REMOTE SENSING[1]
(1/2010)

Conservation of cultural resources is of prime importance to archaeologists and Native American peoples. Threats to cultural resources, a non-renewable resource, are greatly increasing with the rise in development throughout Oregon and current efforts in many communities to expand urban growth boundaries. Geophysical techniques provide non-intrusive methods which permit the undisturbed reconnaissance of potential archaeological sites and can provide essential data for management planning purposes and future archaeological investigations as well as a means to target areas needing the stabilization of historic and/or prehistoric structures. Such techniques, because they are rapid and generally non-destructive, provide archaeologists with an efficient planning tool to target specific excavation or stabilization objectives as well as providing a means of locating buried cultural phenomena. However, geophysical surveys do not take the place of archaeological excavations. It is important to remember that subsurface anomalies identified through geophysical surveys need to be verified. Interpretation is usually the weakness in the use of geophysical surveys and it is important to test different classes and possible feature types to verify predicted results. This ground-truthing process will require subsurface testing and can not be obtained from only looking at the ground's surface.

To promote conservation efforts remote sensing techniques are gaining increased use by archaeologists to assist in identifying the locations of archaeological sites while protecting the sites. Remote sensing offers many types of investigative techniques that can provide an investigator with a means to identify and evaluate resources within a proposed project area without causing undo damage to the site or structure. These methods can provide an efficient initial use of labor and funds in collecting important information on subsurface anomalies (features) that can be used to help identify buried cultural resources. Typical archaeological excavations are both destructive and slow. Most archaeological sites can not be completely excavated due to cost, time involved and the desire to preserve as much of a site as possible. While excavations provide detailed data at discrete locations within a site, they do little to describe overall site conditions. Geophysical surveys offer a less-intrusive and less-destructive method of assessing site integrity than subsurface testing by providing detailed evidence of previous activities/occupation of an area that is not visible from the surface without excavation. Ground-truthing of discovered anomalies, however, is still required. Other advantages for conducting geophysical surveys include: 1) the possibility of mapping large areas quickly and inexpensively; 2) the ability to create a sub-surface map before beginning excavations; 3) the ability to assess site patterning and integrity; and 4) target specific features for excavation while avoiding others. Such data can compliment excavation data and allow researchers to understand excavation results within an entire site context.

The most often employed geophysical methods include: electromagnetic resistivity, magnetometry and ground-penetrating radar. Other survey methods that may

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be useful under special circumstances include electromagnetic conductivity, magnetic susceptibility, metal detector, and soil compaction.

For example, electromagnetic (EM) and resistivity methods induce a field (electromagnetic or electrical) into the ground with measurements then collected on how the medium responds. As the sensors are moved across the ground in transects, changes in the induced field can be related to the presence or absence of buried archaeological features or geological changes. When displayed in a gridded map form, many buried features are visible. Magnetometry (e.g., magnetometers) can be a passive method which measures changes in the ambient magnetic field of the earth over an area due to physical and chemical changes in near-surface material, which can relate to buried materials or very near-surface archaeological features that are not visible to the human eye. These geophysical tools collect data quite rapidly and can quickly produce useful maps, but they are not able to accurately measure the depth of buried features. In contrast, ground-penetrating radar (GPR), which measures the reflection of radio waves transmitted into the ground, can measure both the depth and spatial extent of buried features. For archaeological mapping in some environments, GPR is rapidly gaining acceptance as its successes are demonstrated and data collection and interpretation techniques improve.

Remote sensing techniques summarized here include the use of magnetometers, conductivity meters, ground-penetrating radar, magnetic susceptibility, metal detectors, resistivity meters, and soil compaction meters. Table 1 provides a quick comparative summary of the various techniques. More detailed information on each of these techniques is summarized below along with a list of their advantages and limitations.

Magnetometers

Some types of buried features (e.g., holes, ditches, prior excavation units, hearths, camas ovens) and artifact classes (e.g., bricks, fire-altered rock, iron artifacts) are known to leave magnetic signatures that can be detected from the surface through the use of magnetometers. A surface survey of an area using a magnetometer at 0.5 meter transect intervals can often identify many buried features. The primary application in archaeology is the locating of historic iron artifacts, features of fired earth (e.g., hearth, earth oven) and detecting soil disturbances and patterned anomalies (e.g., ditches, walls). Graves, old excavation units, privies, and postholes are difficult to detect. Other non-archaeological applications include locating and mapping ferrous metal, geologic mapping, and locating unexplored ordnance. Factors influencing the use of magnetometers include: 1) area soil iron content; 2) depth of possible feature; 3) biochemical alteration; 4) volume and shape of buried feature; and 5) sensitivity of gradiometer and latitude. Soil content may also impact results in that organics are more magnetic (e.g., burned soils) and flood plains offer less contrast. A basic understanding of local formation processes and past land use history of a site is important in achieving a successful survey design and appropriate interpretation of the geophysical survey data. This technique is best done with two-three people due to the need to lay out grids and constantly move them through the recording process.

ADVANTAGES	LIMITATIONS
Good results over wet ground conditions and in flood zones.	Does not work well near highly magnetic sources (e.g., cans, rebar, metal fences).
Great tool for detecting fire hearths.	Depth to source not as accurate as some other methods (e.g., GPR).
Works well on uneven surfaces	Plow scars can influence reading but can be processed out through software.
Relatively quick: 20 x 20m area done in 20-40 minutes when no obstacles (e.g., trees) exist.	
Ease of processing data.	

There are two popular types of magnetometers: 1) Cesium and 2) Fluxgate.

Photo 1: Cesium Magnetometer

Photo 2: Fluxgate

Ground-Penetrating Radar

Ground-Penetrating Radar uses electromagnetic pulses and records their reflections due to changes in subsurface properties (e.g., burials, voids, buried architecture, metal and non-metal artifacts, stratigraphy). This technique provides the highest resolution of any geophysical method, it is relatively easy to operate, and can be pulled by hand or towed by a vehicle from 0.5 – 5 mph. It is very useful in: 1) detection of grave locations; 2) urban areas; 3) if you need to get good depth readings or the target is too deep for other methods; and 4) is possibly good for detecting privies. Ground-penetrating radar can also be used with other analytical techniques to evaluate interior structural components of walls, floors and foundations of both prehistoric and historic structures. This technique is not useful in: 1) conductive ground conditions; 2) locating very ephemeral sites; 3) looking for single small objects; or 4) very overgrown or broken terrain, because the transmitting and receiving unit must be in contact with the ground surface. A downside to the use of GPR is the time it takes to process the data which can make this technique somewhat time-consuming.

ADVANTAGES	LIMITATIONS
Provides approximate depth to target and layering of anomalies thru time slicing.	High conductivity soils make signal penetration difficult.
Penetrates asphalt and reinforced	Need good ground contact (e.g., low grass).

concrete. Excellent tool for urban/industrial archaeology.	
Excellent for locating/delineating graves. Radar doesn't detect bones but evidence of disturbance to soil like presence of vaults (removed graves in shaft produce similar appearance to existing grave).	Can't use cell phones within 30 feet or it will interfere with data. Must keep 200 feet or greater away from cell phone tower.
Output is a continuous graphic picture-like display, resembling geological cross sections.	Very rocky soils may scatter data. Differential moisture of sediments impacts readings and must be considered during data analysis.
Detects a wider variety of features than any other geophysical instrument.	Can't operate in brush

Photo 4: Ground-Penetrating Radar

Conductivity Meters

Electromagnetic conductivity meters measure the electrical conductivity (i.e., ease of flow) through the soil by inducing a flow of electric current without the use of subsurface probes. This technique is useful in detecting voids, stone walls, earthen features, and accumulations of materials. This technique is slower than magnetometers but it picks up on buried objects more than resistivity surveys. It is sensitive to a wide range of metals and has a high potential for detecting disturbance. Depth is also very difficult to measure.

ADVANTAGES	LIMITATIONS
Measurements easy to make.	Susceptible to interference from nearby metal pipes, cables, fences, vehicles, noise from power lines and atmospheric storms.
Carried by hand or towed by vehicle at speeds from 0.5 – 5 mph.	Effectiveness decreases at very low conductivities.

Excellent lateral resolution when continuous measurements are used.	Not suitable if soil is very sandy.
Data often used with little processing	

Photo 3: Conductivity Meter

Magnetic Susceptibility

This technique measures the ease to magnetize materials. It provides a sensitive measure of soil formations and is useful in detecting earthen features, fired features, burials, and soil stratigraphy. This method is slow, cheap, and better for mapping soils (anthropogenic impacts). The magnetic signature of a previous feature can often be picked up where excavations have revealed no distinguishing characteristics.

Photo 5: Magnetic Susceptibility survey

Resistivity Meters

Electrical resistivity meters inject electrical current through the use of probes pushed into the ground and measure resistance to the flow. With this technique one is able to measure depth and identify constructed features, compacted or disturbed soils, and accumulations of materials. Its operation is largely a function of water permeability in that coarse soil, such as sand, produces a high resistance while low resistance is found in clay soils. This technique is best done with two-three people due to the need to lay out grids and constantly move them through the recording process. A team using a resistance meter should be able to cover nine 20 x 20 meter grids per day (1 meter spacing at 60 x 60 meters or 0.5m spacing at 30 x 30 meters). The depth of resistivity readings is equal to the separation of the mobile probes. A wider distance between probes will be less accurate but useful in detecting larger items at a greater depth.

ADVANTAGES	LIMITATIONS
Easy to do	Slow, labor intensive
Robust	Measurements vary with season/weather
Cheap equipment.	Tree roots disturb usefulness.
	Does not readily detect metal.
	Difficult to make good electrical contact in areas of hard pavement.

Photo 7: Resisitivity Meter survey

Metal Detectors

Metal detectors are useful in detecting near surface artifacts (upper 10-14 inches). They are quick and easy to use, useful in clearing modern metal refuse from a grid, and they are more valuable than shovel testing on metal-bearing sites. The largest limitation is that they are only useful for sites containing metal.

ADVANTAGES	LIMITATIONS
Measurements are relatively easy and rapid to make.	Susceptible to interference from nearby metal pipes, cables, fences, vehicles, buildings, and metallic surface debris.
Continuous measurements can be made.	Depth of investigation limited by the size of the receiver coil in the instrument.
Instrument is small and easy to transport.	No data logger to allow for mapping.
Often provides better lateral definition of shallow targets than do magnetometers.	

Photo 6: Metal Detector

Electromagnetic survey techniques include conductivity meters and ground-penetrating radar (GPR). Electrical resistivity techniques include resisitivity meters that can produce vertical electrical soundings and resistivity profiles. The following table compares electromagnetic conductivity surveys to electrical resistivity surveys.

Electromagnetic Conductivity	**Electrical Resistivity**
Fastest for lateral surveys	Slower for lateral surveys.
Operable by one person.	Usually requires 2-3 people.
Can use in brushy terrain.	Bushy terrain poses problems for dragging wire.
Sensitivity to metal (e.g., fences), overhead power lines and spherics.	Not effected by above-ground metals, power lines or spherics.
Avoids electrical current insertion problems.	Insertion problems in resistance ground and noise fluctuations because of resistivity in homogeneities near the electrodes.
Can use in-phase metals.	Only measures electrical resisitivity.
Relatively inflexible for depth profiling and limited ability to sound with depth.	Extremely flexible for tracing both lateral and vertical changes.
Limited ability to interpret and quantify vertical changes.	Able to interpret and quantify lateral and vertical changes in resisitivity.
Less sensitivity to tree roots	Tree roots show up well – noise.
Limited dynamic range	Larger dynamic range.
Problems with drift, particularly with I/P	Resisitivity meters tend to be more stable.
More expensive purchase and rental but lower crew cost.	Can be cheaper to purchase and rent but generally higher crew cost.
Can be used over pavement.	

Soil Compaction Meters

A Soil Compaction Meter is useful for detecting unmarked graves. Grave fill is looser than surrounding soils and the difference can be assessed. This technique could also be useful in the detection of areas that would have greater compaction than the surrounding site area, such as trails and historic roads. Maximum depth of readings is limited to approximately 18 inches. Compaction meters offer no data loggers so that measurements must be recorded by hand. The equipment is relatively inexpensive but its use is physically demanding.

Photo 8: Soil Compaction Meter

Summary and Recommendations

The usefulness of geophysical survey techniques will vary depending on the local soil characteristics, topographic restrictions, and what types of sites/features you are hoping to identify. General limitations to the use of a particular technique is summarized above but it is important to remember that there is always ambiguity in interpretation of results so that ground-truthing discovered anomalies is critical to the understanding of results. Some techniques can not detect both shallow and deep features while natural features can often mimic or mask buried archaeological features. Geophysical instruments are often expensive and complex so that a professional is needed to operate and interpret survey results. Any unwarranted signal can produce noise that will mask features in the vicinity of the noise. Our office recommends that, when considering the use of geophysical surveys you contact a professional in the area to help determine the best equipment for your needs, relative cost of a survey, and timeline for its completion and interpretation of results. A list of firms that currently offer various types of geophysical surveys in Oregon is included here for general reference. Our office can not recommend a particular firm for your project but we strongly encourage you to discuss your project with a number of available firms requesting information on the depth of their experience, available equipment, completed types of studies, and past project references that you could contact prior to your selection.

It is generally recommended that multiple instruments be used during surveys. In this way detection problems inherent in any one method (e.g., changing surface or subsurface materials) can be identified, verification and refinement of detected anomalies can be completed, and the target anomalies better characterized.

Table 1: Comparative Description of Main Geophysical Methods for Field Archaeology

Geophysical Method	Main use	Info obtained	Advantages	Difficulties	Limitations
Ground-penetrating radar	Search for graves, walls.	Plan of buried objects.	Continuous measurements; able to locate deep anomolies/features	Screning effect from covered clay layer.	Depth depends on type and moisture of soil.
Magnetic prospecting	Detail mapping of settlements, kilns, iron-smelting centers, ditches, banks.	Plan and character of buried objects.	One of the most universal methods, deep, simple.	Sensitiveness to noise from small modern iron objects in topsoil and industrial objects.	Interpretation is not simple.
Resistivity prospecting	Detailed mapping of settlement, walls, ditches, banks.	Plan and character of buried objects.	Can work under big magnetic noises.	Dependence of soil moisture.	Small, deep, interpretation is not simple.
Electromagnetic survey	Search for metal objects.	Location of buried objects.	Suseptible to magnetic and electrical properties.	Sometimes transmitter influence on receiver.	Subsoil objects.

Table information extracted from workshop handbook supplement by T.N. Smekalova, Radiophysics Department, Physical Institute, St. Petersburg University, St. Petersburg, Russia.

Consulting firms offering Geophysical Surveys

Consulting Agency	Technique(s) Offered
AMEC Earth & Environmental Lara Rooke 11335 NE 122nd Way, Suite 100 Kirkland, WA 98034 425-820-4669 X 3040 425-821-3914 FAX Email: Lara.Rooke@amec.com Website: www.amec.com	Ground-Penetrating Radar Magnetometry
Applied Archaeological Research, Inc. Bill Roulette RPA Aimee Finley MS 4001 NE Halsey Street Suite 3 Portland OR 97232 503-281-9451 Fax: 503-281-9504 Email: *bill@aar-crm.com* Website: *www.aar-crm.com*	Magnetometry Metal Detector
Archaeological Investigations Northwest, Inc. John Fagan, PhD. Terry Ozbun, MA 2632 SE 162nd Ave. Portland, OR 97236 Email: John@ainw.com Website: www.ainw.com	Ground-Penetrating Radar Magnetometry Metal Detector
B.A Silva Sensing Systems Billy A. Silva 832 Lake Canyon Avenue Galt, CA 95632 209-744-9232 Email: basilva@yahoo.com Website: www.basilva.com	Ground-Penetrating Radar Magnetometry Resistivity Conductivity Geo-thermal Imaging
Byram Archaeological Consulting LLC R. Scott Byram, Ph.D., RPA Sarah Purdy, MA 9948 Stayton Rd. SE Aumsville OR 97325 541-954-2466 or 541-954-0386 Fax: 866-873-8338 Email: byram@bacnorthwest.com	Ground-Penetrating Radar

Consulting Agency	Technique(s) Offered
CH2MHill Jim Sharpe, Cultural Resource Supervisor Hanford Square 3060 George Washington Way MSIN HO-23 Richland, WA 99352 Email: JJSharpe@mail.bhi-erc.com	Ground-Penetrating Radar
Confederated Tribes of the Umatilla Shawn Steinmetz; Cultural Resource Program PO Box 638 Pendleton OR 97801 541-276-3629 or 541-966-2339 Fax: 541-276-1966 Email: Shawnsteinmetz@ctuir.com Website: http://www.umatilla.nsn.us/crpp/crpphome.htm	Ground-Penetrating Radar Metal Detector
Fort Vancouver National Historic Site, NPS Doug Wilson, Ph.D. 612 E. Reserve Street Vancouver, WA 98661 360-816-6251 Email: doug_wilson@nps.gov	Ground-Penetrating Radar
Geophysical Archaeometry Laboratory Dean Goodman, PhD., Geophysicist 20014 Gypsy Lane Woodland Hills, CA 91364 818-716-6957 818-434-9932 Email: dean@gpr-survey.com Website: www.GPR-SURVEY.com	Ground-Penetrating Radar Magnetometry Resistivity
Geophysical Investigations, Inc. Larry Conyers, Ph.D. 2595 S. St. Paul Street Denver, CO 80210 303-871-2684 Fax: 541-276-1966 Email: lconyers@du.edu Website: http://mysite.du.edu/~lconyer/geoinvest/GeoInvest.html	Ground-Penetrating Radar

Consulting Agency	Technique(s) Offered
Heritage Research Associates Rick Minor, Ph.D. 1997 Garden Avenue Eugene, OR 97403 541-485-0454 X105 Email: rickminorhra@aol.com Website: www.heritage-hra.com	Ground-Penetrating Radar
Oregon Museum of Cultural and Natural History Thomas Connolly, Ph.D. Pat O'Grady, Ph.D. 1224 University of Oregon Eugene OR 97403-1224 541-346-3031 Fax: 541-346-5122 Email: connolly@darkwing.uoregon.edu Website: http://naturalhistory.uoregon.edu/pages/home.html	Ground-Penetrating Radar Metal detector
Z-Too Archaeogeophysical Prospection Kendal McDonald 7720 SW Forsythia Place Beaverton, OR 97008 (503) 641-1003 Email: *Kendal@z-too.com* Website: *www.z-too.com*	Magnetometry Metal Detector

REFERENCES

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