wide) plow furrows are likely to be visible as clutter in maps produced by all of the sensors considered here. To the extent that the furrows impede controlled movement of the sensor across the site, they may increase the level of noise and slow rates of coverage. It is always important to orient the data collection transects parallel to the furrows. Some processing softwares allow the effect of pronounced furrows to be significantly reduced if they are parallel to the transects. Linear features oriented parallel to the furrows may also be removed by such processing.

11) Clutter associated with an abundance of nonmagnetic rocks can pose a problem for GPR and resistance. Nonmagnetic rocks are not a problem for magnetic or conductivity sensors.

12) Isolated impacts to a site by heavy equipment should not preclude use of any of the sensors. One should, however, avoid conducting geophysical surveys at sites that have sustained broad impacts (13) from heavy equipment. Surveys of such sites are highly likely to be unreliable due to an excessive amount of noise and/or clutter.

14) All of the sensors considered here can potentially be used in sandy soils. Resistance surveys are the most problematic. Localized variation in resistance related to noncultural factors can easily be far more pronounced than the variation associated with low-contrast cultural features. All other factors being

equal, GPR should be considered as a first choice in sandy soils. Magnetic survey may be very effective if the soil contains sufficient iron.

15) All techniques except GPR are compatible with clayey soil. The moisture retentive properties of clay tend to cause the energy introduced by a GPR instrument to be attenuated rather than reflected, and this dramatically reduces sensor performance (Conyers and Goodman 1997; Kvamme 2001:360).

16) Magnetic surveys can be conducted when the soil is very wet so long as one can carry the instrument properly. Very wet soils are not amenable to GPR or resistance surveys (Clark 2001:51-56; Kvamme 2001:361). Conductivity survey may also be problematic.

17) Magnetic surveys can be conducted in very dry conditions. GPR survey may also be productive when the soil is extremely dry. The absence of moisture will reduce resisitivity contrast, however, and may make it extremely difficult to collect resistance data (Clark 2001:51-56; Kvamme 2001:361). Conductivity results may be problematic under very dry conditions (Clay 2006).

18) Gradiometer surveys are characterized by the greatest rate of coverage. All other factors being equal, magnetic survey should be the first choice, particularly when large areas must be surveyed. GPR and conductivity surveys have intermediate rates, whereas resistance is the slowest.

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Appendix G: Conclusions

This PWTB provides nontechnical guidance on how to determine if an archaeological site represents a good candidate for geophysical survey, and how to select appropriate geophysical techniques for use at that site. It is desirable, whenever possible, to use at least two techniques in order to increase the likelihood of detecting at least some features and, under favorable circumstances, to detect a wider range of feature types. Because the focus here is on helping novice users avoid disappointing or misleading results, the guidance tends to err on the side of caution. Experienced geophysical practitioners will be able to cite exceptions to many of the recommendations. It is not wise, however, for the novice sponsor of a geophysical survey to assume that his or her site will be such an exception. A thoughtful approach to the selection of sites and techniques will help cultural resources managers and archaeological consultants realize the potential advantages of geophysics (less invasiveness, greater reliability, and potentially lower costs) without a needless waste of time and resources on surveys that have a low probability of success.

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Appendix H: Figures

Figures 1-7 exemplify how clutter and noise can diminish the usefulness and reliability of a geophysical map. In Figures 1 and 4, the clutter is so pervasive as to preclude the detection of relatively low-contrast anomalies that might be associated with prehistoric or historic features. Figures 2, 3, 6, and 7 exemplify situations where clutter and noise make it more difficult to detect such features. Figure 5 shows the possible effects of heavy equipment impacts combined with differences in contrast related to seasonal variation in soil moisture.

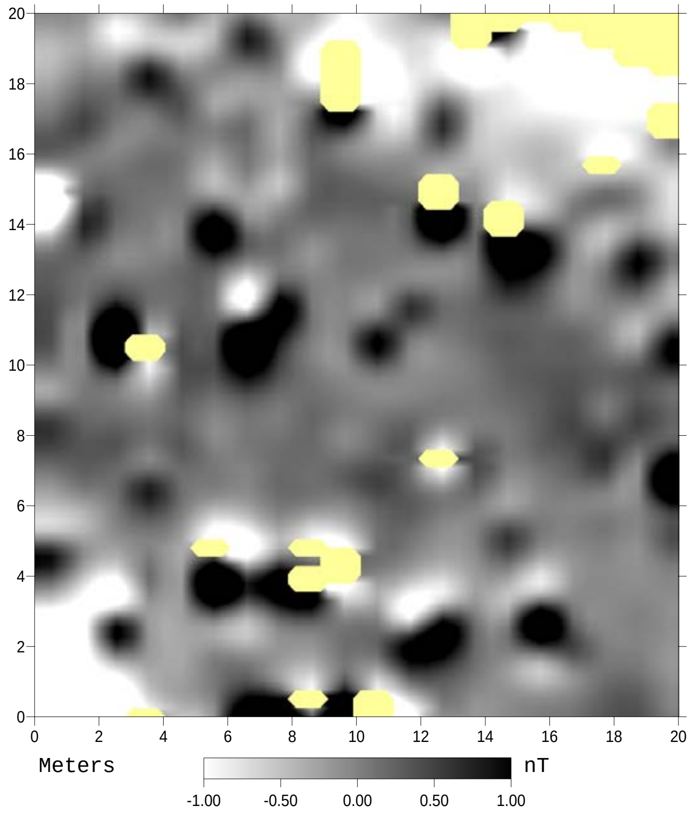

Figure 1: Magnetic field gradient survey at Marksville, LA. Here clutter associated with metallic trash from nearby houses precluded the detection of a circular earthwork. Note: yellow indicates very high and low values that were removed during data processing.

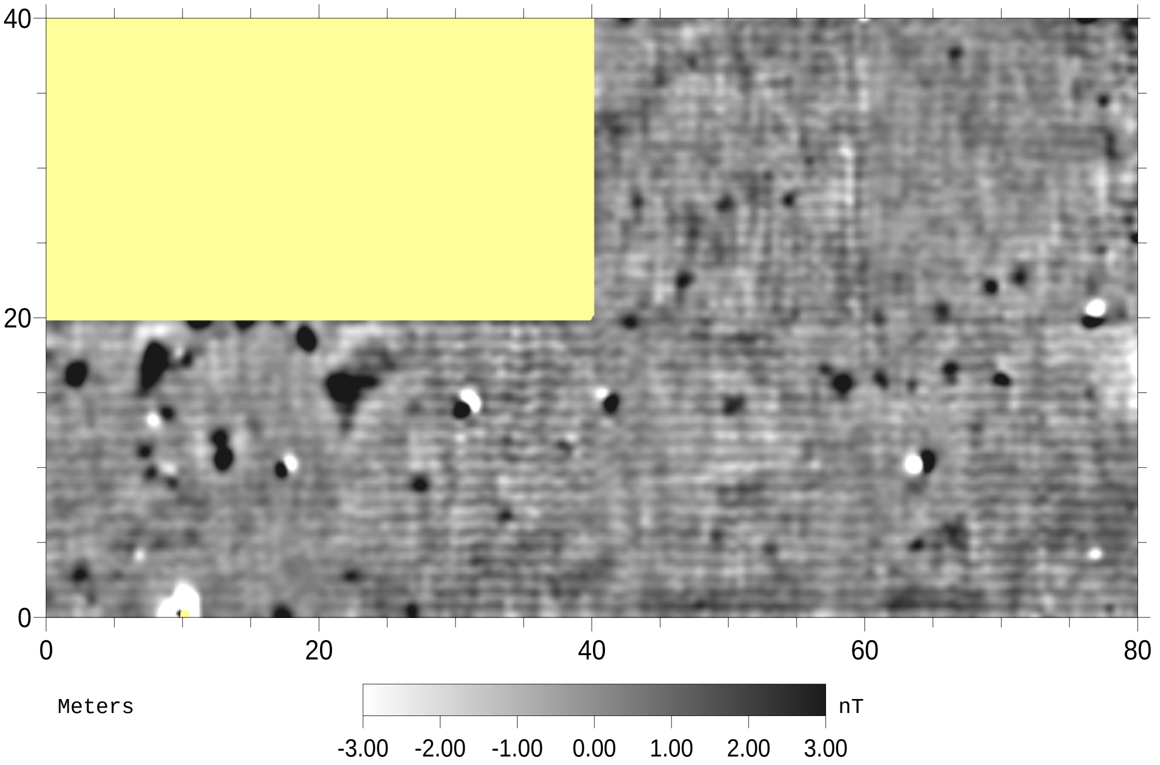

Figure 2: Magnetic field gradient survey at the early Mississippian Pheffer site, IL. Horizontal lines represent clutter stemming from a periodic defect related to the surveyor’s stride and an imperfectly balanced gradiometer at a magnetically quiet site. In this case, dark (magnetically positive) anomalies associated with pits and a few houses are detectable in spite of clutter.

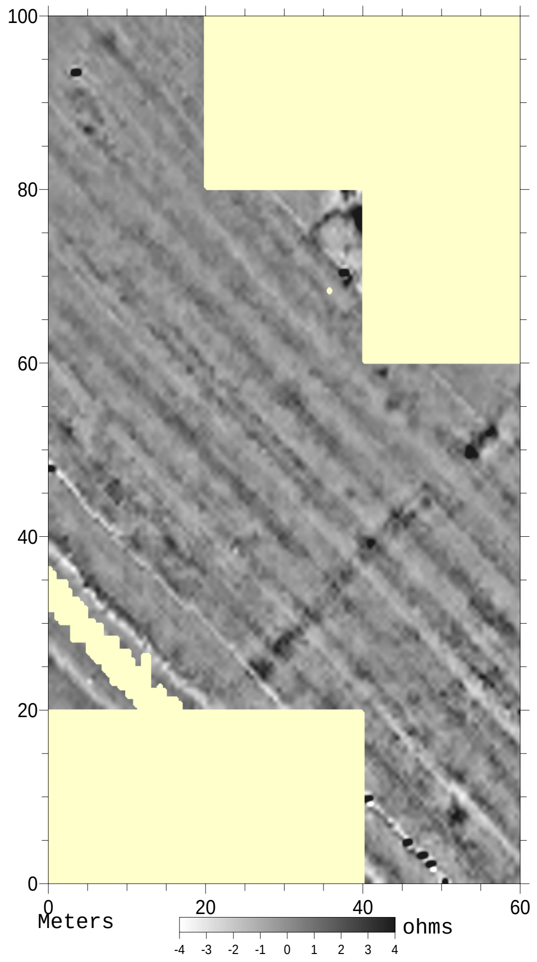

Figure 3: Electrical resistance survey at New Philadelphia, a historic town site in Illinois. Here clutter associated with recent plow furrows and ridges complicates the detection of early historic features. Excavations in 2004 and 2005 by the NSF-funded University of Maryland and University of Illinois Field Schools verified the presence of substantial architectural features. For example, the square anomaly located at E53 N7.5 is associated with a cellar. (North is at the top of the map).

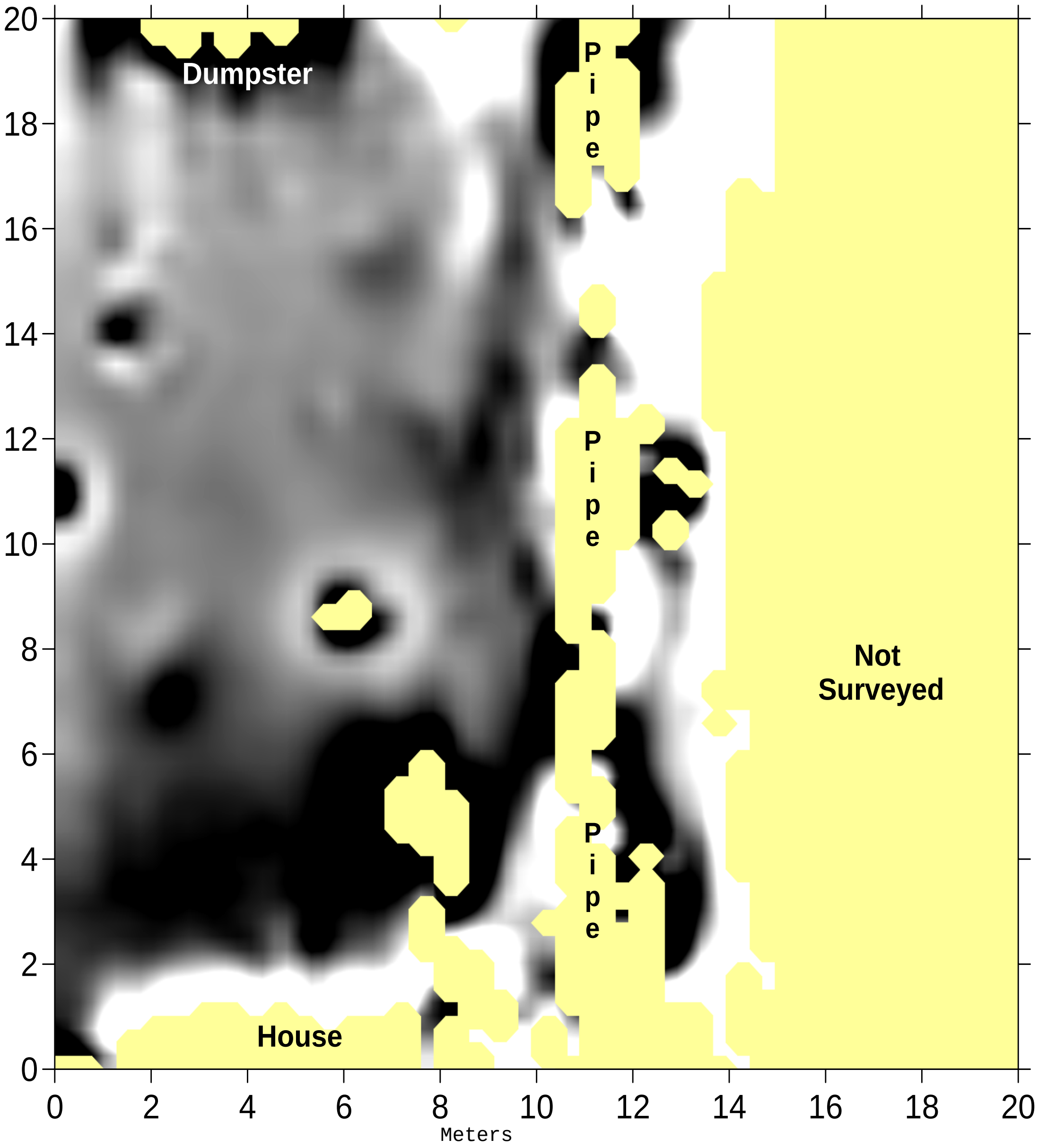

Figure 4: Magnetic field gradient survey of the small yard behind a historic house in Collinsville, IL. Magnetic clutter associated with the house, a massive dumpster, a probable underground pipe, and other infrastructure complicates the detection of features such as small pits. Note that yellow areas indicate missing data, including nonsurveyed areas and very low or high values that were removed during data processing.

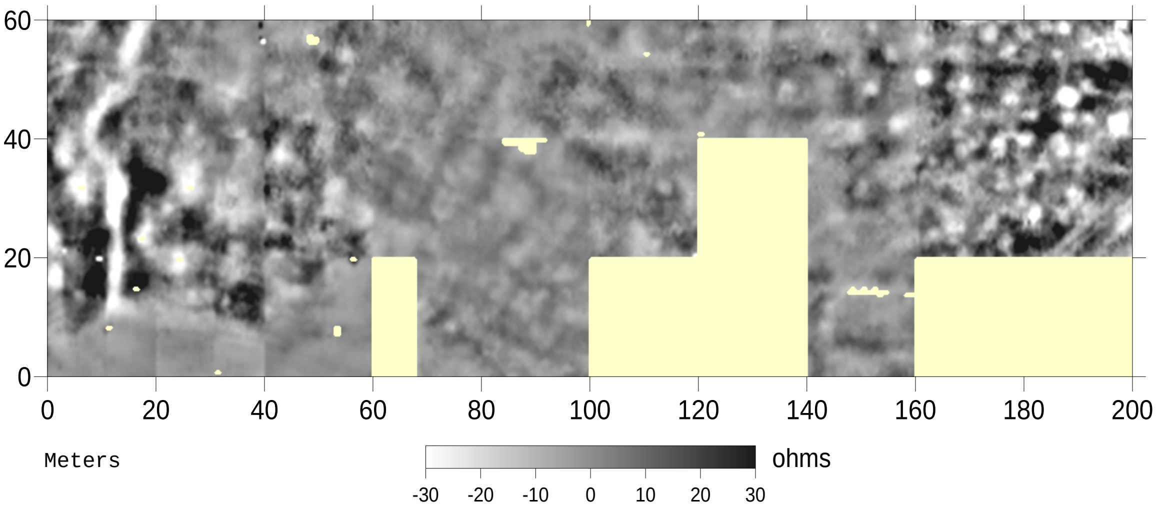

Figure 5: Electrical resistance survey of Upper Mississippian Hoxie Farm site near Chicago. East (right) and west (left) areas, surveyed in March, exhibit many strong anomalies, but only very weak, amorphous anomalies are apparent in the central area that was surveyed during dry conditions in June. Extensive soil coring demonstrated that features are present in the central area but tend to be somewhat smaller and shallower. Seasonal variation in soil moisture and feature contrast, and possible impacts from heavy equipment may account for the apparent paucity of features in the resistance data for the central area.

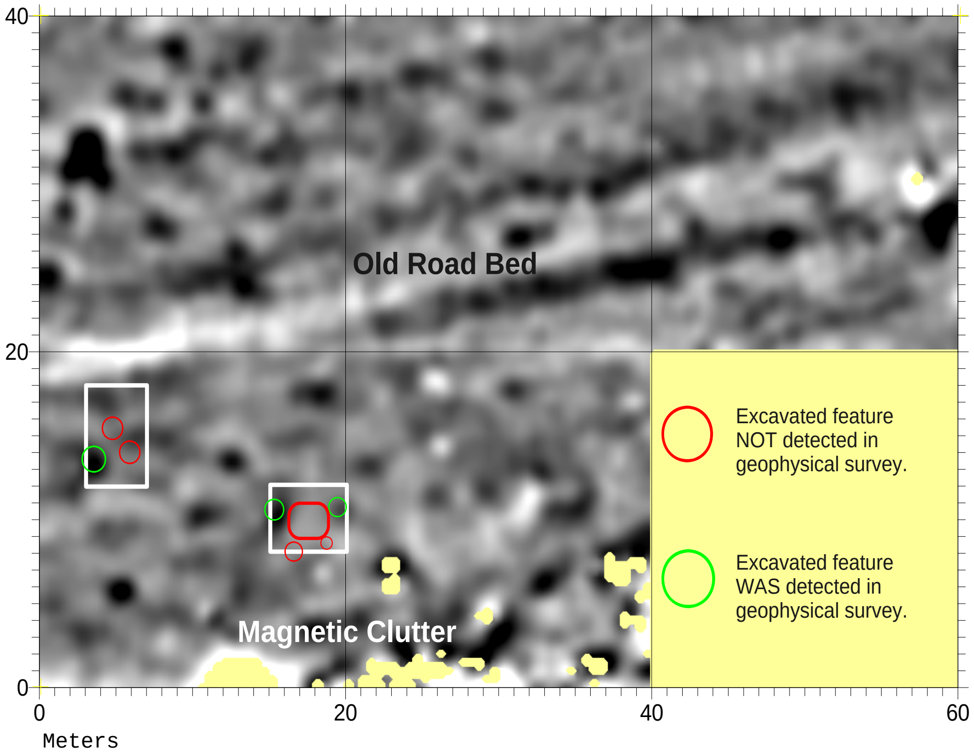

Figure 6: Magnetic field gradient survey at Harmon Site, IL. Clutter along lower edge (shown in yellow) relates to nails used to map features excavated there. Evidence of a dirt road used by heavy equipment is also visible. Excavations conducted by the Southern Illinois University at Edwardsville Field School found that some of the small positive (black) magnetic anomalies are associated with Late Woodland Period pits. Several other excavated pits and one relatively large pit house were not detected in magnetic data.

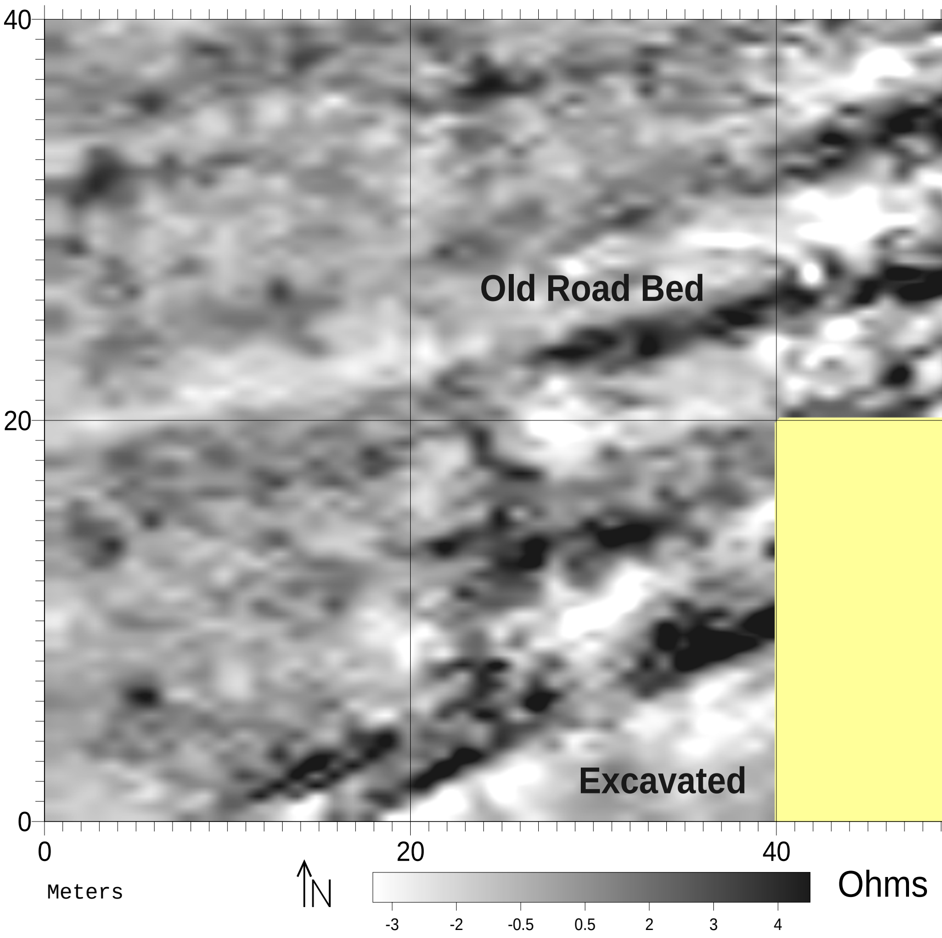

Figure 7: Electrical resistance survey at the Harmon Site, IL. A triangular-shaped area in lower right corner was mechanically stripped to expose features for excavation. Back-dirt and heavy equipment tracks border the excavated area. Evidence of a dirt road used by heavy equipment on earlier occasions is also visible. Note that magnetic clutter associated with nails used to map excavated features seen in magnetic data (Figure 6) does not show in resistance data.

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