LANDSCAPE LINES

6

Geophysical Survey Techniques

Introduction

Geophysical survey techniques indirectly measure the presence of resources concealed within the earth's subsurface as a result of geologic processes or human disturbances. Geophysical survey techniques detect subsurface contrasts, including mass-density relationships, ionic or electrical potentials, magnetic susceptibilities, and elemental decay. The surveys can reveal the location of archeological resources and lead to their identification.

Geophysical survey equipment is used to investigate buried prehistoric and historic structures and artifacts. The use of geophysical survey equipment and computer aided interpretation has increased the accuracy of archeological surveys to the point where potentially destructive, random excavations can be minimized.

Geophysical survey techniques cannot positively identify a buried cultural resource, but they can provide data for interpretation from which strong inferences can be made. Geophysical surveys use remote sensing techniques, which examine earth features from a distant platform situated above a target area and usually employ high altitude aircraft or satellites. From a platform situated on or just above the earth's surface, geophysical survey equipment remotely sense earth features in a target area located beneath the earth's surface.

Applying Geophysical Survey Techniques to Cultural Landscape Research

Geophysical survey techniques are either passive or active. Passive techniques measure naturally occurring earth-related processes, such as the earth's electromagnetic or gravitational field. Magnetometry is a passive geophysical survey technique. Active techniques involve transmitting an electrical, electromagnetic, or acoustic signal into the subsurface. Interaction of the input signal with subsurface materials produces a modified return signal that can be measured. A familiar, amateur active technique is the metal detector. Other active geophysical techniques include ground penetrating radar, electrical resistivity, and electromagnetic conductivity.

Geophysical techniques were used in an archeological survey of Virginius Island, a nonextant, nineteenth century industrial community in Harpers Ferry National Historical Park. (See Figure 1.) Geophysical services were contracted to determine the location of twelve, nineteenth century residential structures and their associated outbuildings, buried within four acres of river terrace landscape. (See *A Guide to Cultural Landscape Reports: Appendices*, "Appendix J: Project Agreements.") The general location of these residences was derived from historical documentation, maps, and photographs, but the precise location of the outbuildings and their yards was unknown. The project agreement for the geophysical survey specified ground penetrating radar and electromagnetic conductivity, but allowed for the possibility of using additional techniques to verify the location of a feature. The results of the geophysical survey led to the excavation or "ground-truthing" of specific sites to produce an accurate site plan of Virginius Island. Results of the survey facilitated development of a treatment plan, which included an interpretive program. (See Figures 2 and 3.)

Passive Geophysical Survey Techniques

Passive geophysical survey techniques measure naturally occurring, local, or planetary fields created by earth processes. Passive techniques include magnetic surveying with a magnetometer and gravity surveying using a gravitometer. A magnetometer measures the earth's total magnetic field. It is useful for detecting buried ferrous objects or magnetic anomalies in soils. A gravitometer measures the anomalous acceleration of gravity due to mass/density relationships of buried features. Currently, the technique has limited use because detection is very subtle.

Implementation and Limitations of a Geophysical Survey

Successful implementation of a geophysical survey depends on the following:

- **A comprehensive survey design that specifies the set of techniques chosen for a survey (multiple techniques are requisite for a thorough site investigation), the order in which the techniques are implemented, the size and location of the survey grid applied, and the compatibility of the techniques with the site (that is, compatible with geology and physical access).**
- **An experienced geophysicist contractor who is skilled in multiple geophysical methods and knowledgeable about the physical and historic context of the survey and the nature of the expected results.**

Possible limitations of geophysical surveys include the following:

- **Geophysical surveys are equipment-intensive and may be expensive to conduct.**
- **Geophysical survey equipment cannot distinguish between cultural and geologic anomalies.**
- **Geophysical survey techniques are limited to near-surface detection. There are limits to the depth and scale of resolution.**
- **Geophysical survey equipment may not detect subtle contrasts or weak signals. If the contrast between the sought-after archeological material and incubating soil is small, detection is hindered.**
- **Erroneous readings may occur as a result of distortion from nearby cultural entities with physical or electromagnetic properties, such as subterranean utilities, powerlines, metal fences, transmission towers, buildings, roads, railroads, aircraft, and two-way radios.**

Figure 1. This photograph of Virginius Island shows the proximity of the former industrial community to the Shenandoah River. The nineteenth century buildings were largely destroyed by successive floods by the turn of the century. A geophysical survey of selected areas of the island yielded information about the location of ruined residences and outbuildings. This information was used in developing a treatment plan for the cultural landscape. Harpers Ferry National Historical Park. (NPS, 1865)

Magnetometry

Magnetometry is used within a large landscape area to detect the presence and location of archeological resources with magnetic properties. It is useful for a preliminary level of a subsurface investigation and is particularly suitable for detecting brick structures and metallic artifacts.

Magnetometry, or magnetic surveying, uses the proton magnetometer to measure the magnetic susceptibility of buried materials. The earth's total geomagnetic field can be measured and used as a control point of reference to compare local magnetic interferences. When compared to the total geomagnetic field, local disturbances or anomalies can indicate the position of ferrous objects, displaced soils, and earthen structures.

The magnetometer is a highly sensitive instrument, capable of measuring perturbations or anomalies with an accuracy of one part in 100,000. The proton magnetometer is one of the simpler, less expensive, and more accurate geophysical instruments, and consequently is used frequently for geophysical surveys. Acquisition of spatial data over large areas is relatively easy, and qualitative interpretations can be made rapidly with relatively less geophysical experience. (See Figure 4.)

Active Geophysical Survey Techniques

Active geophysical survey techniques involve transmitting electrical currents, electromagnetic, or acoustic energies into the earth's surface.

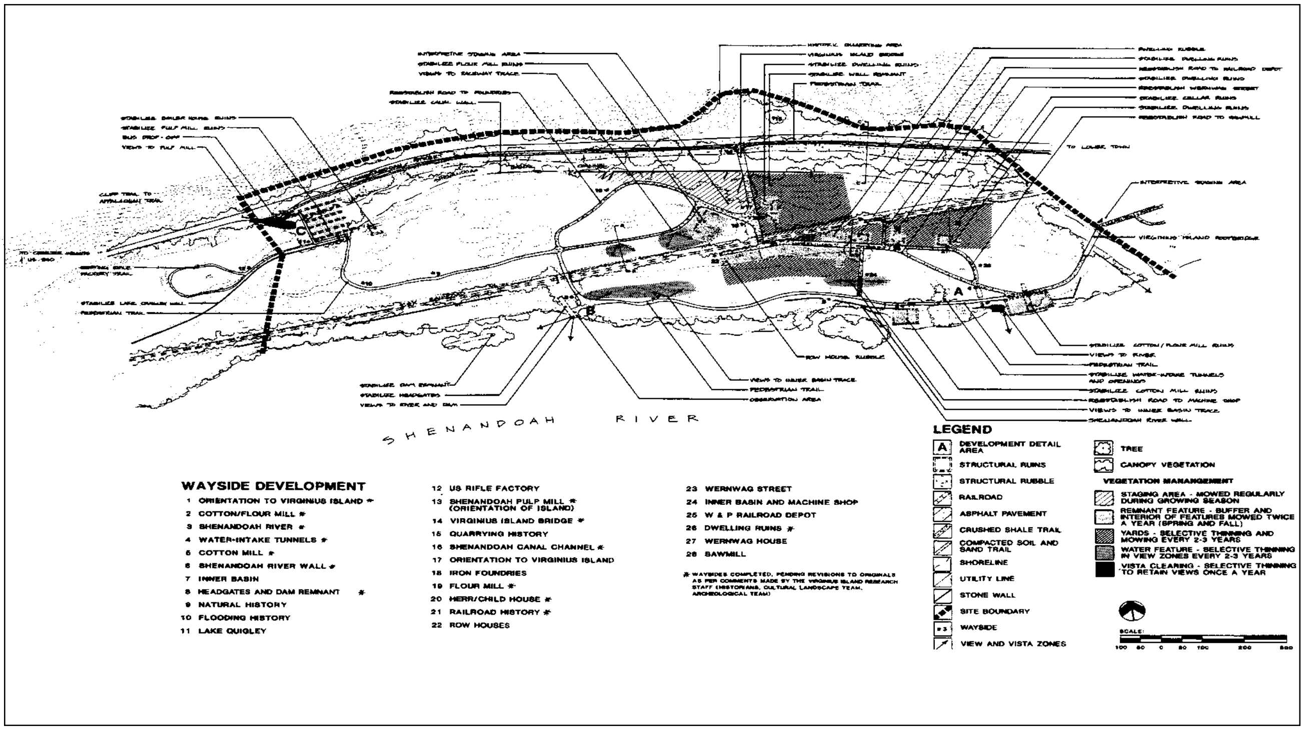

Figure 2. Proposed treatment plan for the cultural landscape of Virginius Island. Data from geological surveys, archeological site investigations, and historical research contributed to the development of this plan. Harpers Ferry National Historical Park. (NPS, 1992)

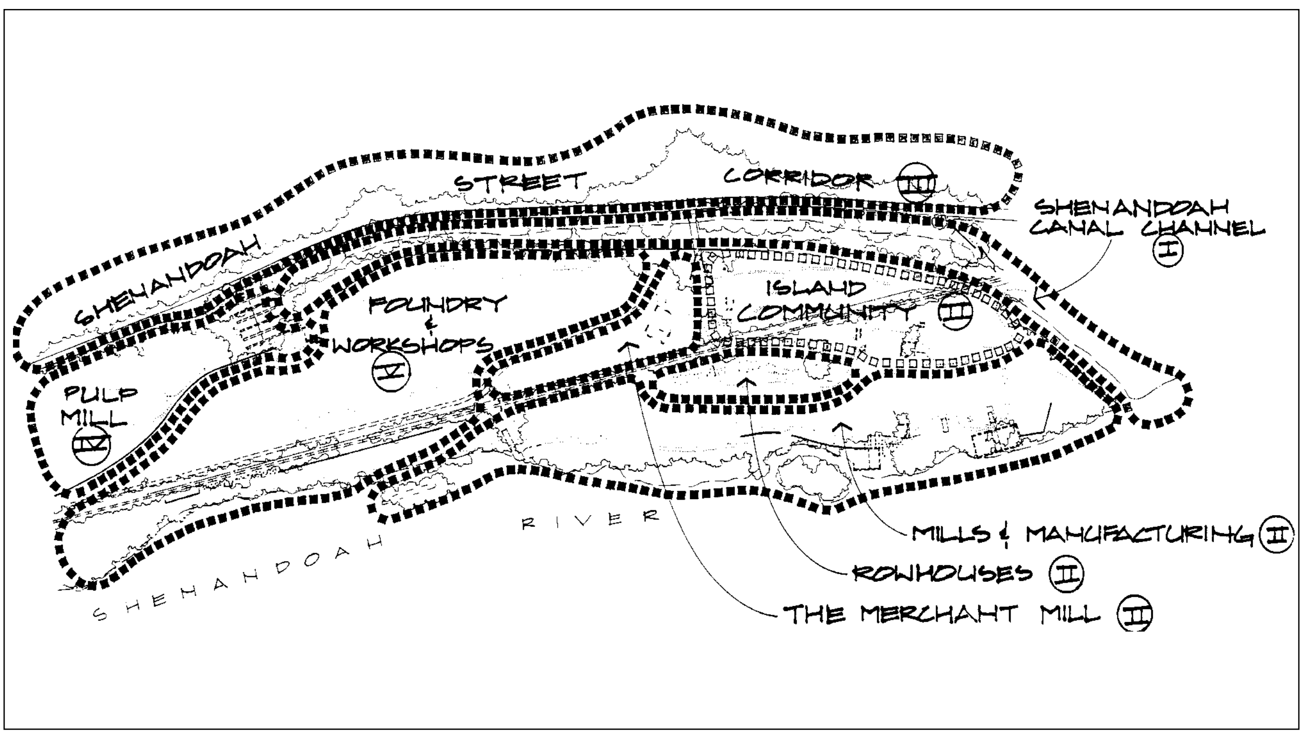

Figure 3. Proposed management zones for Virginius Island. The management zones are based upon historic land uses on the island, which were identified through historical research and archeological site investigation. Harpers Ferry National Historical Park. (NPS, 1992)

Active techniques include ground penetrating radar, electrical resistivity, and electromagnetic conductivity. Earthen material, such as soil or rock, are generally considered to be relatively poor conductors of energy. Much of the energy that geophysical equipment introduces is dissipated into the subsurface. Often geophysical receivers magnify the return signal to compensate for the poor conduction of energy. A comparison of amplitude, frequency, wavelength, and time delay between the input and return signals leads to the detection of buried cultural resources.

Ground Penetrating Radar

Ground penetrating radar (GPR) is used to determine the depth and physical properties of buried cultural and geologic features. It can effectively map soil layers, depth to bedrock, cavities, buried stream channels, burial sites, underground utilities, structures (including concrete structures), and metallic objects.

GPR is most often used to measure reflected low frequency electromagnetic energy, which is introduced into the subsurface via a surface-contact, transmitting antenna. (See Figure 5.) As the energy passes through the earth, it may encounter buried materials of varying electrical properties. At these electrical interfaces, energy may be either reflected or attenuated. A receiving antenna on the earth's surface detects reflected energy. The receiving antenna is positioned in close proximity to the transmitting antenna. Comparison of the return signal time delay with the input signal (in billionths of a second) is a function of the speed of the signal as it passes through the buried material. This comparison can be used indirectly to calculate the depth of the buried material. A comparison of the amplitude and frequency of the reflected signal with the input signal provides information about the physical properties of the buried material.

Figure 4. A magnetic survey using a GEM 19 magnetometer. Fort Laramie National Historic Site. (NPS, 1993)

Site-specific conditions may limit the success of GPR in geophysical surveys. The presence of highly conductive clay soils in proportions of 10 percent or more is probably the greatest limiting factor affecting radar signals. Highly conductive soil conditions result in the attenuation of electromagnetic energy, a reduction in signal velocity, and a decrease in depth of signal penetration. Water-saturated soils also produce a highly conductive environment. Seasonal groundwater level variations may be relevant in timing a ground penetrating radar survey.

Figure 5. A ground penetrating radar being pulled across the ground. Lockwood Stage Stop, Pinon Canon Maneuver Site, Colorado. (NPS, 1991)

Electrical Resistivity

Electrical resistivity uses electrical resistance (poor conductivity) properties to identify buried cultural resources. A highly refined electrical resistivity survey may be the most revealing geophysical technique, but it is expensive to perform because it requires a high number of readings per unit area.

Resistivity experts interpret electrical resistivity patterns to identify the presence of nearly all forms of constructed features, such as foundations, paths, and roads. The technique can also reveal compacted soils, indicative of a former pathway, and disturbed soils, such as those found at burial sites and cultivated fields. Electrical resistivity is useful for measuring depth to bedrock and is often performed before GPR in geophysical surveys involving multiple techniques. Depth to bedrock measurements are useful in calibrating GPR equipment.

Electrical resistivity uses current electrodes to introduce into the soil an electrical current of known amplitude (amps) and frequency (volts), and potential electrodes with an ohmmeter to measure resistance changes in the soil, vertically and horizontally. (See Figure 6.) Measurements of vertical changes in resistivity are called “soundings” and measurements of horizontal changes in resistivity are called “profiling.” The technique requires at least three individuals to move two current electrodes and two potential electrodes along a survey grid. It is assumed that the incubating soil has a homogeneous resistivity (due to an assumed even distribution of soil and water) and that buried cultural resources can be identified as anomalous readings of resistance.

Along survey gridlines, changes in resistance readings are used to create “contour maps” of soil resistivity. On the map, concentric contours emanating from a location (called a “spot elevation”) represent material of lowest conductivity,

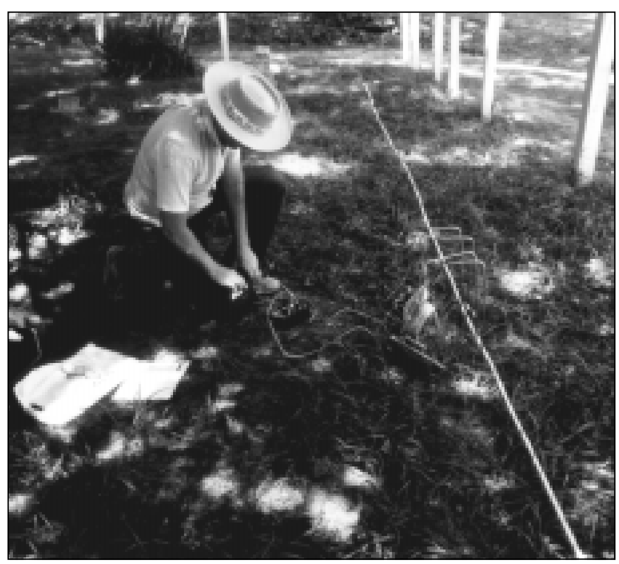

Figure 6. An electrical resistivity survey using a Gossen resistivity meter. Scott Air Force Base. (NPS, n.d.)

or conversely, greatest resistance. Because soil conductivity is directly related to the presence of water, locations measuring the greatest resistance will have a lower soil-water content. Nonsaturated soil conditions reveal more contrasts between potentially buried cultural resources (that have lower water content) and native soil material (having higher water content).

Ideally, electrical resistivity tests should be performed in more than one season with varying soil-water conditions. In some geologic conditions the native soil may have a lower water content and therefore higher resistivity than buried cultural resources. Because resistivity is directly related to permeability, degree of saturation, and the chemical nature of entrapped fluids, prior knowledge of indigenous geologic conditions is requisite to accurately interpret resistivity data.

Electromagnetic Conductivity

Electromagnetic conductivity, also called EM and induction, is used to detect and differentiate metallic artifacts buried near the earth's surface. The technique locates near-surface cultural features (structures, compaction, excavation, and habitation sites) by their various water saturations (their conductivity). A conductivity measurement is the reciprocal of resistivity, so in theory the results of a lateral conductivity survey should mirror the results of a resistivity profile.

The main advantage to using conductivity over resistivity is that the measuring instrument does not require surface contact. Two individuals are required to perform the technique, but the conductivity instrument can be moved from station to station by one operator. Resistivity requires a crew of at least three to move and place electrodes in the ground along a survey line. (See Figure 7.)

Electromagnetic conductivity uses a nonsurface contacting radio transmitter and receiver. The transmitter induces an electromagnetic field in the earth, causing an electrical current to flow. The electrical current generates a secondary magnetic field that causes the flow of an electrical current signal in the receiver. The receiver signal is measured for conductivity by a voltmeter incorporated in the EM instrument. The voltmeter is calibrated to measure the soil as having a homogeneous level of conductivity. It is assumed that buried cultural resources cause anomalies in the homogenous level of conductivity detected along survey lines. Large fluctuations in conductivity are indications of highly conductive subsurface materials, such as buried

Figure 7. An electromagnetic conductivity survey using a Geonics EM38 soil conductivity meter. Fort Laramie National Historic Site. (NPS, 1993)

utilities. Observing the physical extent and orientation of the anomaly can provide clues to its identification.

Sources of Geophysical Prospecting Equipment and Surveyors

United States Governmental Agencies

United States Geological Survey

United States Bureau of Reclamation

United States Bureau of Mines

Environmental Protection Agency

State Agencies

Geologic Surveys

Health & Environmental Agencies

Universities and Colleges

Geological Departments

Geophysical Departments

Engineering Departments

Private and Nonprofit Organizations

Private Concerned Citizens

Geophysical Equipment Manufacturers

Geophysical Equipment Rental Companies

Geophysical Consultants

For access to the last five groups, acquire a copy of the Geophysical Directory, published each March. This directory provides the most comprehensive listing of sources of equipment and geophysical survey experts available.

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