6. CONCLUSIONS

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6.1. BENEFITS OF REMOTE SENSING IN ARCHAEOLOGY

Remote sensing is relatively new to archaeology, but has begun to make impacts on the goals and practice of the discipline. As exploding populations result in massive changes to the landscape, efficient and cost-effective methods to locate, map, and acquire information from sites of our cultural heritage are needed before they are lost. Costs of archaeological excavations have skyrocketed and they commonly examine only trivial areas. Remote sensing techniques allow large regions of the subsurface to be rapidly investigated at relatively low cost. These methods can detect archaeological elements unseen on the surface, precisely map them, and offer interpretations based on form, distribution, context, and measurement characteristics. It is increasingly being realized that remote sensing may offer the only pragmatic means for locating, mapping, and inventorying much of the world's archaeological resources. Although this implies that remote sensing is only a descriptive tool, it also offers many methodological avenues for the *interpretation* of that record, a fact emphasized in this project.

The traditional view of remote sensing sees it as a means to (1) discover new archaeological sites and site features, (2) guide expensive excavations to archaeological features of interest, and (3) produce cost savings by making site explorations more efficient. All this is accomplished non-destructively because remote sensing is non-invasive, permitting the resource to remain intact (an important consideration when exploring culturally sensitive burial, sacred, or ceremonial sites) (Weymouth 1986; Wynn 1986). Remote detection of cultural features can reduce amounts of excavation, and therefore costs, because field teams can go directly to features indicated. Smaller artifact collections may also be recovered, decreasing curation charges because the volume of excavation is reduced when archaeological features are reliably located. Moreover, prior detection of subsurface features lessens the risk of inadvertent discoveries of cultural resources and attendant mitigation costs (Hargrave 2006).

Success in these areas has promoted the notion that remote sensing is suited only for discovery purposes, but recent advances have allowed these technologies to evolve into new domains of inquiry. In some cases remote sensing can yield *primary data* suitable for the study of cultural forms within archaeological sites and landscapes. In other words, culturally patterned anomalies can reveal organization and structure within settlements or larger spaces. The identification and examination of relationships between such individual site components as houses or house clusters, lanes, dumping grounds, public structures, storage facilities, gardens, plazas, fortifications, cemeteries, and the like, can be made through interpreted imagery. Likewise, inter-settlement comparisons of form, estimates of numbers of houses, average house sizes, or the examination of house shapes, orientations, and arrangements of interior components can also be attempted through remote sensing alone (Bales and Kvamme 2005; Gaffney et al. 2000; Kvamme 2003). This capability offers the possibility of direct study of settlement content and form through remote sensing. The compilation of libraries of site plans of Neolithic enclosures and Roman villas in Britain, derived entirely from geophysical data sets, exemplifies this capability (*The English Heritage Geophysical Survey Database*, http://www.eng-h.gov.uk/SDB).

The ability to image large areas of the subsurface has profound implications when contrasted with traditional methods of archaeological excavation. Their costs and time requirements mean small exposures limited to a few square meters, which forces a mindset that commonly views human spaces in terms of tens of *meters* as opposed to the tens of *hectares* within which most people live and interact. In other words, human activities occur within settlements and cultural landscapes covering hectares or even square kilometers. Until remote sensing, there has not been a ready means to visualize subsurface cultural distributions over such large areas, and there is generally a tremendous amount of archaeological ignorance about the size, structure, and layout of settlements, inter-settlement relationships, and cultural uses of landscapes. Areas of the subsurface "exposed" by remote sensing are several orders of magnitude larger than can be achieved by excavation.

Many of these ideas have been promoted in this project. The remote sensing programs have revealed the "big picture" about several archaeological sites by defining much about their layouts and overall structures. The success of this study rests in application of several innovative approaches. (1) Multiple complementary remote sensing techniques have been applied to a series of archaeological sites, each offering somewhat different visualizations of the subsurface. (2) These results have been integrated to allow simultaneous visualization of multiple dimensions of the subsurface, allowing improved understanding of archaeological content. (3) Large areas have been investigated at each site to facilitate recognition of cultural elements through pattern recognition principles. (4) Interpretations based on remote sensing have been archaeological tested for accuracy, allowing revisions of interpretations.

6.2. BENEFITS OF DATA FUSION

The integration or fusion of multiple remote sensing data sets offers a number of benefits to interpretation and the understanding of archaeological sites. They impart a more holistic view of the subsurface by showing all results simultaneously. A single survey might reveal only part of a buried building, but integrated information from several surveys could illustrate the entire structure as well as its interior components. This aids understanding of single features, but also overall site structure, layout, and organization. Surveys of large areas aid interpretation by allowing imaging of complete features and their forms—a house is better recognized when viewing its full shape as opposed to only a small portion of it. Large-area surveys show context and associations between features further aiding interpretation. By visualizing data from several sensors simultaneously, an improved understanding of sensor relationships, redundancies, and underlying dimensionality is achieved. This is accomplished visually, and with some methods quantitatively through correlation coefficients, loadings, factors, and other statistical indicators.

Graphical solutions for data integration are easy to implement and effectively combine information from disparate sources into interpretable displays. They allow complex visualizations of the subsurface, but their weakness rests in relatively low dimensionality—only 2-3 data sources may effectively be represented. Moreover, these methods are purely descriptive, yielding only images, not new data that may subsequently be analyzed. Discrete integrating methods, on the other hand, allow application of readily available Boolean operations to any number of geophysical data sets. A shortcoming is the binary maps upon which these methods are based that rely on arbitrary thresholds to define significant anomalies, while more subtle ones must be ignored. Continuous data integrations can yield insights beyond the capabilities of other methods. Robust *and* subtle anomalies may be simultaneously expressed, producing composite imagery with high information content. Interpretive data are also generated in the form of principal component scores, factor loadings, regression weights, or knowledge-based rules that add to understanding of interrelationships and underlying dimensionality. Supervised and unsupervised classification methods are noteworthy because they introduce a predictive aspect to the integrating process. Resulting data fusions, based on multivariate relationships between a suite of sensors, may actually extend the capabilities of subsurface remote sensing because mappings will contain more information about particular anomaly types (or corresponding archaeological feature types) than any single sensor. They therefore offer a possible means to augment prospecting capabilities. Which fusion methods work best may depend on purpose. Some yield visually pleasing results that well-integrate available information while others appear less revealing but offer interpretive or predictive potential.

Although integrated data yield several benefits, when generating interpreted maps the analyst must nevertheless return to the primary data to define boundaries of individual anomalies and determine by which method anomalies were identified. These are important issues in forming accurate interpretive maps (as in Section 5.12). With data fusion some anomalies may grow larger in extent making it difficult to pinpoint the locus of an anomaly's source. Moreover, to interpret an anomaly one must often look beyond its form. Knowledge of the type of sensor that revealed it is critical. If an anomaly is indicated by magnetometry an interpretation of a burned feature may be warranted; the same form of an anomaly may be interpreted as a cluster of stones to electrical resistivity. Without this primary information only limited interpretation is possible.

6.3. TOWARDS AN EPISTEMOLOGY OF ARCHAEO-GEOPHYSICAL FIELD VALIDATION

While geophysics is now more widely used by archaeologists in the U.S. than ever before, it is not yet well integrated into the practice of university based research or cultural resource management (Hargrave et al. 2002). Field validation of anomalies by excavation, or "ground truthing," is even less well established. Important issues such as appropriate sampling strategies and the reliability of alternative field methods relative to site characteristics are only beginning to be considered (Hargrave 2006). It is therefore useful to conclude by discussing some of the issues that will need to be considered as archaeologists begin to formulate an epistemology of geophysical validation.

The factors, that were considered in evaluating the suitability of sites for geophysical investigation and inclusion in this study—contrast, clutter, and environment (Section 3.3.1), are also important considerations when attempting to validate anomalies through excavation. Characteristics of the cultural deposits must be added as another (perhaps the most) important factor. An important point exemplified by the SERDP project (particularly by the Silver Bluff site) is that the acquisition of seemingly "good" geophysical data does not guarantee that excavation will yield satisfactory validations of interpretations.

Familiarity with the local archaeology is an important component in effective ground truthing under any circumstances, and particularly in situations where features exhibit little visual and textural contrast with their surroundings. Where archaeological excavation is the primary means of validation, the visual and textural contrasts between a feature and its immediate surroundings assume primary importance. Materials commonly associated with historic features such as brick, concrete, and metal almost always exhibit a marked contrast with the surrounding soil in terms of texture, hardness and, in many cases, color. Visual and textural contrasts between an earth-filled pit (the most common type of prehistoric feature in the United States) and the surrounding soil can range from weak to strong. Two factors that contribute to this variation in contrast are the relative abundance of organic debris at the site when the feature was used and eventually filled, and the extent to which site environmental conditions resulted in the preservation of the organic content of the feature's fill. Efforts to identify discrete features in sandy soils where organic stains are faint or absent (as was sometimes the case at Pueblo Escondido), or in situations where midden-filled pits occur in a matrix of midden both demand extensive familiarity with the range of variation in feature types that occur in the region.

A close cultural link with the archaeological deposits being investigated also increase the effectiveness of ground truthing. Army City, for example, is similar in many ways to existing, older sections of towns in the United States. While most archaeologists do not recall the time when dirt-streets were common, the spatial relationships among streets, alleys, sidewalks, and commercial buildings seen in historic photographs of Army City are very familiar. The photographs themselves are invaluable aids to the interpretation of geophysical anomalies (e.g., Figure 3.2). In some cases, the actual sidewalk edges, curbs, and gutters visible in photos of Army City may be those detected in the geophysical imagery. The SERDP investigators' cultural link to the 18th century Silver Bluff site was far more tenuous. Nevertheless, the overall layout of Galphin's trading post, as known from historical descriptions, previous archaeological investigations, and the geophysical data, was far more familiar to the excavators than was the case at Kasita Town or Pueblo Escondido.

Sites that exhibit strong patterning in feature distribution are also more amenable to effective field validation. Army City, an early 20th century "planned" community, epitomizes this observation. At Army City sidewalks consistently occurred between streets and buildings, utility pipes were located in alleys and beneath structures, building entrances were a standard distance from the street, and so forth. These planned patterns are documented in the town plat and historic records (Rion 1960), can be verified through examination of the historic photographs (Hargrave et al. 2002; Kresja 2005; Rion 1960), and are apparent in the geophysical data. Minimal excavation is required to further verify these patterns at Army City. Substantially more excavation would, of course, be needed in situations where the focus was on evaluating site condition and integrity, particularly if subsequent occupations had impacted the archaeological remains of Army City.

Kasita Town exemplifies the difficulty of interpreting anomalies in a site where little patterning is apparent in the geophysical data (here we ignore a few prominent linear anomalies associated with recent drainage pipes, etc.). Anomalies at Kasita Town were amorphous, highly variable in size, shape, and amplitude, and not easily assignable to standard archaeological feature types. It is now known that much of this variation is the result of localized cutting and filling of the site as it was leveled during airport construction. The absence of clear patterning in the geophysical data made it difficult to use excavation results of a small but representative sample of anomalies as a basis for reliably inferring the nature of the remaining anomalies. Some anomalies in the Kasita Town data are almost certainly associated with real archaeological features rather than simple site clutter, but it would probably require the investigation of an impracticably large sample to develop an ability to differentiate features from clutter.

Archaeologists who are not familiar with geophysical techniques often view the results of careful excavation as the "best" evidence for the presence, absence and nature of archaeological deposits. At Pueblo Escondido, for example, many geophysical anomalies categorized as systematic small features, lineations, and in a few cases, structure floors and walls were not verified by excavation. In most cases, the arrangement of these anomalies in obvious linear patterns made their existence virtually certain (Section 5.16.2). Explanations for the failure to detect features or other deposits associated with these anomalies that were suggested by TRC and/or the SERDP team included the possible misplacement of excavation units, the effects of past looting, and the possibility that vegetation is spatially correlated with architectural remains. While each of these possibilities warrants consideration, they should not preclude consideration of a more controversial possibility. It is likely that, at some sites, geophysics can detect features that are largely invisible to the archaeologist's trained eye and hand. Geophysical techniques "work" because subtle contrasts exist in magnetic, electrical conductivity, dielectric, thermal, and other characteristics. During excavation, archaeologists rely almost exclusively on visual (largely color) and textural contrasts. These contrasts often—but not always—co-occur with the geophysical contrasts. In short, skilled excavators can sometimes detect variations in the archaeological record that are not detected by geophysical sensors, but in the same manner, geophysics can sometimes detect phenomena that archaeologists cannot. The existence of seemingly "invisible" features is a troubling prospect, but the possibility should not be categorically denied. Ground truthing strategies simply need to include alternative means of verifying the presence of features that have no visual or textural manifestation. Examples include the use of geophysical techniques that are based on distinct types of contrast, chemical tests, geological particle analysis, etc. (Mandel and Bettis III: 2001; Sherwood 2001).

The existence of deposits invisible to conventional excavation techniques is not an insurmountable problem for cultural resource managers. It is likely that such deposits will be found to occur in a relatively restricted range of site environments, and to be associated with a relatively narrow range of past activities and feature types. Such deposits are unlikely to represent a "wild card" in assessments of a site's eligibility for nomination to the National Register of Historic Places under Criterion D because they will probably be found to be relevant to a very narrow range of research topics (e.g., the spatial patterning of facilities and activities). Archaeo-geophysicists and archaeologists need to be aware of the possibility of such deposits, and to work together to devise innovative, multi-faceted approaches for their verification or negation.

6.4. FIELD VALIDATION OR “GROUND-TRUTHING”

One of the biggest revelations of the project was the general shortcoming of field archaeology for confirming interpretations gained through remote sensing. This deficiency was manifested in several domains. First, the expense of field archaeology is so great that meaningful statistical sampling is not possible owing to relatively low numbers of excavations. Moreover, because archaeology is invasive, large numbers of excavated holes are frowned upon and may not be permitted because they lead to destruction of a site.

Second, archaeology frequently lacks a certain depth of knowledge when it comes to interpreting findings in the ground. In this project, issues were constantly raised concerning what particular archaeological features should “look like.” How, for example, should an alley gutter, a subtle floor, or a street rut appear in the soil? Much ambiguity and uncertainty exists in feature identifications within field archaeology such that absolutely certain identifications may not be possible. This was true at each project site, but particularly at Silver Bluff where numerous soil stains were located by excavation as sources for anomalies although identifying what those stains represented (in terms of a particular type of cultural construction or activity) was often not possible. This uncertainty is exacerbated because the nature of archaeological remains changes not only from region to region but also from site to site as culture types, soils, and specific climate conditions change.

Third, the human senses of sight and touch, upon which archaeologists must rely, respond to only a narrow range of physical phenomena. This range may not be wide enough to detect the sources of a significant percentage of anomalies by normal excavation practice. Several examples of this phenomenon exist in the project from anomalies representing houses at Pueblo Escondido to linear and rectangular anomalies at Silver Bluff that could not be validated by excavation. This deficiency suggest the need for a new ground validating tactic that employs field and laboratory methods from soils science and geoarchaeology as adjunct tools for anomaly confirmation.

Fourth, it is unfortunate that in United States higher education the method and theory of geophysics and remote sensing is not commonly taught to students of archaeology. As a consequence, few archaeologists know about this domain or trust it. The immediate impact is that field archaeologists, although understanding the local archaeology, may not know what to look for when attempting to locate an anomaly source in a “ground-truthing” exercise. Had time allowed it would have been ideal to have the field archaeologists at each site work jointly and share their expertise with the SERDP remote sensing team to develop interpretations for each anomaly in the laboratory prior to fieldwork and during the excavations. Time and funding was far too short during the rapidly conducted fieldwork phase of the project, however.

Last, an ultimate goal of remote sensing may be to give very specific interpretations of individual anomalies, such as “adobe wall,” “brick floor,” “hearth,” “storage pit,” or “trail.” While an ideal, such interpretations may lead to spurious perceptions of error as when pipes classified as metal turned out to be a highly magnetic fired ceramic and a source of error in efforts at Army City. More generic classes that still give meaningful interpretation of archaeological classes appear to be a superior course of action (e.g., using the generic term “pipes”).

6.5. GROUND-TRUTHING VS. VALIDATION

Some archaeo-geophysicists in the U.S. are uncomfortable with the term "ground truthing," particularly when it is used in reference to efforts to verify interpretations of geophysical data by means of excavation. Barring instrument or user errors, anomalies indicated by geophysics are factual: *a real physical cause of an anomaly must exist in the ground*. The issue in validation, then, is not whether a source exists for an anomaly, but whether the interpretation of the kind of archaeological or natural feature an anomaly represents is correct. In most cases, a physical source for an anomaly can be determined by excavation, whether it stems from a change in soil type or a construction made of stone. In such cases the term "ground-truthing" certainly applies and may be employed to confirm remote sensing interpretations. Yet, in many instances the methodology of excavation falls short as a mechanism for validation. The most obvious is when the source of an anomaly is not visible to the excavator's senses of sight and touch. In these cases laboratory analyses or sophisticated field instrumentation must be brought to bear to determine an anomaly's source. Another more common shortcoming of excavation occurs when the source of an anomaly is located in the ground, but the nature of the evidence is ambiguous, precluding *archaeological* interpretation of what the discovered feature represents. This circumstance was highlighted in this project by the many soil stains of ambiguous source and function at Silver Bluff Plantation; archaeological explanations for many of them could not be established. This raises the notion of two sources of error in the anomaly validation process: errors in interpretation by the remote sensing specialist and interpretive errors by the field archaeologist. In such contexts it is difficult and probably inappropriate to use one to validate the other. Given these possibilities, traditional excavation methods cannot always impart "truth" to the process of anomaly validation.

6.6. DATA REDUNDANCIES AND COST-BENEFITS

Weymouth (1986) has observed that magnetometry, resistivity, and GPR generally respond to independent dimensions of the subsurface: magnetism, conductivity, and dielectric contrasts. To this might be added thermal properties. This suggests that, at least theoretically, redundancies may not be present in geophysical data. Analyses in Section 5.7 supports this notion where a Pearsonian correlation matrix between six different sensors showed a maximum absolute correlation of only $|r|=.3$ (Table 5.3) and a first principal component captured only 30% of the total variance (Table 5.4). In this sense, most of the geophysical data explored in this project can be considered to yield very different representations of the subsurface and the archaeology it contains. Viewing any of the geophysical mappings in Section 4.6 suggests this to be the case where new anomalies and different results are portrayed in each one.

Nevertheless, in practice a single archaeological feature might exhibit contrasts simultaneously along several physical dimensions—a stone wall is highly resistant (and low in conductivity); it might be composed of igneous rock and thus be magnetic; and it is likely to possess dielectric differences compared to the surrounding soil and thus generate GPR reflections, for example. This perspective can be witnessed in many of the geophysical results of Section 4.6 as well, where certain subsurface features generate anomalies in several different data sets. This was illustrated most forcefully in Figure

5.9c where certain subsurface entities generated anomalies in as many as six different geophysical data sets.

Aerial (or space) methods will always be cost-effective to acquire because of rapid acquisition of scenes over very large areas. This characteristic must be balanced against data content. In this project, few of the air or space data sets yielded data of use or interest.

In general, as seen in Sections 5.12 and 5.16, GPR is probably the single most productive geophysical survey technique at the types of sites investigated by this project. More anomalies, and significant anomalies, were consistently defined by this method than the others, and most of the vectorized interpretations were derived from GPR. GPR data are associated with greater "costs," however. GPR typically requires somewhat more time to acquire data over large areas (although rapid survey technology is constantly improving), and data processing costs in time are enormous. As a rough estimate, approximately 10-50 times more effort is required to process GPR than other geophysical data sets, but this situation is rapidly improving as well.

The utility of other geophysical methods depends much on site type and conditions (see below). Resistivity proved enormously beneficial at Army City owing to concrete and masonry foundations and floors. In the northern Great Plains, on the other hand, magnetometry is the method of choice because most archaeological features are soil features with variable magnetic properties (Kvamme 2003).

EM induction methods probably represent the principal source of redundancy in the project. The quadrature phase yields conductivity data, which theoretically replicates the inverse of resistivity, and the in-phase component yields magnetic susceptibility (but only to a depth of less than 50 cm), a component recorded by magnetic gradiometry. Kvamme (2006) has shown that the conductivity component consistently reveals less detail than corresponding resistivity surveys. At Army City the conductivity survey failed to reveal any of the many concrete floors detected by resistivity, but the towns numerous sewer pipes were well indicated (they were also shown by magnetometry). In-phase EM was also informative at Army City where likely burned areas and street gutters were revealed and at Pueblo Escondido where numerous lineations and architectural features were defined.

6.7. EFFECTS OF ENVIRONMENT ON DETECTION

Determining the effects of environment on the ability of remote sensing to detect subsurface archaeological features is a difficult issue to confront with only four principal sites targeted in this study. Based on the SERDP teams' experience in more than 25 states a number of generalizations can be made, however.

6.7.1. Urban Environments

Urban settings are plagued with large concentrations of metallic debris and rubbish, iron and steel fencing, buried pipes, lamp posts, signage, electromagnetic fields, people with their metallic adornments and cell phones, passing and parked automobiles, and the like, all to the point where useful survey geophysical results might be impossible. On top of these factors, given that urban landscapes frequently have undergone extensive and intensive reworking, discerning pattern associated with culturally produced anomalies can be extremely challenging and even unproductive in the complex deposits that occur in these settings.

6.7.2. Non-urban Settings

In general, remote sensing works best in open fields with uniform ground cover. Croplands must be surveyed when crops are down and years of plowing can reduce the possibility of remote detection or even eliminate the subsurface archaeology if shallow. Heavily vegetated or wooded landscapes impede movement of ground-based instruments and forests hamper visualization from the air. Steep slopes also make for difficult ground-based surveys. Even in non-urban settings landscaping such as field leveling and modern pipeline and transmission line intrusions must be watched for.

6.7.3. Aerial (and Space) Methods

The detection of archaeological features from the air is best suited to two environments. The first is arid landscapes with sparse vegetation where archaeological ruins on the surface may easily be witnessed. The second lies in farmland under uniform crop types, as nearly a century of work in European aerial archaeology has shown (Wilson 2000). In farmland, each individual plant acts as a "sensor" to conditions below; its health may be stunted by certain kinds of archaeological features (stone walls and pavements) and promoted by others (buried ditches, pits, and middens). These variations in health are reflected in plant color, height, and other factors that may be witnessed from the air. Such "crop marking" should be visible across the country, but is generally limited to robust architectural remains, and is dependent on season and stages of crop development.

6.7.4. Geophysics

Geophysical instrumentation is designed for a wide range of conditions, but each has environmental limitations.

Magnetometry. This technique responds largely to magnetic particles in the soil, but in young or undeveloped soils native magnetic susceptibility may be too low for detection purposes. This frequently occurs in the Southwest where soil development is poor and was witnessed in this project at Pueblo Escondido where magnetic anomalies were extremely subtle. Magnetometry is also not useful in volcanic areas or regions of igneous rock outcropping, owing to high levels or remanent magnetism. Iron or steel debris, when abundant, can preclude useful results with this method.

Resistivity. This method requires soil moisture, and so is limited to winter and spring surveys in much of the arid West. Even in more moderate climates sufficient soil moisture may be a problem as the landscape dries out between periods of rain. It also cannot be undertaken in winter when the ground is frozen, a circumstance that can produce near-infinite resistivity. Shallow or rising bedrock can also produce spurious readings. A benefit of resistivity is that in urban contexts it is insensitive to metallic artifacts and electromagnetic fields, allowing recovery of this data type.

EM Induction. This method largely parallels resistivity, but it may be possible to acquire data when the surface is dry because probes are not used and electromagnetic fields can be induced in subsurface deposits. A drawback of these methods is that they are also sensitive to metals of any kind. Results can be degraded when metallic litter is abundant.

GPR. The principal shortcoming of this technique is too much moisture and clay deposits. Both promote conductivity, which disperses radar energy and limits penetrating. While it is true that water can sometimes enhance contrasts (when particular subsurface features concentrate water) in general it reduces the method's utility. Additionally, GPR is sometimes too sensitive, picking up every tree root, rodent hole, cavity, and rock in the soil and generating too many anomalies that may obfuscate detection of culturally significant ones when soils are not uniform.

Characteristics of key geophysical instruments are summarized in Table 6.1.

6.8. BEST SUBSET OF INSTRUMENTS

The best subset of instruments to employ in an archaeological project depends on a wide variety of factors. Primary considerations lie in the nature of the environment and its climate and the nature of the archaeological remains to be detected.

6.8.1. Environment

The nature of the environment must first be considered, as discussed in the previous section. In volcanic areas, magnetometry should be avoided. In arid or frozen environments, resistivity should not be considered. Instruments sensitive to electromagnetic interference should not be employed in urban settings.

6.8.2. Nature of Archaeological Remains

The second consideration in selecting instrumentation lies in the type of archaeological site being investigated, the depth to cultural features, the typical size of targets to be located, and the amount of area to be investigated.

Large areas. Aerial and space imaging allow quickest detection over large areas if the site is in a suitable context that will yield crop or vegetation marking or shadow marking if shallow. If a ground-based method is required to locate subsurface anomalies then magnetic gradiometry should be considered. It is the most rapid data collection method with a single instrument allowing 1-2 ha of survey per day. EM instruments can also allow rapid coverage of large areas.

Table 6.1. Characteristics of four principal subsurface prospecting methods.

		Magnetic	**Resistivity**	**EM**	**GPR**
Units:		nT	ohm/m	mS/m or ppt	ns
Common depth:		< 1.5 m	.25-2 m	.75-6 m quad 0-.5 m in-phase	*500 MHz: .5-3 m 300 MHz: 1-9 m
Typical sampling density:	**Low:**	1/m	1/m	1/m	>1 m transect spacing; 10 traces/m
	High:	16/m	4/m	4/m	.25-.5 m transect spacing; 50 traces/m
Survey time (20 m grid of 20 lines):		20 min.	45 min.	20 min.	30 min.
Area/day:		.5-2 ha	.5 ha	.5-1 ha	.25-.75 ha
Sensitivity to metals:		ferrous only	no	any	any
Situations to avoid:		metallic debris, igneous areas	surface very dry, saturated earth, shallow bedrock	high resistance areas, very dry or saturated earth, metallic debris	highly conductive clays, salts, rocky glacial deposits (e.g., moraines)
Tree effects:		impede survey, invisible in data	impede survey, positive anomaly	impede survey, negative anomaly	impede survey, roots yield anomalies
Advantages:		speed, hearths, burned areas detectable	good feature definition, moisture differences, rock; specific depth settings	speed, ease of use, collect conductivity & MS simultaneously	vertical profiles, stratigraphy, results in real time
Disadvantages:		restricted depth, need open parkland for speed, iron clutter detrimental, sensor facing critical, constant pace of movement	probe contacts slow, must deal with cables	less spatial detail, metal clutter detrimental, must maintain constant ground angle, need open parkland for speed	equipment bulky, difficult data processing, interpretations difficult
Daily data volume:		high	low	low	high
Data processing complexity:		moderate	low	moderate-low	high
Costs (USD):		$5k-25k	$600-15k	$6k-18k	$15k-30k

***** depends on soil properties**.**

Deep sites. Most geophysical instruments are designed for near-surface detection, primarily sub-meter. For survey below a meter, certain EM instruments (the EM31 by Geonics Ltd.) allow soil conductivity prospecting to a depth of 6 m, but spatial resolution is low. The same is true of electrical resistivity, which has no real depth limitation with wide probe separations, but spatial resolutions suffers with depth. If soils are not too conductive, GPR with a low frequency antenna (e.g. 200-300 MHz) can allow detection to depths of several meters.

Size of Targets. When targets to be located in an archaeological site are very small one must utilize very high sampling densities to detect contrasts and form anomalies. Small targets generally are sub-meter in size and include archaeological categories such as post holes and small pits, for example. Graves may fall in this category as well. In general, GPR is best suited for resolving small targets because from dozens to more than a hundred traces may be sent to the subsurface each linear meter, giving best chance of detecting small targets. Magnetic gradiometry offers next highest sampling densities with 10-20 measurements per meter typical.

Type of archaeology. If the site being investigated contains constructions of stone then resistivity survey is a must. It is also highly revealing when large ditch or sunken features (pits, cellars, subterranean dwellings) may be present because it is so able to detect moisture differences. Magnetometry is useful whenever magnetically enriched topsoil is reworked and redeposited. Mounded topsoil features are highly detectable, as are pits and depressions filled with topsoil. Areas of topsoil removal (e.g., ditches) also appear as negative anomalies. Any form of intensive burning enhances soil magnetism, making hearths and burned houses readily detectable. GPR responds well to most subsurface archaeological features, but is less sensitive to magnetic ones typically detected by magnetometry. EM induction instruments are largely redundant on resistivity and magnetometry. Moreover, the magnetic susceptibility component is sensitive to only very shallow targets (less than a half-meter) and experience suggests that the soil conductivity component resolves less detail than corresponding resistivity surveys.

6.8.3. Considerations of Dimensionality

Weymouth (1986) has suggested that magnetometry, resistivity, and GPR generally respond to independent dimensions of the subsurface: magnetism, conductivity, and dielectric contrasts. To this might be added thermal properties. In general, different anomalies may theoretically be indicated in each domain suggesting that multi-method surveys are warranted whenever possible (i.e., when environmental conditions allow).

6.9 COST/BENEFIT OF TECHNOLOGY

Recent events, including the conflict in Iraq and the war on terror, have underscored the fact that realistic military training is more important than ever before. As military vehicle and weapons systems evolve, there is an ever increasing need for large contiguous land areas for effective training. Archaeological sites categorized as eligible or potentially eligible for the NRHP currently are normally avoided, fragmenting the lands available for training. One way to reduce this problem is to mitigate sites located within key training areas. Using archaeo-geophysical techniques to identify sites and portions of sites that include important subsurface deposits could dramatically reduce the costs associated with site mitigation. These amounts can be estimated, although actual percentages will depend on the training needs and nature of the archaeological resource base at individual installations, as well as other factors. The Army presently manages ca. 90,000 archaeological sites (source: Army Environmental Center). We can assume that a majority of these (e.g., 66%) are relatively small sites that lack complex cultural deposits. The remaining sites (n=30,000) are relatively large and complex. Only a fraction of these sites--for present purposes, we can assume 10% (n=3,000)--are located in areas critically needed for military training. A carefully conceived CRM plan might propose mitigation of 20% of these sites (n=600), with the rest made available for military training. The traditional approach to mitigation involving excavation of a large portion of each site is very costly. For present purposes, we estimate the cost of traditional mitigation at $100,000 per site. The total cost to mitigate 600 sites is therefore $60,000,000. If the methods used in this project were in wide use, we believe that the mitigation cost per site (and total cost for 600 sites) could be reduced by at least 50%, representing a cost avoidance of $30,000,000. If the 600 sites were mitigated over the course of 10 years, the cost per year would be $6,000,000 for traditional approaches vs. $3,000,000 for a strategy based on archaeo-geophysics and targeted excavation. The cost savings for the latter would be $3,000,000 per year, or $15,000,000 over five years. Note that these estimates are not adjusted for inflation.

6.10 TRANSITION STATUS

As the previous section illustrates, it is not unreasonable to anticipate that there could be dramatic direct cost savings to DoD if the methods applied in this project were widely used. In addition to these direct savings we believe, as many of the sections in this chapter document, that the quality of information will increase and the likelihood of unintended damage to resources and the unintended exposure of Native American human remains will be reduced. We believe that there are three major impediments to the rapid adoption of this approach. These are (1) the absence of a pool of qualified archae-geophysical practitioners, (2) the extremely time consuming and complex software processing that is currently the “state-of-the-art” and (3) the lack of awareness and acceptance of the methods by the regulatory agencies (e.g. SHPOs, Tribal Historical Preservation Offices (THPO) and Advisory Council). Issues 2 and 3 are currently being directly addressed by a recently initiated ESTCP Project: *Streamlined Archaeo-Geophysical Data Processing and Integration for DoD Field Use*

The ESTCP project has two primary objectives: 1) assemble a single software package,
ArchaeoMapper, that will serve as an effective medium for infusing the integrated, multi-sensor geophysical approach into wide use; and 2) demonstrate and validate the cost and performance benefits of the approach and technology infusion tool, in conjunction with the annual NPS *Current Archeological Prospection Advances for Non-destructive Investigations in the 21st Century Workshop.* The multi-agency demonstration will involve DoD geophysicists, representatives of federal, state, and THPOs, CRM practitioners, and federal and state resource managers. The project should also serve to address aspects of the first impediment by providing an easier-to-use software environment that should serve to increase the number of practitioners. In addition, as the value of archaeo-geophysical methods becomes increasingly obvious from projects such as this and many others, the number of interested archaeologists in growing.

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APPENDIX A: SUPPORTING DATA

Approximately 8 gigabytes of project data and metadata (readme) files are available via anonymous FTP from the Center for Advanced Spatial Technologies.

URL: **ftp://serdp.cast.uark.edu/serdp/**

Please direct any questions to debbie@cast.uark.edu.

APPENDIX B: LIST OF TECHNICAL PUBLICATIONS

Articles Published In Peer-Reviewed Journals

- Kvamme, Kenneth L. (2005). Integrating Multidimensional Geophysical Data. *Archaeological Prospection*. http://dx.doi.org/10.1002/arp.268 (in-print version slated for February, 2006 issue)

Technical Reports

- Foster II, H. Thomas (2005). *Excavations at the Muskogee Town of Cussetuh (9CE1), Draft Report*. BHE Environmental, Inc., report submitted to the University of Arkansas and Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois.
- Herron, Tammy Forehand, and Robert Moon (2005). *Ground Truthing of a Multi-Sensor Remote Sensing Survey at the George Galphin Site, Silver Bluff Audubon Sanctuary, Aiken County, South Carolina.* Draft report submitted to the Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois, by the Savannah River Archaeological Research Program, South Carolina Institute of Archaeology and Anthropology, University of South Carolina, Columbia.
- Koons, Michele L. (2005). *Visualizing Ground-Penetrating Radar Data in Three-dimensions*. University of Pennsylvania report submitted to University of Arkansas.
- Krejsa, Paul, and Jacqueline M. McDowell (2005). *Draft Archaeological Ground Truthing of Remote Sensing-Derived Anomalies at Army City, Fort Riley, Kansas*. Public Service Archaeology Program Research Report No. 87, submitted to Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois.
- Maki, David (2003). *Ground Based Geophysical Investigations of Two Archaeological Sites.* Archaeo-Physics Report of Investigations No. 66, submitted to University of Arkansas.
- Lukowski, Paul, and Elia Perez (2005). *Ground Truthing Remote Sensing Data at the Escondida Site (LA 458), Otero County, New Mexico*. TRC Environmental report submitted to Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois.
- Sever, Thomas L. , and Burgess F. Howell (2005). *Aerial Multi-Sensor Remote Sensing Investigation for Archeological Resource Inventory.* Report submitted to the Center for Advanced Spatial Technologies, University of Arkansas.

Conference/Symposium Proceedings

- Kvamme, Kenneth L. (2005). Archaeological Modeling with GIS at Scales Large and Small. In *Reading Historical Spatial Information from Around the World: Studies of Culture and Civilization Based on Geographic Information Systems Data.* 24th International Research Symposium, International Research Center for Japanese Studies, Kyoto, Japan, pp. 169-187.

Published Technical Abstracts

- Kvamme, Kenneth L. (2005). *Integrating Geophysics with GIS*. Indo-US Science and Technology Forum Workshop on Digital Archaeology: A New Paradigm for Visualizing the Past through Computing and Information Technology, Mussoorie, Uttaranchal, India.
- Ernenwein, E.G., and K.L. Kvamme (2005). *Geophysical Data Fusion: Combining Sensor Outputs through Graphical, Mathematical, and Statistical Approaches*. Computer Applications and Quantitative Methods in Archaeology Conference (CAA), Tomar, Portugal.
- Kvamme, K.L., and E.G. Ernenwein (2005). *Multidimensional Fusion of Geophysical and Other Data from Army City, Kansas, and Pueblo Escondido, New Mexico*. Poster presentation, Annual meeting of the Society for American Archaeology, Salt Lake City.
- Hargrave, M.L., K.L. Kvamme, and E.G. Ernenwein (2005). *Methodological Issues in Ground Truthing the Results of Remote Sensing Surveys*. Poster presentation, Annual meeting of the Society for American Archaeology, Salt Lake City.
- Kvamme, Kenneth L. (2005). *Integrating Remote Sensing Data at Army City, Kansas*, Poster presentation, Annual Conference on Historical and Underwater Archaeology, Society for Historical Archaeology, York, England.
- Limp, W.F., K.L. Kvamme, E.G. Ernenwein, D.L. Harmon, M.L. Hargrave (2005). *Fusion of Geophysical Data for Subsurface Archaeological Detection and Mapping*. Paper presented at the Partners in Environmental Technology Symposium, Washington, D.C. (2005).
- Kvamme, K.L., E.G. Ernenwein, T.L. Sever, D.L. Harmon, W. F.Limp, and M. Hargrave (2005). *Data Fusion of Archaeological Remote Sensing from Ground-, Air-, and Space-based Platforms*. Poster presented at the Arkansas GIS User Forum Conference, Hot Springs, AR.
- Kvamme, Kenneth L. (2004). *Multidimensional Remote Sensing & Data Fusion in North American Archaeological Sites*. Paper presented at the meeting of the International Union of Pre- and Proto-historic Sciences, Commission IV: Data Management and Mathematical Methods in Archaeology, Santa Fe, New Mexico.
- Ernenwein, Eileen G., and Kenneth L. Kvamme (2004). *Ground-penetrating Radar at the Landscape Scale: New Problems and Possible Solutions*. Paper presented at the Archaeological Sciences of the Americas Symposium, University of Arizona, Tucson.
- Ernenwein E.G., and K.L. Kvamme (2004). Archeo-Geophysical, Panchromatic, and Multispectral Data Synergy at Army City, Kansas. Poster presented at the Annual Conference on Historical and Underwater Archaeology, Society for Historical Archaeology, St. Louis, Missouri.
- Kvamme, Kenneth L. (2004). *Data Fusion of Archaeological Remote Sensing from Ground-, Air-, and Space-based Platforms*. Paper presented at the Partners in Environmental Technology Symposium, Washington, D.C. (2004).
- Ernenwein, Eileen G., Kenneth L. Kvamme, W. Fredrick Limp, Deborah L. Harmon, Michael L. Hargrave, Thomas L. Sever (2004). *Archaeo-Geophysical,*

Panchromatic, and Multispectral Data Synergy at Four DoD and DoE Archaeological Sites. U.S. Department of Defense Conservation Conference, Savannah, Georgia.

- Kvamme, K.L., E.G. Ernenwein, T.L. Sever, D.L. Harmon, W. F.Limp, M. Hargrave, and L.E. Somers (2003). *Archeo-Geophysical, Panchromatic, Thermal, and Multispectral Data Synergy at Four DoD And DoE Archaeological Sites*. Poster presented at the Partners in Environmental Technology Technical Symposium & Workshop, Department of Defense, Washington, D.C.
- Ernenwein, E.G., K.L. Kvamme, W.F. Limp, D.L. Harmon, M. Hargrave, T.L. Sever, and L.E. Somers (2003). *Multi-Dimensional Remote Sensing: Fusing Ground, Air, and Satellite Data from Archaeological Sites*. Poster presented at the annual meeting of the Society for American Archaeology, Milwaukee.
- Limp, W.F., K.L. Kvamme, E.G. Ernenwein, D.L. Harmon, M.L. Hargrave, T.L. Sever, and L.E. Somers (2002). *Multi-Dimensional Remote Sensing: A SERDP Project Fusing Ground, Air, and Satellite Data from Archaeological Sites*. Poster presented at the Partners in Environmental Technology Technical Symposium & Workshop, Department of Defense.
- Ernenwein, Eileen G., and Kenneth L. Kvamme (2002). *Multi-deimensional Remote Sensing at Army City, Kansas: A SERDP Project Fusing Ground, Air, and Satellite Data.* Paper presented at the 60th Annual Plains Anthropological Conference, Oklahoma City.

Published Book Chapters

- K.L. Kvamme, J.K. Johnson and B.S. Haley (2006). Integrating and Interpretation of Multiple Instrument Applications, In *Geophysical and Airborne Remote Sensing Applications in Archaeology: A Guide for Cultural Resource Managers*, J. Johnson, ed., University of Alabama Press, Tuscaloosa.
- Kvamme, Kenneth L. (2006). Archaeological Modeling with GIS at Scales Large and Small. In *Reading Historical Spatial Information from Around the World: Studies of Culture and Civilization Based on Geographic Information Systems Data.* Uno Takao, editor, International Research Center for Japanese Studies, Kyoto.
- Kvamme, Kenneth L. (2006). Integrating Multiple High Resolution Geophysical Data Sets. In *Remote Sensing in Archaeology,* J. Wiseman and F. El-Baz, editors, Plenum Publishers, New York, *volume in preparation.*
- Kvamme, Kenneth L. (2006). Remote Sensing: Archaeological Reasoning Through Physical Principles and Pattern Recognition, In *Archaeological Concepts for the Study of the Cultural Past*, A.P. Sullivan III, ed., University of Utah Press, Salt Lake City, *volume in preparation*.
- Tullis, Jason, Jack Cothren, Kenneth L. Kvamme (2006). In Situ Methods. In *Manual of Remote Sensing,* CRC Press, New York, *volume in preparation.*