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Canadian Archaeological Association
Association canadienne d'archéologie

Conductivity Survey

Recommended Data Collection Procedures for Locating Unmarked Graves

Introduction

While Ground-Penetrating Radar (GPR) is one of the most common and reliable remote sensing techniques for locating unmarked graves, communities should be aware that other approaches are also available. This is important, as there are circumstances where GPR survey does not work, such as areas with unsuitable/ highly conductive soil types that prevent radar penetration (e.g. clay), or areas with heavy vegetation that prevents the radar antenna contacting the ground. In such cases, we need to look for alternative approaches.

Even where GPR does work, it is considered best practice to apply multiple techniques to remote sensing projects, as each provides a distinct data set that can offer different insights on features of interest and help confirm the presence of a grave, thereby improving confidence in the results. The following brief overview of conductivity survey is intended to provide communities with enough information to work with remote sensing specialists to achieve the results they want and need.

Conductivity survey, also known as electromagnetic induction (EMI) survey, measures the ability of the ground to conduct an electric current. Conductivity instruments induce a low frequency electromagnetic signal in the ground using a coil held near the ground surface. The transmitted signal causes the soil to generate its own faint signal, which will vary in strength depending on the composition and formation of the soil. The receiver coil in the instrument, in turn, detects the signal generated by the soil to measure the soil's conductivity. Like most geophysical techniques, conductivity survey does not disturb the ground and most conductivity meters are carried above the ground.

Figure 1. Conductivity survey with Geonics EM38Mk2, Grand-Pré, Nova Scotia

Identifying graves through conductivity survey is challenging and should be performed by experts. Like all geophysics techniques, the ability for a conductivity survey to identify buried features, such as graves, depends on how different the grave fill is from the surrounding soil. This will vary depending on a number of factors, such as type and depth of burial, but most importantly, the natural vertical variation in the composition of the soil column (e.g. topsoil versus subsoil) at the site. As a rule of thumb, the larger the variation in electrical properties between upper and lower layers of the soil, the more likely conductivity survey will identify areas of disturbance such as graves. When a grave is dug and refilled, the topsoil and subsoil are often mixed together. As a result, the grave shaft fill has different electrical properties than the surrounding soils. Additionally, differences in the compaction and distribution of the soil in the grave fill can lead to differences in its water saturation compared to the surrounding soil. For example, if a grave is found to hold moisture, this may increase its ability to conduct an electrical current and result in it being more 'visible' in conductivity survey data. However, if the differences between the grave and surrounding soils are small, then grave shafts may be "invisible" to the conductivity survey. Other factors can also negatively impact the ability to identify graves, including the presence of buried metal pipes or areas below power lines, which produce their own electromagnetic frequencies that interfere with the instrument. Conductivity survey will therefore, in most instances, be used as a supplemental survey technique to GPR to improve confidence in the results.

In the case of large areas, conductivity survey will also play an important role in narrowing down areas for GPR survey. This is because conductivity survey is relatively fast, which allows for large areas to be surveyed quickly. As the technique can locate buildings and other features that are remembered by survivors or identified in archival records but may no longer exist above ground, using this technique to avoid 'disturbed' areas will be invaluable in helping to guide GPR investigations to areas of greatest potential.

1) Planning

Not all soils or locations are suitable for conductivity surveys. As noted above, variation in the vertical soil column plays an important role in the potential success of a project. Regions with little or no difference in the soil column are less likely to provide successful results. Local soil maps and borehole logs should be consulted prior to the survey. Additionally, many conductivity meters have been configured so that they can estimate the vertical changes in the soil column, allowing sites to be evaluated directly. Areas of 19th or 20th century habitation, such as residential schools, are often strewn with ferrous waste (nails and other small pieces of iron from old buildings and refuse dumps) that can seriously impede conductivity survey. The area that you wish to survey should be investigated prior to doing a conductivity survey to assess the likelihood of success and to establish the best survey methodology. This can save both time and money and avoid disappointment. Additional time and expense can be saved if potential burial areas are identified through survivor testimony and archival research prior to the survey. While conductivity meters are carried above the ground surface even small obstacles, such as small bushes, can seriously impede the survey and add considerable time and expense. It may be necessary to prepare the survey area to remove low vegetation and long grass. Areas close to fence lines, parking lots, buildings and other sources of metal are not suitable for conductivity survey.

Mapping the survey area and the management of the resulting spatial data is a critical aspect of any remote sensing project. The survey area(s), areas of high potential, obstacles and other landscape features should all be identified on the ground, mapped and added to a data management system (e.g. GIS). There are many mapping tools available, depending on the location of the work. These include high-precision GNSS/GPS, total station theodolites, handheld low-precision GPS, or even chain and compass from known landmarks. Surveyors should use the greatest precision available. GNSS and total station theodolites are the most accurate and have the advantage that most are used with computer mapping software, allowing the automatic recording and description of survey points. Chain and compass and/or hand tapes are slower, require thorough note taking, and may have repeatability issues if completed by inexperienced personnel. They may, however, be the only option as tree canopy can block GPS signals and dense undergrowth can inhibit total station survey. Regardless of the approach, the survey should be accurate enough to allow communities to relocate the position of any identified graves or other features of interest after the survey is complete. You may wish to consider marking the corners of the survey grids with plastic (not metal) tent pegs to aid in relocating grids and features identified within them, in the future.

While conductivity survey is one of the faster ground-based remote sensing techniques, it is still time consuming. The number of individuals needed to complete a survey will depend on the instrumentation used and the site conditions, including ground cover and other obstacles. Generally speaking, conductivity surveys are most efficient when done by three people, with one person operating the instrument and two people moving ropes and tape measures that guide the instrument operator. We estimate that a crew of three technicians can conduct a mapping survey of about 3000 – 6000m^2 in one day, depending on conditions and instrument used. Such surveys require permissions, access, and the development of agreements on scheduling, deliverables, timelines, training and, if required, budgets. Communities often require specific protocols to be followed including necessary ceremonies, timeframes, and rules about comportment and behaviour when working with ancestors.

There are a variety of conductivity instruments on the market, most of which are aimed at the environmental or engineering sectors, rather than archaeology. It is important, therefore, to choose an instrument that is suitable for grave detection. The most important factors to consider are depth sensitivity and speed of the instrument. The depth at which conductivity instruments operate will depend on the intercoil spacing within the instrument. The wider the spacing, the deeper they will "see". However, deeper is not necessarily better. In most instances, graves are located in conductivity survey by identifying differences in the grave fill compared to the surrounding soil. These differences will be apparent from the ground surface. An instrument with a depth sensitivity of around 1.5m will therefore suffice. Conductivity instruments that can survey to greater depths are large and unwieldy making survey slow and difficult.

Graves are relatively small targets and require high-density data acquisition in order to be convincingly identified. Having an instrument that can record points rapidly is therefore important, as is an instrument that can be connected to a data logger to automatically record data digitally. Data loggers, in some cases, will also allow GPS points to be recorded simultaneously. Much will depend on what is locally available, but one instrument that is often favoured by archaeologists is Geonics' EM38. Geonics is a Canadian Company, so it will also likely be one of the easier instruments to access.

2) Data Collection Protocols

The recommended methodology for data acquisition will differ depending on the goals of the survey. However, one aspect where we recommend consistency is in the direction travelled along transect lines. Many near-surface geophysics instruments allow for data to be collected in either unidirectional (also known as parallel) traverses, where the operator returns to the same baseline at the start of each traverse, or bidirectional (also known as zig-zag) traverses, where the operator walks back and forth along the transects. Zig-zag traverses are often preferred as it halves the time to do a survey, thereby saving time and money. However, some conductivity instruments (e.g. Geonics EM38) have a significant lag (ca. 0.5m at walking speed of 1m/s) between the point measured by the instrument on the ground and the coordinates recorded by the data logger. This leads to an offset of approximately 0.5m between the locations of recorded values for features compared to their actual location on the ground. If a conductivity survey is conducted bidirectional, this offset happens again but this time in the opposite direction leading to a 1m offset between adjacent transects. This is known as "staggering" and makes small linear features, such as graves, extremely difficult to identify. While some geophysics processing software can remove staggering quite easily, we strongly recommend that all conductivity surveys, regardless of methodology, are conducted using parallel traverses to obtain the best quality data possible.

Many conductivity instruments log readings continuously, with the instrument turned on at the start of a transect and off at the end. The number of data points collected along a line will therefore depend on the speed that you walk the line. Care should be taken to walk slowly enough that the sample density is high enough to identify graves. Walking speed should also be consistent in order to obtain similar numbers of readings along each transect. This takes some practice. Walking along marked ropes while counting in your head can help standardize your walking pace as can inserting "digital" markers in the data as you collect it.

Other considerations for conductivity surveys are the presence of metal and temperature drift, both of which adversely affect the collected data. We have already noted that sites with abundant metal in the topsoil are not ideally suited to conductivity survey. It is also important that the individuals conducting the survey have no metal (e.g. zippers, small studs, buttons etc.) on their clothes from the waist downwards and that the data recorder and associated cables are kept as far from the instrument as possible. Temperature drift is where the recorded conductivity (mS/m) changes as the instrument warms up or cools down during the day. This results in drift in the data, which can obscure target features of interest in the data. Again, while geophysics software can remove this drift, you can alleviate these issues by frequently zeroing the instrument during the survey and turning the instrument on and leaving it to come to ambient temperature at the site before beginning data collection.

3) Reconnaissance survey and mapping survey

Archaeologists often differentiate between two types of survey methodology: reconnaissance survey and mapping survey. Reconnaissance survey is where a large area is surveyed at lower resolution to identify the general location of a large target of interest (e.g. a cemetery). Mapping surveys are used to cover smaller areas at higher resolution to map the distribution and number of individual features (e.g. graves) within them. The two types are often used together and can both incorporate conductivity survey. Reconnaissance surveys often precede a mapping survey and have the potential to save both time and money by helping to pinpoint areas of interest quickly and efficiently over a large area. Any area of interest identified in the reconnaissance survey can be further investigated through a higher resolution mapping survey to provide greater detail. However, reconnaissance surveys, due to their lower resolution, can miss small, ephemeral features such as graves, which are difficult to locate.
While some conductivity instruments allow data collection with an integrated GPS, the logged positions are not accurate enough to provide the resolution necessary to identify graves. It is also harder to keep track of where you have surveyed with a GPS system, leading to inconsistent data densities, and in some cases, for areas to be missed entirely. The CAA therefore recommends that all conductivity surveys are conducted within grids. Common grid sizes are 10 m, 20 m and 30 m squared. Some people find it helpful to conduct surveys within rectangular shaped grids to avoid inadvertently confusing the orientation during processing.

Unless the survey area is small, grids should be established using a total station or GNSS/GPS to an accuracy of 5 cm. For small areas (e.g. 20 m x 40 m) laying the grid out with tapes should suffice. The corners of the grids should be recorded with GNSS/GPS so that their location can be re-established, and any features of interest identified within them located. Conductivity survey is performed by carrying, pushing or pulling the instrument back and forth within grids that have been laid out over the ground. We recommend taking at least 8 readings/m along transects spaced 25 cm apart.

Once the survey is completed, the survey data needs processing in computer software to generate plots for interpretation and presentation. File outputs are often in ASCII format with associated x, y and z data representing the east and west coordinates and recorded values of each survey point. Processing conductivity data can be done in numerous gridding software options such as a GIS package or Surfer (the latter offering excellent visualisation options). However, data often requires numerous processing steps to remove data collection errors. Iron spikes in the data may need removing and periodic, slope, edge match, traverse stripe and staggering resulting from temperature drift and operator errors all need to be addressed. This can be achieved in specialist geophysics software, though organising the data to enable data transfer can be complicated. The offset between recorded values and the location of features in the ground also needs to be accounted for.

Conductivity survey data can be difficult to interpret and should be done by trained individuals. Even then, results may not be certain. It is not uncommon for geophysics results to include different levels of confidence. For example, an archaeologist might assign a 70% confidence level that graves exist in a location, depending on how clear the results are. This is where having other sources of evidence, such as other remote sensing techniques (e.g. GPR) or survivor testimony is beneficial, as multiple lines of evidence that all point in the same direction will provide more certainty. The survey report should make a clear distinction between different levels of confidence, including inferences based on scientifically demonstrable criteria and those arising from informed speculation based on prior experience.

4) Presentation

The final report should include:

• Copies of unprocessed raw data should be included with the report for archiving.

• A brief site description indicating underlying soil types and geology, ground conditions and vegetation, description of built architecture, previous disturbance including previous archaeological investigations and known underground services that might impact the results.

• Photographs, if appropriate, of each survey area showing the ground conditions.

• The survey methodology should provide a description of the instrumentation used and indicate the traverse line separation/direction, inline sampling interval and the resulting effective spatial resolution achieved.

• A map showing the location of survey grids in relation to other features at the site.

• All location maps must be geo-referenced and annotated with the geographic coordinate system and projection used in order that the location of the grids can be re-established by a third party.

• Plots of minimally processed or raw data should be included prior to or in comparison with the presentation of final processed plots.

• All data processing steps should be described in full and their effects on the data highlighted.

• Anomalies resulting from data collection errors that cannot be removed through data processing should be described and distinguished from other responses.

• The interpretation should distinguish anthropogenic from natural features identified in the data.

• Grayscale plots are generally recommended over false colour maps, due to the eye's ability to better differentiate subtle detail in black and white than colour. False color can, however, be useful in instances where delineation of features of interest might benefit from highlighting through colour. All plots should include a north arrow, range bar including appropriate values and units, and be presented in and include an appropriate scale for interpretation.

• Interpreted plans indicating all features of interest should be included alongside the data plots.

• Anomalies of interest should be identified with a unique identifier on the plots, and described in full to indicate shape and signal amplitude. This might best be achieved in a table rather than a long descriptive narrative.

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