Searching For Missing Children:
A Guide to Ground Search Techniques

CAA Working Group on Unmarked Graves

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Canadian Archaeological Association
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CAA Working Group on Unmarked Graves on behalf of
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Cover Image

Using ground penetrating radar to search for Métis cabins in southwestern Saskatchewan.
Photo Credit: W. Wadsworth

The CAA Searching for Missing Children Series consists of:

1. **A Guide to Unmarked Grave Investigations**

2. **A Guide to Ground Search Techniques**

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Trigger warning

This document may retraumatize or trigger readers because of the highly sensitive content related to the search for unmarked graves of children who attended Indian Residential Schools. Please consider identifying where you will turn for help if needed.

⚠ If you are experiencing trauma or feeling triggered, help is available 24/7 for survivors and their families through the **Indian Residential Schools Crisis Line** at **1-866-925-4419**. Mental health support for Indigenous Peoples across the land known as Canada is available through the **Hope for Wellness chatline** at **1-800-721-0066** or using the chat box at https://hopeforwellness.ca/. The **Indian Residential Schools Survivors Society** provides information about these and other supports that are available: https://www.irsss.ca

The CAA Working Group on Unmarked Graves

In response to the identification of approximately 200 potential burial sites reported by Tk'emlúps te Secwépemc in May 2021, the Canadian Archaeological Association (CAA) established a Working Group on Unmarked Graves (WGUG). Its members have a range of expertise and experience relevant to potential ground searches for unmarked graves and are collaborating to develop best practices in this very specialized application of remote sensing techniques. They are also working to advance technical knowledge and create information and training resources for Indigenous communities thinking of pursuing or pursuing unmarked graves investigations. These resources are posted on the CAA website (Resources for Indigenous Communities Considering Investigating Unmarked Graves | Canadian Archaeological Association / Association canadienne d'archéologie (canadianarchaeology.com)).

1. Introduction

Ground searches involve a broad range of expertise, and no single resource could cover the entire subject matter. This guide is intended as a brief introduction, written in an accessible format, to the various techniques that communities might consider in their ground searches for missing children at Indian Residential Schools (IRS) and associated sites. It briefly outlines the most commonly used techniques that archaeologists use to identify buried features (including graves), while outlining some of the associated considerations and challenges. Many of these techniques apply geophysical instruments. Geophysics is a natural science discipline that studies the physical properties and processes of the earth and the surrounding spaces. In archaeology, when we talk about geophysics, we are referring to techniques used to image the subsurface without the need for excavation. The guide covers steps 5-8 of the CAA's recommended pathway for locating unmarked graves around residential schools (Figure 1): database development, area mapping and preparation, ground searching, and the communication of results. These are the four areas where archaeological expertise is most relevant to IRS missing children investigations.

Figure 1. The Canadian Archaeological Association's recommended pathway for locating unmarked graves around residential schools. Topics highlighted in orange are covered in this document.

2. Frequently Asked Questions

2.1 Do you need to conduct a ground search?

Ground searches are not necessary to know the devastating truth of the existence of unmarked graves of missing Indigenous children at former Indian Residential Schools and associated sites. Ground searches can sometimes be used to show specific locations of potential unmarked graves. However, ground searches cannot locate all children who died at or went missing from residential schools. Current methods focus on terrestrial landscapes; we have fewer tools for underwater searches. Ground searches are only necessary should Indigenous communities wish to better identify the locations and distribution of potential unmarked graves to either protect and memorialize these areas or to conduct further investigations. All decisions about whether to conduct ground searches and how to proceed following them are up to the Indigenous communities involved and should be free from external pressure or interference.

2.2 When should you conduct a ground search?

Ground searches are a potential approach for finding missing children but should not be considered the first stage of any investigation. Several phases should be considered first, including but not limited to health and spiritual supports, ceremony, community meetings and investigation planning, archival research, and survivor interviews. These steps will provide direction and potentially reveal important information about the locations of unmarked graves. Every investigation will be different because of many variables including the number of communities involved, the unique histories of every school, environmental factors, and financial support. Include the stages or steps that make the most sense for your situation.

2.3 What are the chances of success?

While the utility of geophysics and other ground search techniques in locating unmarked graves in cemeteries is well-established, techniques for identifying unmarked burials outside of formal cemeteries are less well-known and the chances of success will be different depending on the nature of the burials, local geological conditions, land use, and vegetation. Communities should be aware that it is not possible to identify grave locations or the absence of graves with 100% certainty through a ground search, though in some cases identifications can be made with great confidence. More likely, an archaeologist will assign different levels of confidence to their results in much the same way as a weather forecaster predicts the likelihood of rain. One way to increase confidence is to use different geophysical techniques at the same location, as complementary results from different approaches can improve confidence in grave identification. The greatest degree of certainty is achieved when a survey is followed up by excavation. However, full excavation of a potential grave location is not necessary. Excavation of the uppermost ground surface to expose the top of the grave shaft can confirm the presence of a burial without disturbing the contents beneath. Because this type of “ground truthing” disturbs the upper grave shaft, some communities may prefer not to pursue this method. The precise contents of the grave can only be confirmed through full excavation, again something some communities may wish to avoid. It is important to remember that failure to identify graves through a ground search does not mean that graves are not present. It can equally mean that the conditions were not suitable for grave detection with ground search techniques.

2.4 How do you know what ground search techniques should be used?

This will depend on the conditions at the site. Ground-penetrating radar (GPR), the technique used at the Kamloops Indian Residential School, is the most widely used and has the most successful track record for identifying unmarked graves in cemeteries. It has decades of use by archaeologists across the globe. However, there are some conditions where this approach does not work well. Fortunately, there are many other techniques that have also had success in identifying unmarked graves in and outside of cemeteries (Table 1). While one approach may be enough, the best results are often achieved when multiple techniques are used together, 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. Establishing which approach is best should be done by a trained professional with knowledge of the specific site being surveyed, in partnership with the local community.

2.5 What are the risks?

There are no physical risks to the graves or the individuals conducting geophysical survey. In much the same way that navigational radar locates objects at a distance for boats or planes, archaeologists use geophysical survey techniques to see what is below the ground without needing to excavate, so there is no disturbance to the grave or surrounding area. Some methods (such as GPR) benefit from a clear surface, which could require impacts to vegetation. The main risk is the potential for triggering and re-traumatizing community members, so it is extremely important that appropriate mental health supports are in place prior to work commencing. There is also the potential for disappointment and confusion should the results be inconclusive.

2.6 Who should do the survey?

There are many options available for communities looking to have geophysical survey work done, particularly with GPR. The CAA supports Indigenous communities to conduct the surveys and interpretation themselves wherever possible. It is relatively straight forward to learn how to collect the data using a GPR unit. However, the **interpretation and analysis** of GPR data is extremely time consuming and **requires specific training** because the application of GPR to cemeteries is uncommon. For instance, most geophysics is conducted by companies working in industry, identifying utilities or surveying buildings and highways. Importantly, the identification of graves (marked and unmarked) is usually conducted by archaeologists or forensic scientists.

Unfortunately, some companies and individuals without the appropriate training are seeking to benefit from the growing interest in conducting ground searches for graves associated with IRS landscapes. **Therefore, extreme caution is needed**. Communities who already have established and trusted relationships with archaeologists and/or forensic scientists should seek their advice before proceeding if contacted by companies proposing to undertake such work. If you require assistance determining the best course of action for your community(ies), feel free to e-mail the CAA at unmarkedgraves@canadianarchaeology.com. You can also reach out to the National Advisory Committee on Missing Children and Unmarked Graves (https://nac-cnn.ca/contact-us/).

2.7 How long will it take and cost?

Cost is difficult to estimate, as much will depend on who does the work, the conditions at each site, the equipment used, and the intent of the survey, and other project-specific constraints. Communities may only wish to establish a cemetery's general location (known as reconnaissance survey) rather than determining the number and distribution of graves in it (known as formal survey). The benefit of reconnaissance is that it takes less time, but it also results in less detail. Oftentimes, it is most efficient to start with broad reconnaissance, followed by intensive formal survey. Other considerations, such as clearing vegetation to enable access for survey, need to be considered. Data collection with a GPR unit is much easier than processing, analyzing, and interpreting the information that is gathered through survey. Identifying unmarked graves in GPR data is particularly challenging because they produce a wide range of responses, some of which are difficult to distinguish from responses produced by other types of buried objects. Therefore, the most time consuming and expensive part of a survey of unmarked burials is analyzing the data and preparing the report.

2.8 Do I need a permit or permission to conduct geophysical work?

Ultimately, this question depends on where the survey site is located. Permit requirements for archaeological/geophysical surveys vary greatly between provinces/territories and are different for federal land, First Nations Reserves, and Inuit Owned Land. It is essential to check with your provincial or territorial archaeology body and the relevant Indigenous government(s) to see if you will require a permit for the work. Often, there will be similar reporting requirements to a provincial or territorial archaeological body. Work on privately owned lands will also need the permission of the landowner.

Table 1. Some of the more commonly applied technologies available for investigating the location of unmarked graves (from Institute for Prairie and Indigenous Archaeology https://www.ualberta.ca/prairie-indigenous-archaeology/media-library/resources/remote-sensing-technologies-matrix-2.pdf)

Technology	Used For	Cons	Works Well For	Has Issues With	Potential Alternatives
Ground-based GPR	Identifying objects and changes in the subsurface that differ from normal 'ground' based on soil characteristics and other factors Can be used to find grave shafts/pits	Generally difficult to cover large areas quickly. (Cover approx. 1,000 sq. metres per day) Difficult to maneuver in rough or treed terrain	Formal cemeteries or burials Areas cleared of brush Small areas Locating individual burials	Informal or clandestine burials (requires additional information) Clay-rich soils, or areas with a high water table Densely treed areas	Magnetometry Electrical Resistivity Conductivity
UAV/Drone GPR	The basic same technique as ground-based GPR, but mounted on a drone Can be used to locate areas of interest that may contain unmarked graves	Less accurate than ground-based methods, but can cover larger areas much more quickly Weather-dependent	Initial surveying to identify areas of interest Large or densely treed areas May be able to identify some burials	Locating individual grave shafts Soils with a lot of clay Areas with a high water table	UAV/Drone LiDAR UAV/Drone Photogrammetry or Multi-spectral Imagery
UAV/Drone LiDAR	Used to quickly record surface variation and topographic relief of areas Can be used to locate surface expressions of unmarked graves (mounds/depressions) May be used to reconstruct the ground's surface in heavily treed areas	Weather-dependent Only shows ground surface, and graves may not be visible from the surface	Open Areas Can sometimes penetrate heavily treed areas (Boreal Forest) Initial survey to identify areas of interest	Seeing below the surface of the ground Areas with high levels of ground disturbance	Drone GPR
UAV/Drone Photogrammetry or Multi-spectral Imagery	Draws upon visible light, as well as other energy in the electromagnetic spectrum to record aerial images of the ground surface Can be used to locate any areas of interest for unmarked graves based on vegetation cover	Weather-dependent Only shows ground surface, and graves may not be visible from the surface	Clear areas or with low-lying brush (Prairies) Initial survey to identify areas of interest	Heavily treed areas (Boreal Forest) Surveys in Autumn (as plants are at the end of their growth cycle and the ground can be obscured)	Drone GPR

	and ground surface. Also used to map control points for other techniques				
Electric Resistivity	Identifies changes in subsurface deposits based on how they respond to electrical currents Can identify voids (air pockets) and changes in soil compaction and moisture retention	Invasive - you must stick metal electrodes in the ground Very slow (compared to other techniques)	Soils with high clay or moisture content (where GPR is challenging)	Dry environments Large areas	Ground-based GPR Magnetometry Conductivity
Conductivity / Electromagnetic Induction	Can locate subsurface buildings and identify disturbed soils Identifying areas of interest in a large landscape	Regions with little or no difference in the soil column are less likely to provide successful results Negatively impacted by the presence of metal waste materials	Faster than Ground-based GPR (3-6,000 sq. metres per day) Can work in waterlogged soils Supplementing other geophysical work	Identifying specific graves or other small features Urban environments, or soils with lots of metal inclusions	Ground-based GPR Magnetometry Electric Resistivity
Magnetometry	Locating objects and/or changes in the subsurface that have different magnetic properties than the surrounding soil Can be used to find graves (perhaps the disturbed soil fill) and grave features (metal hardware from coffins, nails)	Does not record the shape/depth of the feature, which must be estimated using mathematical equations	Relocating destroyed buildings Identifying graves that have coffins or pieces of iron in them Can be used in areas where GPR cannot Can cover large areas quickly	Soils with a high iron content (igneous geologies) Highly disturbed areas, especially containing lots of surface metal (e.g., dumps) Urban environments	Ground-based GPR Electric Resistivity Conductivity

3. Area Mapping and Spatial Data Management

Kisha Supernant and Edward Eastaugh

3.1 Introduction

Gathering, storing, processing, modeling, analyzing, and delivering spatial data is known as Geomatics and it is essential for unmarked graves investigations. Spatial Data is information that is collected during investigations and associated with a specific location. For example, survivors might remember seeing graves at a specific location or archival documents might indicate areas on IRS grounds that were used for burials.

The spatial data you are likely to collect during your investigations include historic maps, air and satellite photos, building plans, as well as the results and control points (reference markers) of the different remote sensing methods you employ (e.g., Ground-Penetrating Radar) to search for graves. All these need to be gathered and organised in an appropriate spatial data management system. The ideal platform for this is Geographic Information System (GIS) Software.

3.2 Geographic Information System (GIS)

There are a wide variety of GIS software packages to choose from. Two of the most common are ArcGIS by ESRI (https://www.esri.com/en-us/home), which has become the standard software in many industries and municipalities but comes at a high annual subscription and QGIS (https://www.qgis.org/en/site/), a free open source alternative, which has become popular in the archaeological community and other organisations with limited budgets.

Regardless of the platform you choose, GIS are often large and complex pieces of software and inexperienced users may become quickly overwhelmed. Industry specialists often spend many years in college or university learning the full capabilities of GIS software. While some larger communities may already have individuals experienced in GIS in their governments who can assist, given the central role that a GIS platform will have in your investigations, communities may wish to obtain funding to hire a professional GIS technician to manage the spatial data.

One extremely important consideration when choosing your GIS platform is data security and its capacity for sharing. Much will depend on the product you choose and whether you opt for a cloud-based server and data storage or house the data on your own system. It will be important to use a system or platform that will also facilitate and support your long-term needs for the data. Thinking ahead to your long-term plans for researching, manipulating, archiving, and potentially sharing your data with certain users will help to inform your selection.

3.3 Area Mapping

Once you have identified the areas you wish to search, one of your first tasks will be to create maps of those areas to help plan and organise your investigation. This will include identifying and mapping areas of high potential, mapping obstacles and other landscape features within and around the survey area and laying out the grids required for geophysical survey.

Figure 2. Some of the tools archaeologists use to map sites. A: Total Station; B: RTK-GNSS receiver; C: Handheld GPS; D: Hand tapes and E: Drones. Photo credits: A-Neal Ferris; B-Edward Eastaugh; C-https://www.thecoolist.com/best-handheld-gps/; D-Lisa Hodgetts; E-Jean-Francois Millaire.

There are many mapping tools available, depending on the location of the work. These include high-precision Global Navigation Satellite Systems (GNSS) more commonly known as Global Positioning Systems or GPS, unmanned aerial vehicles or drones, total station theodolites, handheld low-precision GPS, or even tape measures (Figure 2). Each of these techniques have different levels of accuracy and precision and cost tends to increase with both. Accuracy is the proximity between the map database and reality; precision is the resolution of the mapping tools. Ideally, we produce results that are both accurate and precise, but some methods can be usefully accurate and imprecise (i.e. when results are needed quickly). Precise and inaccurate work should be avoided. If the goal of ground searches is to locate missing children, then mapping work needs to be able to identify locations to within at least +/- 25c m. Regardless of which technique you use, the most important thing to remember in any mapping project is that it is accurate enough that someone else can relocate features and locations that you map on a future occasion.

Wherever possible, the most precise and accurate tools should be used to ease later analysis. You may find it cheaper, if you wish for a very accurate map of your area, to hire a surveying firm to come and do the work, rather than buy your own equipment. Listed below are some of the more common methods available to you with some information on the relative accuracy and expense of each.

3.3.1 GNSS/GPS

GNSS stands for Global Navigation Satellite System. It is the generic term for groups or "constellations" of satellites that send position data to receivers on earth. The Global Positioning System (GPS) is just one of many constellations that is commonly used in North America. Most high precision surveying systems on the market today take advantage of accessing multiple constellations, including GPS, and are thus known as GNSS systems.

GNSS is often considered the "gold standard" for surveying and provides an ideal solution for accurate and precise global positioning, wherever conditions allow. These units consist of at least one and sometimes two antennas that receive information from satellite networks and generate coordinate information that is globally accurate to <2cm. This means the error between the collected point and its actual global position is less than 2 cm. GNSS systems are used with data collectors (small handheld computers) allowing the automatic recording and description of survey points. This saves considerable time during a survey.

Many models come with a base and a rover. The base is placed in a single known location and the rover collect points over the survey area. These are known as RTK (real-time kinematic) systems. The stationary base station transmits information to the rover by radio signal to help refine the precision and accuracy of the coordinates determined by the rover unit (Figure 3).

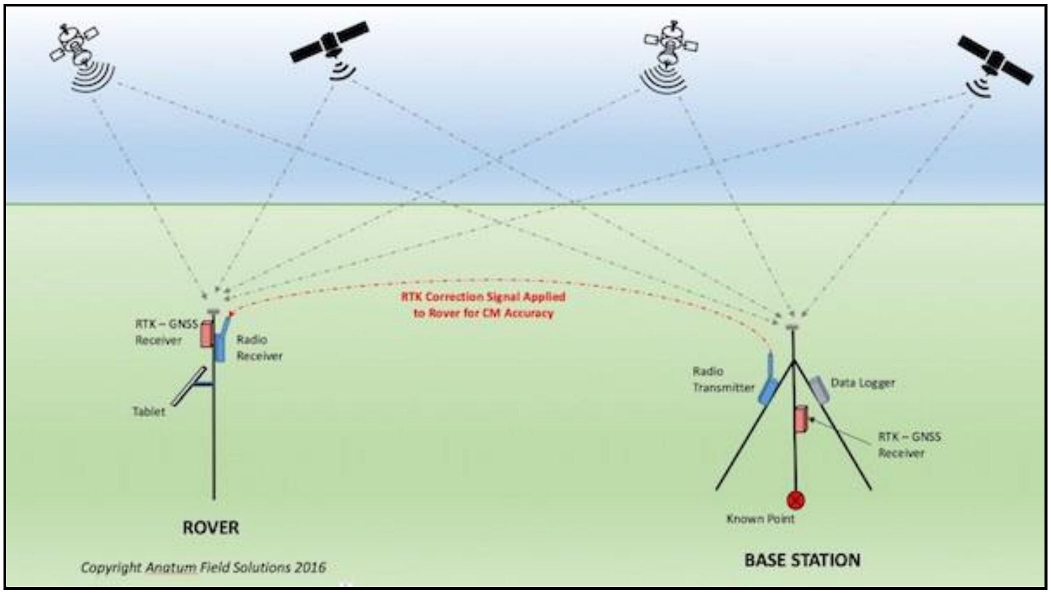


Figure 3: Typical base/rover setup. Image retrieved from https://www.agsgis.com/RTK-GPS-Explained_b_6.html

Specific setups vary depending on the manufacturer, but the basic process is generally the same. The base station is placed in an area with minimal obstructions (away from buildings, trees, and other objects that might interfere with satellite signals) and left to collect data for a set amount of time (typically a minimum of one hour). Leaving the base station to collect multiple points over an hour allows it to obtain a far more accurate position. A radio transmitter (either built in or separately attached) is set to a frequency to broadcast corrections. A rover unit is then set to the same frequency and attached to a pole or placed in a backpack. Locations requiring precise and accurate spatial data are mapped using the rover. In surveys for unmarked graves, mapped locations may include the corners of grids established to collect information using various geophysics instruments, such as ground-penetrating radar, or may include control points to correct the georeferencing of drone imagery. Additional points may be mapped as needed. Once mapping is complete, the information from the base station can be sent for post-processing. In Canada, this typically involves sending the files from the base station to Natural Resources Canada (NRCan), which then returns the corrected coordinate for the base station. Data from the rover can then be further refined using the new coordinate(s) within mapping software programs to maximize the accuracy of the survey results.

Alternatively, rather than using a base station, some GNSS systems use a single antenna (Rover) and a cellular network to obtain corrections. These are often more convenient, but access to the cellular network requires a subscription, for which costs can add up quickly.

The major limitation to GNSS units is that they only work where there is adequate satellite signal. Areas near buildings or with many trees or other dense vegetation can be troublesome. Any obstructions blocking the satellite signal can mean a significant loss of precision and in some instances GNSS will not work at all. Cost is also a major factor. High precision RTK base and Rover systems cost in the tens of thousands of dollars. The proprietary software they operate on also needs to be purchased and renewed annually, increasing the overall costs.

Note that the radio signals used in RTK GNSS systems are within the same frequency range as many ground-penetrating radar (GPR) systems and can cause interference. Therefore, RTK transmissions must be turned off during GPR data collection.

Recently, a new class of RTK has become available via a single GPR receiver and a cell phone app. These tools provide a similar precision to base station/rover systems by relying on the cell phone network of towers. Such units are less expensive and require only one person to operate, but they need a clear cell service signal and a subscription service for high precision results.

3.3.2 Unmanned Aerial Vehicle (UAV) / Drone

Drones, like many surveying instruments, have different levels of accuracy depending on what system you use. Most enable the mapping of features to within +/-1 m of their global position and can be purchased for under $1000. Their main advantage is that large areas can be surveyed very quickly and relatively easily. However, the level of accuracy offered by many drones might make it difficult to relocate features of interest precisely in further investigations. Using ground control points can be improve accuracy of drone surveys, though these require an additional survey instrument, such as a theodolite or GNSS system (see below), to locate their positions. More detail on UAVs is provided in Chapter 5.

3.3.3 Total Station

A total station is a digital survey tool where the distance, angle, and height of a target are measured from a point on the ground where the geographic coordinates are already precisely known. Some communities may already own these instruments and have expertise in their use. Used correctly, a total station can have precision of less than 1 cm over a range as large as several kms. However, a total station cannot detect where it is on the earth’s surface, unless the total station unit also has an integrated GNSS antenna.

The basic components of a total station include a theodolite (with integrated distance measurer) and usually a stadia rod with reflector or prism (some more expensive total stations are reflectorless). The total station is set up over a known point on the Earth called a datum. This is ideally located near the area to be mapped. If a known datum is not available, a GNSS system can be used to create one. The total station is leveled and the geographic location, height of the instrument above the datum, and the bearing (measured in degrees, minutes and seconds) to a second known point, called a back sight, is entered into the total station's computer. During a survey, one surveyor holds a reflector directly over the points of interest while a second surveyor points the total station directly at the reflector using the telescope on the theodolite. Newer robotic units allow a single person to survey using the reflector. The horizontal and vertical angles, and the distance between the reflector and the theodolite are recorded, allowing the total station to calculate the location of the roving stadia rod relative to the known position of the total station (Figure 4).

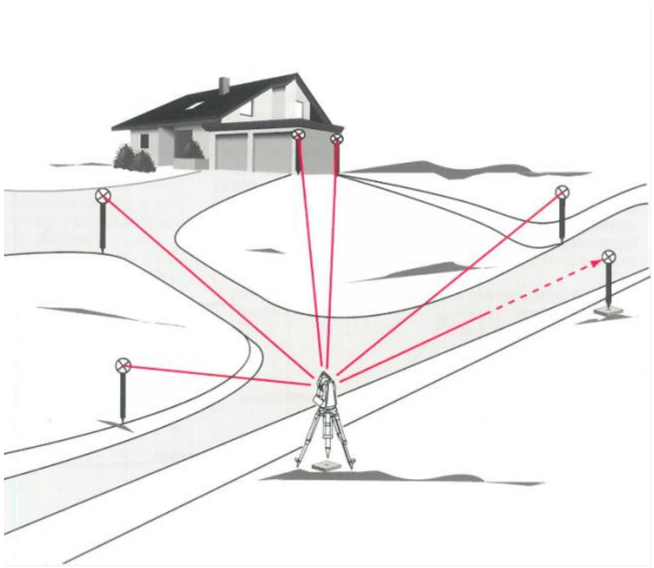


Figure 4. Image of Total Station setup with different stadia rod reflector positions. Image retrieved from https://cpe.leica-geosystems.com/ca/blog/post/what-is-a-total-station-how-it-works.html

The main advantage of a total station is its excellent accuracy, which is usually less than 1 cm. They also work well in and around buildings and trees, though areas with many obstacles that obscure the line of sight can be tricky to survey. They are also considerably less expensive than a GNSS system. There is also a healthy second-hand market for total stations as engineering companies look to upgrade their systems to GNSS.

3.3.4 Hand tapes and triangulation

If a GNSS unit or total station is not available, more basic methods can be used. Tape measures, magnetic compasses, and simple theodolites (an instrument that measures angles) have been used for centuries for surveying. While they are slower and require some math, if used correctly they are extremely accurate and come at a fraction of the cost.

Using tapes and other non-digital devices requires the use of triangulation to determine the location of features. In triangulation, the location of a point is determined by measuring the distance (and sometimes angles) between the unknown point and several permanent landmarks in the survey area, such as the corner of a building or utility pole, that are also visible on satellite imagery. These measurements are then replicated on the satellite image within the GIS software to calculate the true geographic position of the point. If using this system, it is important to measure to enduring landmarks in order that the survey points can be relocated again in the future.

Using hand tapes is slower and requires thorough note taking to avoid replicability issues. They may, however, be the only option in some areas such as wood lots, as tree canopy can block GPS signals and dense undergrowth can inhibit total station survey.

3.4 What should be mapped?

When searching for unmarked graves around residential schools, a few different things should be mapped. These include (but are not limited to):

- Survey grids set up for the purposes of near-surface geophysics, such as GPR. Corners of the grids should be mapped, and where grids occur on a significant slope, points within the grids should also be collected to correct the elevation of the collected geophysical data.
- If geophysical survey areas cover places with slopes or complex topography, it can be helpful for interpretation to create a surface contour model. While these can be done from points collected with GPS or total stations, drone-flown LiDAR is generally the most accurate, fastest, and often least expensive option. Drone LiDAR systems also generate a photomap of the ground as well as a LiDAR model.
- Control points for UAV imagery collected from drones. Drone imagery is more precise when control points are mapped. Typically, highly visible targets are placed on the ground and mapped using a GNSS system. These targets are then used to correctly place the imagery on the earth's surface in a GIS system.
- Other landscape features of interest. The most common would be the positions of grave markers, building foundations, fences, or the location of graves visible on the surface through depressions or mounds.
- All landmark features used as reference points during a triangulation survey.

3.5 Survey grids

If you end up conducting any ground-based geophysics investigations (e.g., ground-penetrating radar) you will almost certainly need to establish survey grids over your area of interest. Unless the survey area is small (less than 40m x 40m), these grids should ideally be established using a total station or GNSS/GPS to an accuracy of 5 cm. Using triangulation for large areas can lead to large errors that compound over distance.

However, for small areas, laying the grid out with tapes should suffice. If you are laying out a grid with tapes, remember that you need to locate the corners using one of the survey methods outlined above.

3.6 Summary

Mapping is a specialized task within ground searches, but one that has several key roles. As a field effort, it collects both information on the land and places the position of search technologies. Doing this accurately and precisely is essential - if a search technology identifies a potential burial within its results, we need to be able to return to the land and point to this place correctly. If our work has an error of more than +/- 25 cm in total, then the place we point to might not be the location of the grave. Managing map information with GIS systems brings together different kinds of information: from ground searches, from survivor knowledge, from archival information, etc. Again, precision and accuracy here allows us to combine different kinds of knowledge correctly and translate that work to places on the land that might have important information, such as the potential resting places of missing children.

4. Ground Search

Edward Eastaugh

4.1 Introduction

Ground search involves obtaining information about objects or areas from a distance, including airborne (e.g., drone or satellite) and ground-based (e.g., ground-penetrating radar) approaches. The most common techniques used in grave detection are ground-based, in a discipline known as geophysics.

Geophysical survey techniques provide a way to locate underground features, like unmarked graves or building foundations, without the need to disturb the ground. They detect the distribution and strength of various physical properties of the Earth including magnetic, electrical, and electromagnetic fields (Figure 5. Buried objects and features will have different physical properties from the surrounding soil and it is these differences that are detected and mapped.

The following sections elaborate on the ground search techniques that will likely be of most value to you in your investigations at Indian Residential Schools, including unmanned aerial vehicles, ground-penetrating radar, magnetometer, conductivity, and resistivity. More attention is given to GPR in this document as it will likely be the primary technique used for investigations. It includes more detail on data processing and interpretation for GPR than other techniques.

4.2 Planning

The success of different ground search techniques will depend on many factors. Of particular importance will be the geology and soil type in the area you wish to survey. This is because near surface geophysical techniques measure differences in the physical properties of (or resulting from) the soil and some approaches are better suited to certain soil types than others. For example, some clay soils are highly conductive when wet, which can significantly reduce the degree of radar penetration. In areas such as these, a GPR survey will not work well, and an alternative method will need to be used. Conversely, magnetometer survey (another common geophysical survey method used in archaeology) might not work in some areas of limestone or igneous bedrock (particularly if close to the surface), whereas resistivity survey does not work well in very dry conditions. It is important, therefore, to understand the local conditions and the most appropriate geophysical approach to use to avoid wasting time and money.

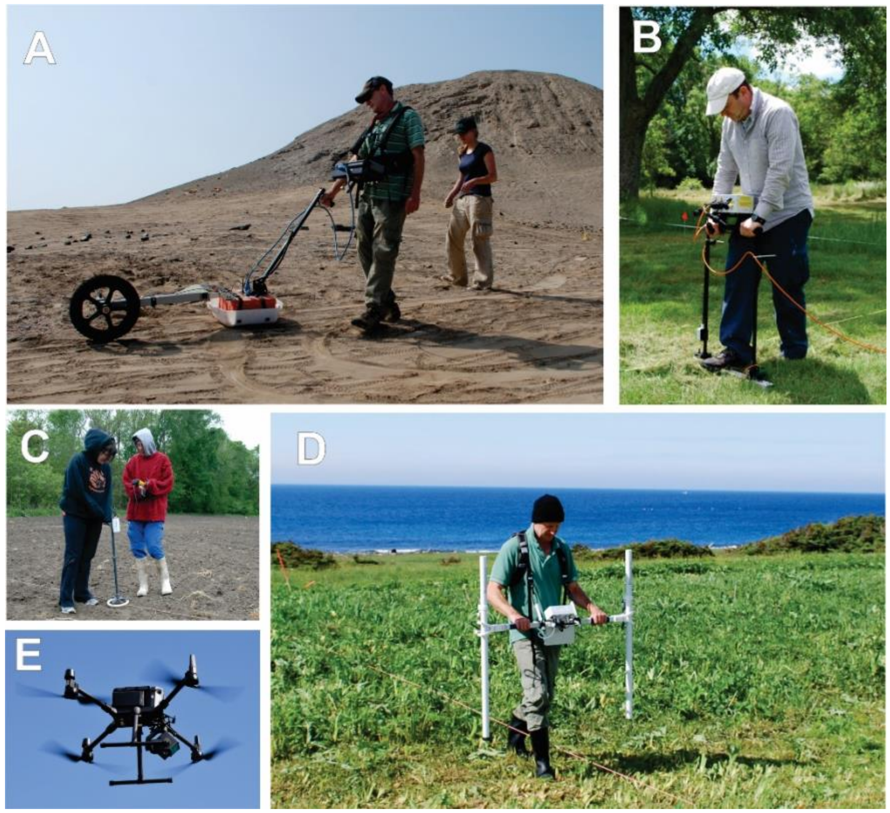


Figure 5. Some of the more common instruments used by archaeologists to locate and map buried features. A: ground-penetrating radar; B: resistivity meter; C Magnetic Susceptibility meter; D: Magnetometer; E: various sensors mounted on drones (UAVs). *Photo credits:* A-Jean Francois Millaire; B, C and E-Edward Eastaugh, D-Priscilla Renouf.

The soils map of Canada is a useful place to start when planning projects: https://agriculture.canada.ca/atlas/apps/aef/main/index_en.html?AGRIAPP=3&APPID=e87af05bd35848598994b13f45a24a25&WEBMAP-EN=c225cc78d5b142d58eacefae91cc535b&WEBMAP-FR=ad0b6822a33e411683f99979a1167efa&mapdescription=true&print=true&breadcrumb=can,agr,b10,b3&adjust_to_viewport=true
You can establish the local geology by examining historical borehole logs (https://open.canada.ca/data/en/dataset/15f4d926-0606-5d3f-9726-763ffa6b8c5f) and water well records (https://open.canada.ca/data/en/dataset/c1a624a7-fbd4-4bc8-8e65-41b294443123), but you will likely want to speak to an archaeologist with the appropriate level of expertise to fully evaluate where you choose to investigate. You can also evaluate the appropriateness of an approach by conducting a small pilot project that surveys a small area of the site to determine if the local conditions are likely to yield positive results. We recommend that search projects start in known cemeteries, when present, as these are places where interpretation of results is simplest.

Other factors such as the amount of vegetation cover, nearby roads, fences and buildings (including building foundations from previous structures), metallic debris and overhead power lines can all negatively impact geophysical survey, depending on the method used. Time and resources may be needed to prepare the area prior to survey (Figure 6). All these factors need to be taken into consideration when choosing the most suitable approach.

4.3 Reconnaissance vs. Formal Survey

Throughout this document you will see references to two types of survey methodology: *reconnaissance* and *formal*. While related, the two different approaches have significantly different data acquisition criteria, which differ depending on the goals of the survey, and it is very important to know the difference.

Reconnaissance survey, also called *prospection* or *roaming*, is where a large area is surveyed at a relatively low resolution to identify the general location of a large target of interest (e.g., a cemetery) or to evaluate the potential of an area to contain graves.

Formal survey is where a smaller area is surveyed at higher resolution to map the distribution and number of individual features (e.g., graves) within them.

Figure 6. Preparing the survey area prior to GPR survey. *Photo credit:* Edward Eastaugh

Reconnaissance surveys often precede a formal survey in order to save time and money by helping to pinpoint areas of interest quickly and efficiently over a large area. These areas of interest are then further investigated through a higher resolution formal survey to provide greater detail. This is relevant to the search for missing children as many of the school grounds cover very large areas, which may be prohibitively expensive or time consuming to survey in their entirety. A reconnaissance survey helps to narrow down investigations to areas with the greatest chance of identifying graves, thus saving time and money.

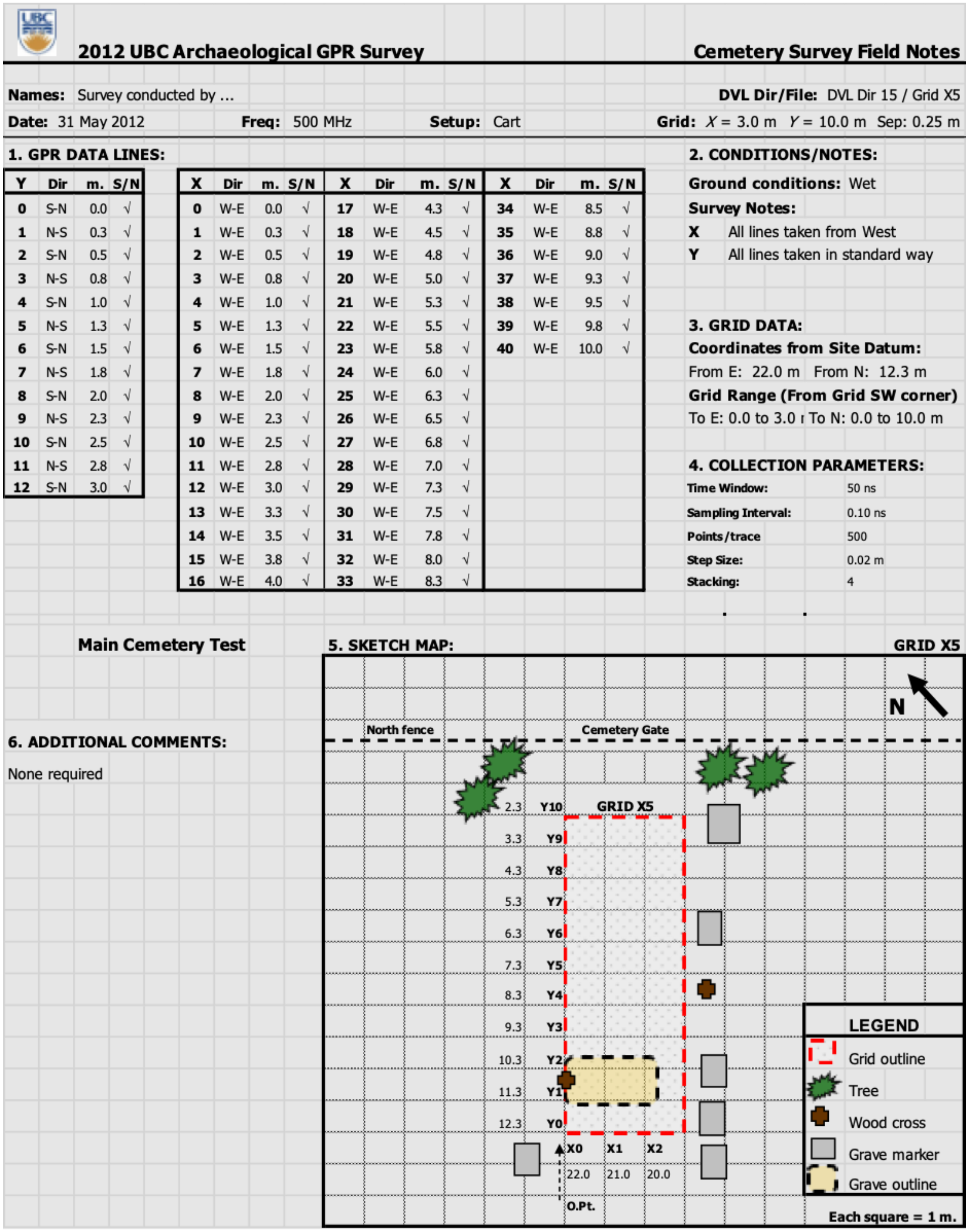
It is important to remember reconnaissance surveys, due to their lower resolution, can miss small, ephemeral features such as graves and should only be used for narrowing down search areas. Investigations that wish to identify the locations of graves should always use the formal survey parameters recommended in this document.

4.4 Field notes

Field notes form an important part of an investigation's archival files and represent the primary field record of any survey. Accurate field notes are essential during fieldwork. While some instruments will automatically log survey parameters (e.g., grid size, data sampling densities etc.), we recommend compiling an additional physical or digital log that stores this information as a backup and also records other pertinent information (such as, weather changes, breaks in survey, and battery changes). Precise and accurate data for the spatial locations of survey grids, and their relationship to one another, is essential to interpretation. Obstacles within grids should be noted, as should the methodology and procedures used to navigate them. Some technologies allow you to generate maps as you work, but it is often helpful to draw a sketch map of the survey area, showing the main topographic features, the relationships between grids (including grid IDs and file numbers), the direction of survey within each grid and obstacles within grids and coordinate these with the date from instruments using numbers and names (what surveyors call code lists). Figure 7 provides an example of the types of information that should be recorded. Field notes might also include photographs (if appropriate), names of field crew, dates, and survey conditions among other information.

Remote sensing output files often have similar names, and it is extremely important that unique identifying names are given to each file to reduce the risk of accidently overwriting previously collected data. The field notes and associated data should be organised and stored in such a way that a third party can reconstruct the survey from the notes and associated files at a later date if necessary. The survey lines and grids themselves should be stored securely and with identifiable file/folder names.

If photographs are appropriate, a photo log should list the subject of each image along with an identifier (such as photo file number). Field notes should be secured and copied as paper or digital back-ups if appropriate, depending on how they are collected.



2012 UBC Archaeological GPR Survey **Cemetery Survey Field Notes**

Names: Survey conducted by … **DVL Dir/File:** DVL Dir 15 / Grid X5

Date: 31 May 2012 **Freq:** 500 MHz **Setup:** Cart **Grid:** *X* = 3.0 m *Y* = 10.0 m Sep: 0.25 m

1. GPR DATA LINES:

Y	Dir	m.	S/N
0	S-N	0.0	√
1	N-S	0.3	√
2	S-N	0.5	√
3	N-S	0.8	√
4	S-N	1.0	√
5	N-S	1.3	√
6	S-N	1.5	√
7	N-S	1.8	√
8	S-N	2.0	√
9	N-S	2.3	√
10	S-N	2.5	√
11	N-S	2.8	√
12	S-N	3.0	√

X	Dir	m.	S/N	X	Dir	m.	S/N	X	Dir	m.	S/N
0	W-E	0.0	√	17	W-E	4.3	√	34	W-E	8.5	√
1	W-E	0.3	√	18	W-E	4.5	√	35	W-E	8.8	√
2	W-E	0.5	√	19	W-E	4.8	√	36	W-E	9.0	√
3	W-E	0.8	√	20	W-E	5.0	√	37	W-E	9.3	√
4	W-E	1.0	√	21	W-E	5.3	√	38	W-E	9.5	√
5	W-E	1.3	√	22	W-E	5.5	√	39	W-E	9.8	√
6	W-E	1.5	√	23	W-E	5.8	√	40	W-E	10.0	√
7	W-E	1.8	√	24	W-E	6.0	√				
8	W-E	2.0	√	25	W-E	6.3	√				
9	W-E	2.3	√	26	W-E	6.5	√				
10	W-E	2.5	√	27	W-E	6.8	√				
11	W-E	2.8	√	28	W-E	7.0	√				
12	W-E	3.0	√	29	W-E	7.3	√				
13	W-E	3.3	√	30	W-E	7.5	√				
14	W-E	3.5	√	31	W-E	7.8	√				
15	W-E	3.8	√	32	W-E	8.0	√				
16	W-E	4.0	√	33	W-E	8.3	√				

2. CONDITIONS/NOTES:

Ground conditions: Wet

Survey Notes:

X All lines taken from West

Y All lines taken in standard way

3. GRID DATA:

Coordinates from Site Datum:

From E: 22.0 m From N: 12.3 m

Grid Range (From Grid SW corner)

To E: 0.0 to 3.0 ı To N: 0.0 to 10.0 m

4. COLLECTION PARAMETERS:

Time Window:	50 ns
Sampling Interval:	0.10 ns
Points/trace	500
Step Size:	0.02 m
Stacking:	4

Main Cemetery Test

5. SKETCH MAP: **GRID X5**

6. ADDITIONAL COMMENTS:

None required

Figure 7. Example of a field note log for a GPR survey

5. Unmanned Aerial Vehicle (UAV) Survey: Recommended Data Collection Procedures for Locating Unmarked Graves

Scott Hamilton and Edward Eastaugh

5.1 Introduction

Unmanned Aerial Vehicles (UAVs), more commonly referred to as drones, and officially described as RPASs (Remotely Piloted Aerial Systems) in Canada, are extremely useful for investigations at Indian Residential Schools. UAVs serve two primary functions: 1) Generating maps to aid in the planning and execution of subsequent ground-based investigations, including GPR and 2) Primary investigation where a variety of UAV mounted sensors are used to try to identify buried features from the air including unmarked graves and other buried archaeological features. There is a dizzying array of UAV options on the market that range in price from a few hundred dollars for a simple quadcopter with camera (typically used for recreational purposes) to fully integrating, multi sensor systems costing tens of thousands that are used in the surveying industry (Figure 8). The level of accuracy and resolution will vary considerably between systems, so it is important to understand some of the basic differences.

Figure 8. Left to right: Fixed wing Sensfly eBee Ag; budget rotary winged DJI mini 2; and DJI Matrice 3000 RTK with multiple sensors. Images obtained from company websites.

Choosing the right system will depend on your survey goals. Most consumer grade UAVs are equipped with GNSS (GPS) capable of ±2-5 metre accuracy, and with a barometric altimeter that can be affected by varying atmospheric pressure and elevation, both of which introduce imprecision into the output from mapping flights. While this level of accuracy might be sufficient in some instances, such as generating maps for planning purposes, if the UAV mapping output is to be integrated with other georeferenced data as part of an investigation for unmarked graves, this level of imprecision might be problematic. It can be addressed in two ways: 1) use of professional grade UAVs equipped with better quality GNSS receivers capable of differential correction; or 2) establishment of control points prior to the UAV flight.

Control points are points on the ground that are identifiable in the images obtained in the drone survey and which have known geographic locations (usually surveyed by GNSS or total station-see above). Their coordinates are used to refine the position of the photogrammetric output. In some circumstances this will render results to accuracy within a few centimetres. This high level of precision and accuracy may be important when attempting to integrate diverse spatially registered data within GIS software.

UAVs come in fixed and rotary winged configurations. Rotary-wing UAVs offer the greatest utility because they are more maneuverable in flight. This includes smaller four-blade quadcopters designed for consumer use, as well as larger and more sophisticated four, six or eight-blade machines intended for professional applications. Fixed wing systems are generally used for surveying very large areas. Lower cost UAVs are usually equipped with built-in cameras, while professional-grade machines can interchangeably mount cameras or thermal, multi-spectral and laser sensors (Light Detection and Ranging or LiDAR). UAV technology (and associated sensors) is rapidly evolving, resulting in regular performance improvement, new features and capacities, and rapid equipment obsolescence. Most UAVs are equipped with still and video cameras that capture visible light imagery at a resolution between 12 to 20 megapixels, many with wide angle and zoom capabilities. More efficient mapping is possible with cameras equipped with mechanical shutters that minimize 'motion blur', thereby enabling faster flights.

Note that in Canada, UAV's that weigh 250g or more are considered aircraft and are regulated by Transport Nav Canada. This means that pilots operating them require various levels of licenses and sometimes require permits to fly them (depending on the airspace). Lighter UAVs are considered "microdrones" and are less regulated. In mapping and searching, the payloads (what the UAV carries - cameras, etc.) are heavy enough to require the whole assembly weigh more than 250g. Cameras, thermal sensors, and LiDAR arrays can require a UAV weighing several kilograms. Such objects can be a hazard to other aircraft, to wildlife, and to other humans if not operated safely and under required licenses and permits.

5.2 Searching for Buried Features Using Drone Survey

5.2.1 Visible light (RGB – red, green, blue) cameras

Buried features are sometimes visible from the air through a phenomenon that archaeologists call crop or parch marks. These occur in areas planted with a single crop where vegetation directly above a buried feature grows or ripens at a different rate than the surrounding area because the available moisture or nutrients in the ground are affected by the buried feature (Figure 9). This can result in positive and negative crop marks, where the vegetation is either taller and healthier (often darker) or shorter and unhealthy (often lighter). This difference in vegetation colour and height is more obvious when viewed from above and can be recorded with standard RGB (visible light) cameras (Figure 10). RGB cameras record 3 "spectral bands" within the visible light range of the electromagnetic spectrum mirroring human sight. Late summer, drought conditions, and evenings with low light and extended shadows are excellent times to identify features this way.

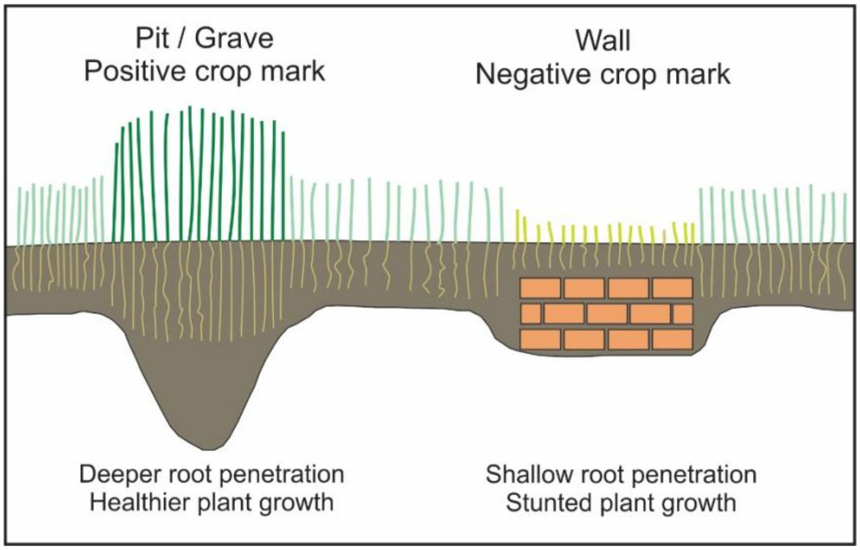


Figure 9. Illustration showing how buried features affect plant growth that is visible on the ground surface as positive and negative crop marks. *Figure by:* E. Eastaugh

Figure 10. Crop marks of buried archaeological structures in the ancient Roman city of Ostia from: https://www.researchgate.net/figure/a-Cropmarks-of-archaeological-structures-in-the-area-of-the-ancient-Roman-city-of-Ostia_fig10_343951237

5.2.2 Multispectral/hyperspectral cameras

While archaeological features and crop marks can be detectible with the naked eye there are instances where we need additional help to identify them. Hyper or multispectral cameras, which record different wavelengths of EM radiation beyond the visible light spectrum, allow us to identify and enhance more subtle differences in the vegetation growing above buried features (Figure 11). Some of these different spectral bands/ranges are well known, such as 'infrared' and 'thermal'. Multispectral imagery can be used to characterise plant health by identifying different levels of chlorophyll within plants (often using the infrared spectral bands). As noted above, plant health is influenced by the underlying soil and moisture conditions, which in turn can be influenced by the presence of buried features such as walls or grave shafts. Thus, plants growing directly above features sometimes have different levels of chlorophyll than surrounding areas. Multispectral survey is best performed several times throughout the growing season to determine when the best results are obtained in a particular locality.

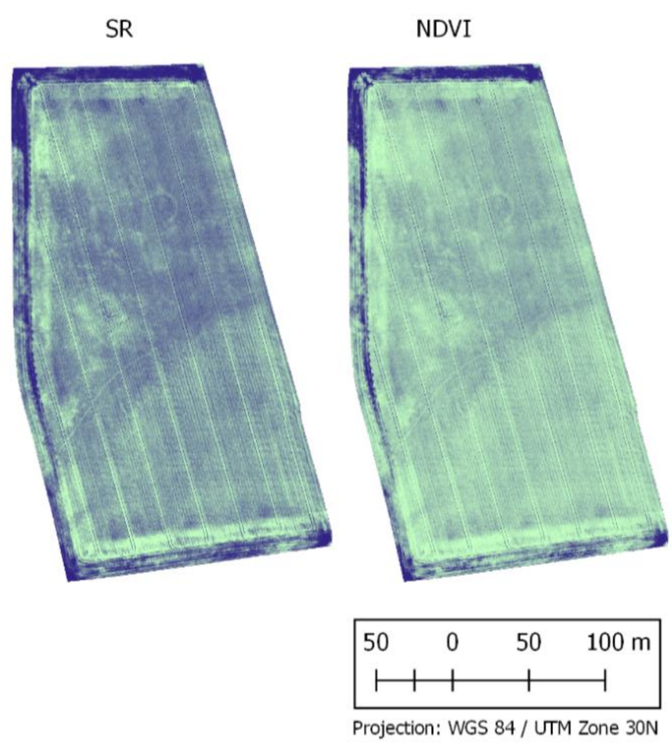


Figure 11. Visualisations of crop marks from buried archaeological features from Fife Scotland in multispectral imagery showing SR (simple ratio) and NDVI (Normalised Difference Vegetation Index) index maps. *From:* https://www.geos.ed.ac.uk/~mscgis/16-17/s1617975/

5.2.3 Thermal cameras

Thermal cameras, in a technique known as thermographic imaging or thermography, are another option for identifying buried features from the air. Buried features will absorb, reflect, and emit heat from the sun at different rates depending on their composition, density, and moisture content (Figure 12). For example, during a 24-hour period, the ground will heat up from the sun which in turn can heat up features buried below the surface, through a process known as thermal conductivity. At night, as the air cools, the ground surface, and features within it release heat. This will happen at different rates over different areas depending on thermal inertia, emissivity and volumetric heat capacity of the soil and features. You may have noticed this phenomenon when walking from a grassed area to cross an asphalt road at the end of a hot day. You still feel the heat coming off the road, even though the air temperature has dropped. A thermal camera detects these differences.

There are, however, some limitations. Firstly, buried features, such as a wall or a pit, are only potentially visible if there is sufficient contrast in the thermal properties between the feature and the surrounding soil. Secondly, this technique only works for features that are relatively close to the surface. It is important to understand, therefore, that we are not trying to identify the burials or coffins themselves, but rather the pits or grave shafts within which they are buried. Thirdly, while hypothetically possible, archeological thermography has mostly been confined to the identification of relatively large, uniform features such as building foundations (Figure 13). Relatively little is known about its utility in the identification of unmarked graves. Thermal imaging is usually best done at night, as there is usually too much radiation from reflected sunlight during the day, which washes out any of the subtle thermal differences that different features might display. Unfortunately, it is impossible to predict how long after dusk the optimum time to survey is as it will be different for each site. You may have to try at different times throughout the night to establish the best time.

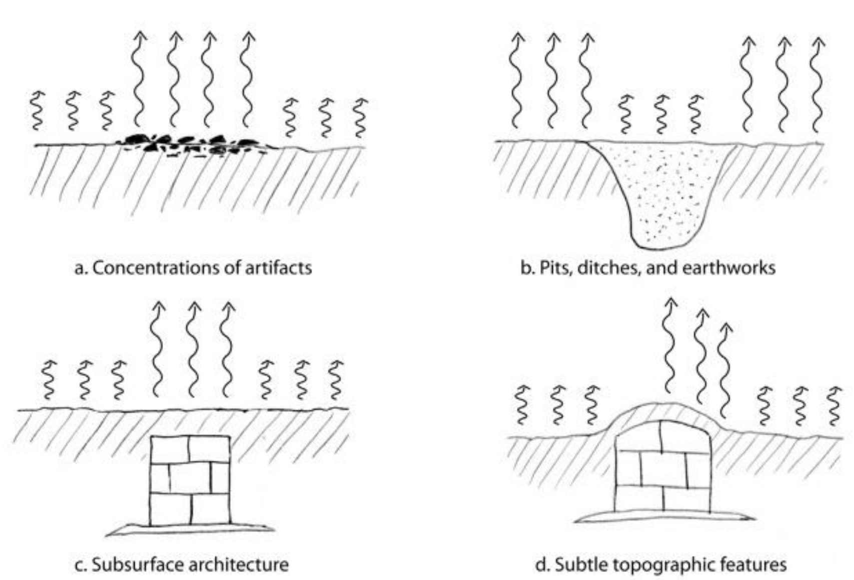


Figure 12. Hypothetical differences in thermal radiance from different buried and surface features. *From:* Casana 2017.

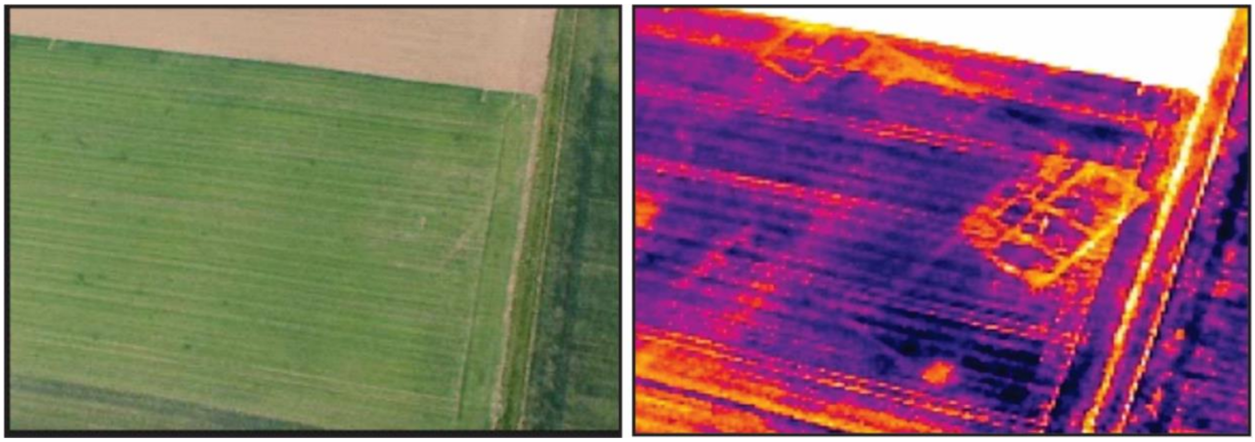


Figure 13. Image showing the increased visibility of a Roman villa complex as observed in a thermal (right) image compared to a visible RGB image (left).
http://www.armadale.org.uk/aerialthermography.htm

5.2.4 Digital elevation models (DEMs)

Buried features can also result in very small, imperceptible differences in the height of the overlying ground. While invisible on the ground, we can sometimes identify these small changes in elevation through the creation of very accurate digital elevation models or DEM (Figure 14). A DEM is an artificial rendering of the ground surface, which is viewed using computer software. DEMs can be manipulated in a variety of ways to accentuate minor elevation differences to facilitate their identification. There are two main ways of creating DEMs through UAV survey: Photogrammetry and Lidar. Photogrammetry is a process where computer software is used to identify thousands of common points in overlapping photographs to create a 3D model through geometric intersection. The photographs are re-oriented, warped and mosaicked together into a single large image, known as an orthomosaic.

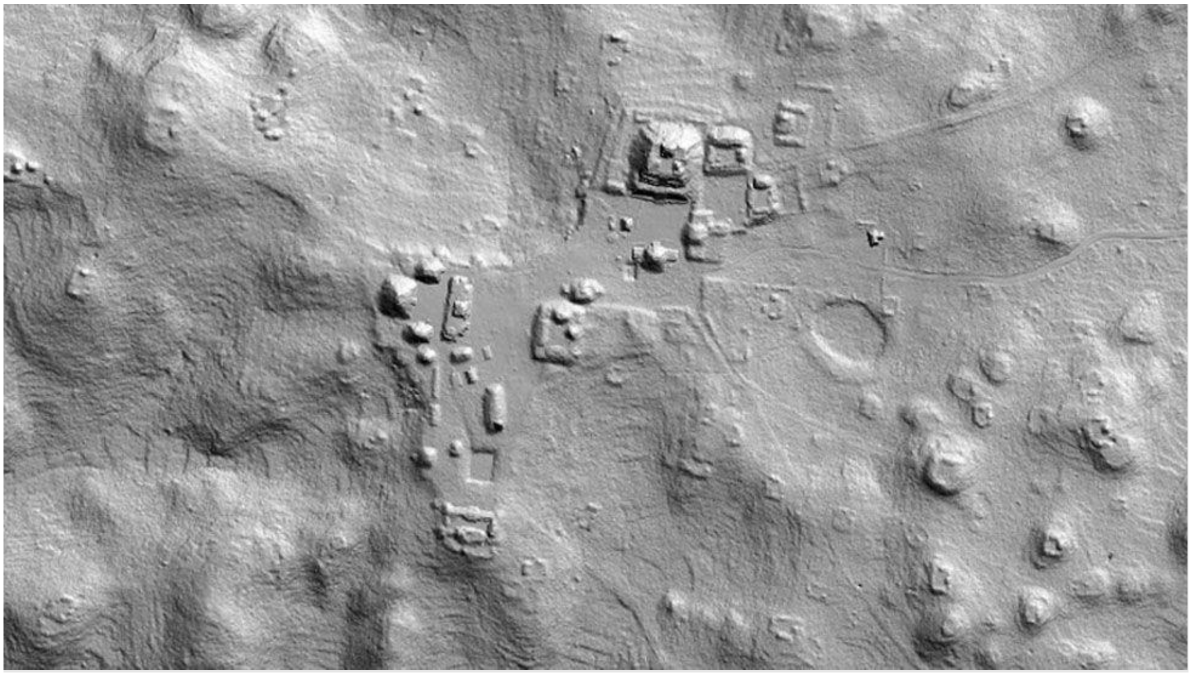


Figure 14. Digital elevation model of a Lidar survey in Belize showing Mayan pyramids, mounds and terraces normally obscured from the air by jungle. *From:* https://www.bbc.com/future/article/20120827-the-laser-archaeologists

The second method for creating a DEM is Lidar survey, which uses lasers to obtain very accurate distance measurements. Aerial Lidar systems send laser pulses downwards to measure distance to the ground. The sensor measures the time taken for millions of points of laser light to leave the UAV, strike the surface below, and then return. This three-dimensional information forms dense 'point clouds' that precisely define the surface. Lidar survey also has the advantage of being able to survey through wooded areas to obtain DEMs of the ground surface below the tree canopy (Figure 15). However, it is worth noting that, contrary to popular belief, Lidar cannot see through trees. Rather, the laser light is able to penetrate through spaces between the branches and leaves to survey the ground below, if the tree canopy is not too dense. If light can get through, so can Lidar. Because of this, it is always advantageous to survey when there is little or no tree canopy as there are more spaces for the laser to penetrate. Early spring before the tree canopy develops an ideal time to conduct Lidar survey.

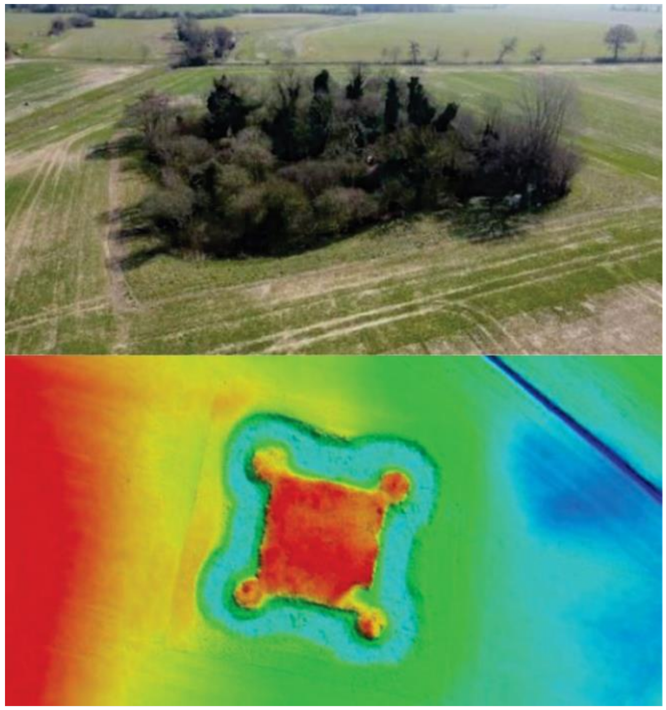


Figure 15. Lidar revealing the remains of Gresham Castle, a 14th century fortified manor in Norfolk, UK, hidden within a tree lot.

5.3 Applications for IRS Landscapes

Digital, thermal, multispectral and LiDAR sensors have roles to play in ground searches of IRS landscapes. They can be primary indicators of burials, depending on local conditions. They can also assist in locating features such as roads and buildings now beneath agricultural fields. Photo maps are very useful in creating accurate and precise models of contemporary landscapes, including the control points of geophysical methods. LiDAR has been successfully used to locate unmarked graves in cemeteries and may have a similar role in less formal burial landscapes.

5.4 Planning

Flight planning is dependent on mapping objectives, site extent, vegetation cover, and airspace status. To collect imagery suitable for photogrammetric processing, the UAV should be flown along transects at a standard height and speed (Figure 16). Photographs are taken along these transects at intervals that allow standardized overlap between adjacent images. This is difficult to achieve using manual flight, but semi-autonomous flight planning software greatly improves efficiency and output quality. Most UAVs are equipped with sensors that enable safe and stable flight. They are controlled through two-way radio communication between the aircraft and the ground controller. The latter is usually paired with a dedicated flight controller, tablet or cell phone to provide telemetry information and the UAV camera view. Many UAVs can also be programmed to fly in grid patterns while automatically collecting overlapping photographs (Figure 16). Using an internet connection, maps (often Google Earth) provide geographic context to identify the flight area. After assigning the flight elevation, degree of image overlap and flight speed, the planning software automatically establishes flight transect lines (Figure 16). The completed plan is saved for upload to the UAV at flight initiation, whereupon it will automatically take off, complete the flight transects and return to the landing zone. However, the pilot can regain manual aircraft control at any time. The optimal flight elevation is dependent upon the preferred image resolution, the coverage area, and potential objects that might be hazardous to the UAV. Selecting flight elevation reflects a balance of considerations. Lower elevation flights generate high resolution images but require more photographs to achieve the required coverage. Higher elevation flights require fewer photographs, but at the expense of image resolution. Depending upon the camera used, a flight elevation of 40 metres will provide ground image resolution of about 1.5 cm per pixel, while offering a reasonable degree of flight efficiency and safety. Higher elevation flights enable more spatial coverage per battery charge, but at coarser resolution.

Electrically powered UAVs usually offer between 20 and 30 minutes of flight time per battery, while newer, more expensive models can offer close to one hour of flight time. Since battery life varies with air temperature, wind velocity and battery age, it is practical to limit flights to no more than 80% of estimated battery duration. The efficiency of semi-autonomous flight planning software can enable flights over smaller areas using only one battery. For example, an area of about 1.5 hectares (15,000 m^2) flown at 40 m elevation at a speed of 2.4 m/second (with 85% overlap between images) will collect about 260 images within a 15-minute flight (one battery). The resolution of such imagery will vary depending upon the camera used. The 260 images in this example flight would require about 2.18 gigabytes on the micro-SD card installed on the UAV. When mapping larger areas, semi-autonomous flight planning software can accommodate multi-battery operations.

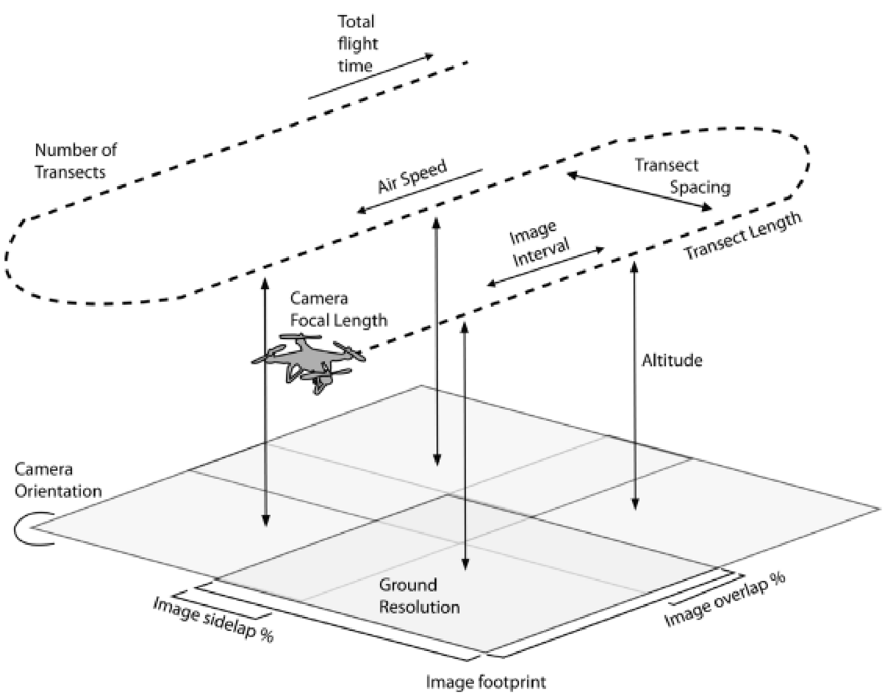


Figure 16. Diagram illustrating the main variables in planning UAV survey. *From:* Casana et al 2017.

UAV survey missions require a pilot and observers. In Canada, UAV flights are governed by regulations and licensing administered by Transport Canada. UAVs must be registered, and pilots must be licensed to a level appropriate for the airspace conditions over the survey area. The pilot controls the aircraft, while the observers monitor the UAV and alert the pilot about approaching aircraft and other hazards. Most UAVs are equipped with sophisticated instruments to ease flying and to reduce crash risk. This includes a Global Navigation Satellite System (GNSS), barometric altimeter, compass, collision avoidance sensors, and a gimbal to reduce image motion distortion. Flight plans should be made in line with Transport Canada regulations prior to the survey to reduce hazards should something go wrong during flight. This might include the loss of sight or control of the aircraft and mechanical failure. Preflight planning also includes determination of airspace status over the survey area and gaining appropriate approval if the planned flight occurs in controlled airspace. Consideration of weather, wind and lighting conditions, and condition of the UAV hardware and firmware is also vital.

5.5 Data collection

Planning photogrammetric mapping flights requires consideration of several variables including the project objectives, field conditions (e.g. vegetation, lighting, wind, time of day, cloud cover) and the camera/sensors used. Ideally, imagery should be collected at a standard height and flight speed and with a suitable degree of overlap between adjacent images. The recommended image overlap varies from a minimum of 75% frontal and 60% to the side for comparatively open conditions, to 80% front and side for agricultural fields, and 85% front and side for dense vegetation and forested conditions. This is required because photogrammetric software seeks out common points identified in adjacent images to generate the composite mosaic. Such common points are also essential for generating digital elevation models. While the number and distribution of common points is generally improved with greater image overlap, often the most important factor affecting data quality is the nature and density of vegetation cover. If the survey area is relatively uniform (e.g. large area of grassland) then identification of common points becomes challenging. One solution is to fly higher with a lower degree of overlap (75 to 80%) in the hope that the large areal coverage will yield distinctive features in adjacent photographs.

In drone survey, archaeologists often try to achieve an image resolution of approximately 2 cm (i.e. one pixel in the image represents 2 cm on the ground) in order to obtain the detail necessary to identify features of interest. Image resolution is influenced by two principal factors: the number of megapixels of the camera and the altitude that you fly the drone during data collection. In general, most drone cameras will obtain imagery with the required 2 cm resolution by flying the drone at an altitude of 40m above the ground. This is also usually high enough to avoid obstacles such as trees and buildings. You can achieve greater resolution by flying the drone at lower altitudes, though this will significantly increase the time needed to complete the mission and process the data.

Accuracy is also an extremely important consideration in drone survey. The primary objective of these aerial mapping flights is to collect high-resolution mapping data to supplement the results from near surface geophysics (e.g. GPR). It is, therefore, necessary to precisely locate the results of your drone survey on the ground with accurate geographic coordinates. Some high-end drones have highly accurate RTK GPS incorporated into their systems allowing the images to be located to with a few centimetres on the ground. These are ideal but are expensive. While cheaper drones also have GPS, they do not provide the accuracy required. It is therefore necessary to incorporate control points into the survey (see above).

If one of the objectives of the drone survey is to create a digital elevation model of the search area, you will also need to fly a second mission to obtain images captured at an oblique angle. While this doubles the time needed for the survey, it allows the generation of 3D models in instances where lidar is unavailable. However, unlike lidar, DEMs generated through photogrammetry, are not able to remove features such as trees.

5.6 Data Processing

It is hard to offer general guidance about data processing, as the appropriate software will depend on the type of instrument you are flying with the UAV. Likewise processing steps will vary for different types of imagery and depend on local conditions. Data quality can often be evaluated through repeated flights over the same area – with consistent results indicating good quality data. Many GIS software mapping systems now have data processing capacity for remote sensing data.

6. Ground-Penetrating Radar (GPR): Recommended Data Collection Procedures for Locating Unmarked Graves

Andrew Martindale, Steve Daniel, William Wadsworth, Eric Simons and Colin Grier

6.1 Introduction

Ground-penetrating radar (GPR) is a form of remote sensing that is commonly used to locate unmarked burials in cemeteries. It works by sending electromagnetic (EM) waves from an antenna into the ground at different frequencies. Soil layers and objects below the surface can reflect these waves, returning them to the GPR to be recorded (Figure 17). The time it takes returning waves to reach the GPR allows us to estimate their depth. Different soils and objects will reflect the waves differently back to the antennae, allowing for visualization of the subsurface. This document considers how to collect GPR data when searching for burials and how to interpret potential burials in GPR results.

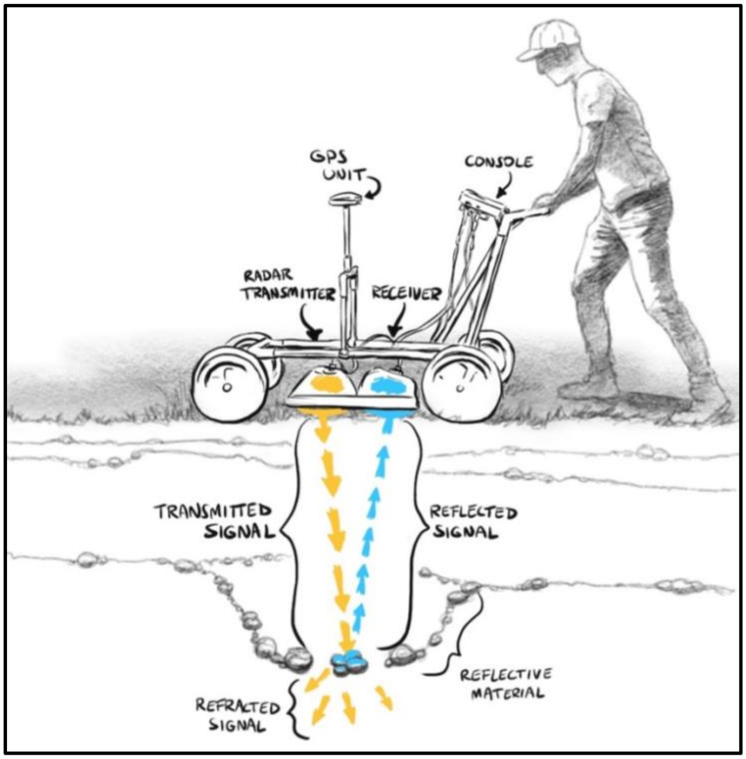


Figure 17. Illustration detailing the main parts of a ground-penetrating radar

GPR scanning is non-invasive; it does not disturb or damage the subsurface. It is widely used in industrial contexts for the detection of buried pipes, cables, building foundations, etc. Its use in locating burials is a specialized application that requires a specific method and experience in identifying grave shaft reflections. When a grave is dug, the soil density and compaction may change; under good conditions, the GPR signal will reflect differently over the grave shaft. Interpreting these signals as graves takes specialist knowledge and experience; archaeologists have been working on refining the use of GPR to detect graves for many years. While GPR cannot provide 100% certainty of a burial, graves can be identified with confidence, especially in formal cemeteries given optimal soil conditions. Its application is less developed in informal or unmarked burials and certain soils (particularly clay) can make grave detection challenging. Negative results in GPR do not ensure that no graves are present; they imply further work is needed. It is important to note that, under normal working conditions, GPR does not detect bones or human remains. It only detects changes in soil density and/or compactness suggestive of burial shafts.

6.2 Instrumentation

There are a wide variety of GPR systems available, and it is extremely important to choose one that will provide your investigation with the desired depth of penetration and resolution required to detect graves. One of the most important variables in your GPR survey is the selection of an appropriate antenna frequency. GPR antenna frequencies typically range from 10 MHz - 2600 MHz. The depth of penetration and the size of object that you can detect will vary depending on the frequency used. Low frequency (e.g., 10-100 MHz) antennas can penetrate up to 50 m but can only identify large, buried objects, whereas high frequency antennas (1000 MHz+) can detect very small objects but might only be able to penetrate 50 cm into the ground. There is thus a trade-off between how deeply you can investigate and the size of the object you can identify. Most archaeological investigations use frequencies between 250 MHz and 500 MHz, which are ideal for grave detection.

You can operate GPR antennas in a variety of ways depending on the environment you are investigating (Figure 18). Four wheeled systems are the most comfortable to operate and facilitate the mounting of a controller and GNSS unit. However, they work best on very flat surfaces such as concrete or manicured grass and may not be suitable for rugged, uneven terrain such as a ploughed field. Two-wheel systems are much more suitable for uneven surfaces and are often more efficient at surveying smaller, irregular areas with frequent obstacles, as they can be positioned much closer to obstructions. However, they are more tiring and uncomfortable to operate, particularly over large areas, as the operator must carry the controller and GNSS. Three-wheel carts with large wheels offer a compromise between the two systems. They work better on uneven surfaces than a four-wheel system and are less tiring to operate as you can mount the controller and GNSS. Fortunately, the mounting options are interchangeable, so large, relatively even areas can be surveyed with a cart wheeled system and more uneven areas with two-wheel types.

Figure 18. Typical GPR configurations used in archaeology: a 250 MHz antenna mounted on a four-wheel cart (left), a 400 MHz antenna mounted on a three-wheel cart (centre) and a 500 MHz with a tow-wheel (right). Photo credits (L-R): https://www.sensoft.ca/georadar/archaeology/; William Wadsworth and Bern Weinhold taken by Kisha Supernant; Kayla Golay Lausanne taken by Edward Eastaugh

6.3 Planning

The area of assessment should be thoroughly investigated and mapped prior to conducting a GPR survey. Landscape features, areas of interest, potential obstacles, and survey grids should be located on the ground, surveyed using UAV and/or land-based surveying instruments and incorporated within a spatial data management system, such as a Geographic Information System (GIS) (see Chapter 3). This will considerably aid subsequent investigations.

GPR surveys should begin with an assessment of the geology of the survey area. This is done by collecting a few lines of data in undisturbed regions of the survey area (i.e., with no burials or other disturbances such as trees, roads, or buildings) to establish what the “background” radar response looks like when there are no buried objects present. This makes it easier to recognise “anomalies” or unexpected differences to the background radar response, which might indicate the presence of a buried object.

One of the more useful features of GPR survey is that it can estimate the depth of buried objects. In order to do this, it is first necessary to establish how fast the radar wave is able to travel through the ground, which will vary from site to site depending on factors such as soil type and moisture content. While it is sometimes possible to measure this radar velocity directly, by calculating the time it takes to travel to and from a buried object whose location and depth is already known, in practice, this is usually not the case. Velocities are usually estimated based on the known average velocities of more common subsurface sediments or through a process known as hyperbola fitting. A hyperbola is a feature observed in GPR results, which looks like an upside down “U” and is the radar’s response to a small, buried object. The shape of the hyperbola will vary depending on how quickly the radar wave is travelling through the ground. Thus, analysing the shape of the hyperbola helps you determine the velocity of the radar signal.

GPR survey is time-consuming. We estimate that a crew of 3 technicians (including a GPR operator and two assistants to move the ropes used to guide the GPR) can conduct formal survey (see below) of about 500 – 1000 m^2 in one day, depending on conditions. It may also be necessary to prepare the site for survey. GPR units work best when in direct contact with the ground, and this may require the removal of low vegetation and mowing long grass.

GPR surveys require permissions, access, and the development of agreements on scheduling, deliverables, timelines, training and, if required, budgets. Depending on the jurisdiction, permits may also be required. Communities often require specific protocols to be followed including necessary ceremonies, timeframes, and rules about comportment and behaviour when working with ancestors. These all need to be worked out and agreed upon prior to starting GPR survey.

6.4 GPR: Reconnaissance vs. Formal Survey

There are two basic forms of GPR survey: reconnaissance (sometimes called ‘prospection’ or ‘roaming’) and formal. In both cases, we recommend an antenna frequency between 250 and 500 MHz. Higher frequencies are sometimes used to investigate a known burial that is very near the surface (within 50 cm), but lower frequencies are more useful for locating unmarked graves.

6.4.1 Reconnaissance Survey

Reconnaissance involves roaming systematically over a target area looking for signals in the GPR display. This can be very useful for confirming that probable graves exist within a large area. When a response indicating a target of interest, in this case a possible grave, is identified, the operator scans the area repeatedly to confirm the identification. Potential graves are then flagged and mapped. Ideally, reconnaissance data would be captured as either screen grabs from the display or stored as compilations of lines or traces. Reconnaissance can be assisted using GPS built into the GPR, although the precision of such instruments is rarely smaller than 1m. In this mode, the GPR can be moved across a wide area relatively quickly to assess the likelihood of graves on a landscape. Reconnaissance is a preliminary step in the GPR survey and should be followed by more detailed investigations.

6.4.2 Formal Survey

GPR survey data are most useful when collected in grids (Figure 19), which can vary in size. While experienced operators may survey grids of up to 50 m square, they usually measure between 10 to 20 m square. Grids that are larger than this can take a very long time to survey and can lead to inaccuracies in the position of the GPR. Conversely, numerous, smaller grids are unnecessarily time consuming to set up and survey. It is likely that you will need multiple grids to entirely cover your study location. It is often helpful to use rectangular survey grids to avoid confusing their orientation during processing (i.e., squares are more difficult to orient because their sides are all the same length).

Radar scans should be collected every 2 cm along data collection lines spaced 25 cm apart to provide enough data sampling points to locate burials when using frequencies between 250-500 MHz. Spacing the GPR lines evenly and close together ensures overlap between the lines and coverage of the full area. Burials are most visible in GPR when the survey crosses the grave perpendicular to its length. As the grave orientation cannot be assumed for unmarked burials, the best practice is to collect lines in perpendicular directions (X and Y) across the grid to increase both the signal density and the chances of crossing the short axis of a grave (Figure 19). When working in a cemetery context where general orientation is known, collecting data along only the axis perpendicular to grave length may be sufficient.

Figure 19. Example of a gridded GPR survey showing the collection of the survey lines in both the X and Y axis. *Photo credit:* https://www.sensoft.ca/blog/tips-collecting-data-around-obstacles/

This application of GPR generally uses unidirectional data collection within grids rather than bidirectional (aka zig-zag). Unidirectional collection is especially important over long distances (+5m) to reduce distance offset errors from inaccurate odometer calibration and uneven terrain. The grid should be rectangular, laid out using non-metallic tape measures or other survey tools to reduce potential signal interferences. Large metal objects on the surface, such as fences, can create noise in the GPR signal and care should be taken to minimize such interferences.

Wherever possible, and especially on sloping terrain, the GPR should be equipped with high-precision, real-time kinematic positioning (RTK) GNSS, or such data should be collected on the grid control points (corners or axes origins). This allows data to be to be correctly located on the landscape, and corrected for slope, which greatly clarifies reflective patterns.

7. Ground-Penetrating Radar (GPR): Recommended Data Processing and Visualization Procedures

Andrew Martindale, William Wadsworth, Eric Simons and Colin Grier

7.1 Introduction

GPR generates data on the amplitude (strengths) of reflections in the subsurface within a chosen study area. Turning these data into usable information is a complex process that will likely involve technical experts employing software to extract useful data from "noise" (not useful/confounding data) and then interpreting the results.
While complicated, the basic workflow and principles of data processing and visualization can be understood by anyone, and this guide is an effort to make sure this middle stage of GPR projects is less of a "black box". Often, processing is conducted after data collection is complete, but it is also advisable to process and visualize a small portion of the data as a pilot step in a GPR project (even during data collection), as this will allow for the early identification and prevention of problems in the data collection process (with the equipment, with software, etc.).

7.2 Generating GPR Reflection Profiles ("Radargrams")

As noted in Chapter 6, GPR data is collected in 2D vertical profiles. The **first step** is to transfer this data to a computer on which the processing and visualization software has been installed. There are several programs that will do this job, and each performs similarly in a general sense. Typically, the proprietary software of the machine's manufacturer is used; however, there are third-party or open-source software packages that work with data generated by many different types of GPR machines. Consultants and researchers likely already have a machine and software workflow established. Usually, the transfer is as simple as connecting the machine's data collector to a USB drive, and then transferring the data to a computer via that USB device. The following steps may be in a different order depending on the specific software you are using. Regardless of the order, each step is an important part of the overall processing and visualization procedure.

Once the data is uploaded to the computer, the **second step** is to ensure that the software understands how the data was collected. This includes: 1) inputting the length of each line (transect) and where they begin/end, 2) transferring system information and settings that describe *how* the data was collected (e.g., the density of scans and the depth that was scanned, though this information is often read automatically), 3) how many profiles were collected, and (4) any other relevant grid/survey information (e.g., removing profiles that include errors, indicating lines that were shorter or longer due to objects in the machine's path). These are all critical to ensure accurate results. Different software packages have different ways to accomplish this, but for software that is paired with the machine (that is, from the same manufacturer) this step can be relatively simple.

The **third step** is to process the data. This usually involves several standard steps initially, including finding "time zero". This means locating the first usable data from when the radar wave hits the ground surface after being emitted from the machine. After finding time zero, the data from above the ground surface can be removed. Following time zero correction, usually a gain model is applied to the data. Since waves lose energy as they continue deeper into the ground the signal from greater depths has to be boosted or "gained". Gain can be automatically applied by the software, or it can be a user-specified amount of boost for different depths that need more or less gain to highlight features for interpretation (note this often takes some experimenting).

The **fourth step** is the application of filters. Filters are applied to the data to reduce "noise" that can obscure collected data and to enhance visualized features. There are various filters and transformation processes that can accomplish this, each of which can greatly aid interpretation (Figure 20a). Generally, it is prudent to apply as little filtering as necessary to avoid creating effects that could be misinterpreted as targets of interest. Commonly used filters include background removal (which removes horizontal lines in the data), a bandpass filter (which removes data frequencies below and above the useful range of the GPR antenna), and a Hilbert transformation (which transforms wave reflections from both negative and positive responses to just positive responses). A process called migration is also often applied at this point, which turns the convex shaped reflections (hyperbolas) made by discrete objects into more of a focused signal. It is important to note that the speed of the wave in the ground can be measured by analyzing the shape of these convex reflections. Experienced software users can and should use this process to accurately estimate the depth of objects in the ground. There are many other types of filters and data transformation that can be applied, and the preferences of researchers do vary. Software manuals usually offer detailed technical discussions of these options. It is important to consider the advantages and potential pitfalls of their application to specific types of data. Experimenting with different filters and transformations for a particular dataset is often helpful).

In cases when the GPR data is not collected on flat ground, correcting the data is typically a necessary step. This makes use of a model of the ground surface contours. Correcting for topography ensures the most accurate positioning of the GPR reflections and amplitudes prior to interpretation.

By the end of these steps, the software should have produced relatively 'clean' visualizations of the GPR profiles (or radargrams) that are ready for interpretation.

7.3 Beyond Radargrams: Slicing and 3D Visualization

Most GPR software also offers the capacity to see GPR data from a bird's eye view at any given depth (also known as amplitude maps or time-slices). While GPR data is collected in profiles, these can be lined up side-by-side and stitched together to form a block. Software can then 'slice' this data block horizontally into GPR maps for specific depths/thicknesses (Figure 20b). Slicing to get these views is often best accomplished with data collected in grids, that is, in rectangular-shaped areas of the ground surface, but they can be generated from other less regularly spaced types of data or GPS-driven data collection sets. These amplitude maps (time slices) highlight strong reflections at specific places within the grid (often called "anomalies" or "targets"), which can correspond to specific features of interest. By default, red areas of the maps show unusually high reflections, while blue areas typically show average background reflection strength, and scaled colours show reflection strengths in between the background average lows and the high peaks (Figure 20c).The various software packages have different ways of creating slices, and users can have to make quite a few decisions when generating them (e.g., how many slices to create, how widely the software will look across radargrams to create the reflection map, how to apply a similar coloring system for the slices across all maps). As such, this step is best undertaken by someone with experience with the software being used. Interpreting amplitude maps/slices has several advantages: the reflection patterns are presented in a relatively intuitive way, one can inspect surface reflection patterns at any depth, and one can usually scroll up and down the slice depths to get a picture of subsurface features at various depths. It should also be kept in mind that slices are an interpretation, meaning they are based on a smoothed and transformed data set. Using both GPR profiles and these depth maps to understand any anomaly/feature is vital to the interpretation process.

Indeed, many GPR visualization software programs can combine these two forms of data to create impressive 3D visualizations of the subsurface. These tools can be used to create impactful and intuitive representations of subsurface features (including graves) and the soil layers in which they are embedded.

7.4 Getting the Best Results

The steps involved in processing GPR data are technically complex, but the basic principles are readily understandable. Not all communities that undertake or commission GPR surveys will complete this middle stage of work on their own. The goal of this brief overview is to provide enough information so that communities can work with GPR specialists to achieve the results that communities want and need.

It is important to recognize that the various contexts in which GPR is applied can present some challenges but overall many steps in the process are the same. The processing and visualization stage will likely involve significant trial and error to best represent the features that are of most interest. There are no cookie-cutter ways to do each of these steps, but the overall sequence of steps and goals is similar in most cases. GPR software packages often have “recipes” of pre-determined processes and filters that can be applied to data. It is important to recognize that these stock recipes may not be appropriate for your data, especially not without careful exploration and assessment of the results relative to other recipes or single transformations. Most advanced researchers create their own “recipe” based on the specific site conditions, and we recommend this approach strongly.

Once the GPR data has been processed and visualized, the third stage of the GPR project can be started: interpretation.

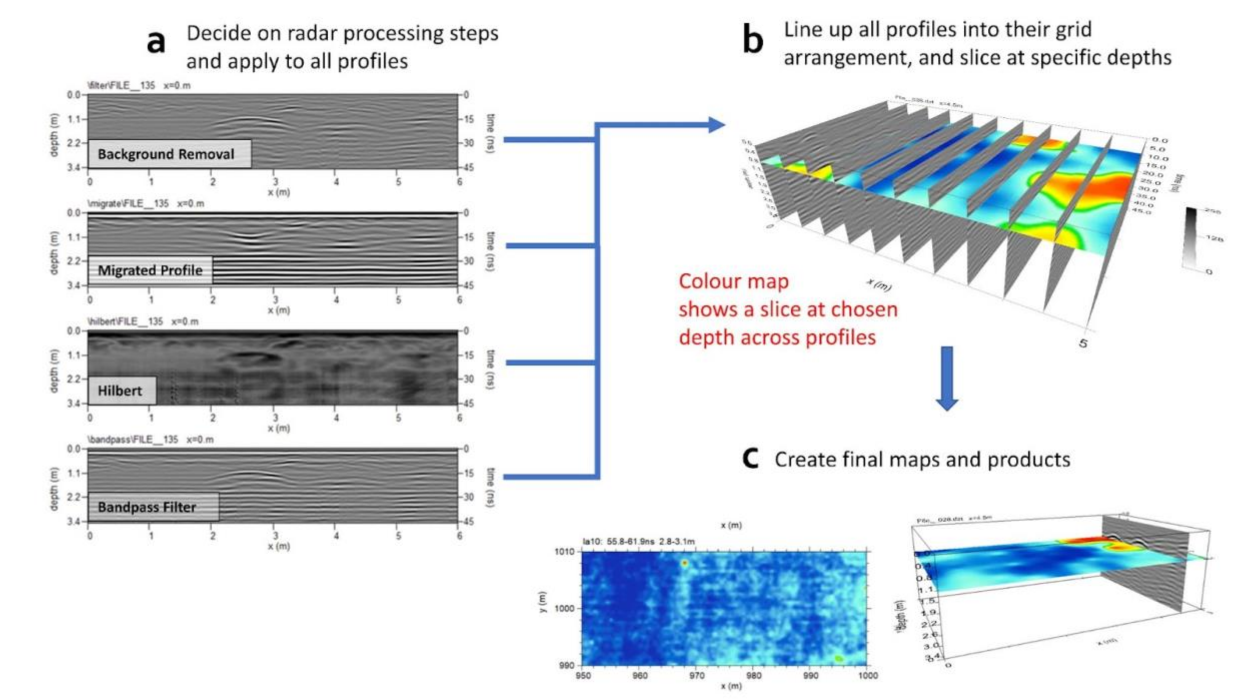


Figure 20. a) GPR profile data showing various levels of processing and different techniques. At any point along the processing procedure the GPR analyst can decide it is time to move to the next step, creating a 3D data volume. b) By lining up the GPR profiles into a grid arrangement, software can then ‘slice’ the profile data horizontally and create GPR amplitude maps for specific depths. c) This newly created depth/amplitude information can then be visualized as bird’s eye view maps and viewed in combination with radargrams.

8. Ground-Penetrating Radar (GPR) Interpretation Guide

Andrew Martindale, William Wadsworth, Eric Simons and Colin Grier

8.1 Introduction

The final step in GPR survey for unmarked graves is data interpretation. This step involves 'reading' the visualised GPR signals in the form of radargrams and amplitude maps and developing interpretations of what those signals represent. It is the most challenging of all the GPR steps.

Here, we provide a simplified model of how to interpret GPR data and identify unmarked graves. This document will provide some insight into how archaeologists use GPR to interpret burials and help stakeholders understand technical GPR reports. While these documents do not replace a geophysical education, they provide an important starting point for understanding the results of a GPR survey.

This document will proceed through the following steps of GPR Interpretation:

1. **Defining the Context:** Expected characteristics of unmarked graves and their environment
2. **Fundamentals of GPR and Unmarked Graves:** What do graves typically look like in GPR?
3. **Interpreting GPR Burial Traits:** Looking for specific indications of burials, depending on your environment and context

While our focus is to understand how to identify characteristic GPR grave signals, it is equally important to be able to differentiate signals that are produced by the sediments surrounding the grave (background geology) and other types of buried features. Consequently, we need to consider several potential signals that may be produced from a GPR survey in the search for unmarked burials.

8.2 Step 1. Defining the Context: Expected Characteristics of Unmarked Graves

The contrasting relationship between a grave and its background geology (surrounding sediments) creates the opportunity to identify burials with GPR.

8.2.1 Environmental Context

The properties of the ground influence GPR reflection patterns. In general, the less that background sediments reflect a GPR signal, the easier it is to identify signal reflection patterns produced by burials. In other words, the more strongly a reflected signal from a burial contrasts with a weaker reflected signal from background geology, the clearer the burial feature appears. However, conditions differ in each context, so general principles are just a starting point; a local assessment is necessary to develop a survey. Understanding how the background geology appears in the GPR signal is crucial for understanding what a burial may look like against that background. As such, the first step is to assess what the sediments are like in the survey area and develop some expectations for how they influence GPR signals in particular contexts.

Table 2 contains a few examples of the issues and challenges that may be encountered in different environmental background contexts. Modern, planned cemeteries tend to be located in landscapes of homogenous geological sediments, which are good conditions for GPR surveys since they tend to provide uniform (less 'noisy') backgrounds. Informal and concealed burials, such as those potentially associated with IRS landscapes, may be located in complex geological conditions.

Table 2. Some common expectations of GPR performance in different environments.
Note: This table does not represent every context, but some observations based on our collective experiences.

Environment	Some Expectations/Issues
Forested Environments	Tree roots obscuring the ground and data collection, obscuring GPR targets; rodent burrows and other more localized disturbances may occur
Clay-rich Environments*	Clay often impedes the GPR signal; in exceptionally high clay contexts, GPR does not work well especially when those soils are wet.
Heterogeneous Environments	Complex geology creates a noisy background against which it is difficult to identify targets such as burials.
Wet Environments	Water slows the GPR signal and in different conditions can reduce or

	increase the depth of the usable signal.
Dry/Sandy Environments	Generally, fairly good radar penetration and performance

* Encountering a clay-rich context or environment does **not** preclude it from study; it just means that adjustments need to be made in the timing of data collection that will improve GPR performance.

8.2.2 Cultural Context

GPR assessments identify burials based on their contrast with surrounding sediments. In general, the GPR reflection corresponds to the contents, shape, and size of the grave shaft. Properties such as moisture retention, compaction, and inclusions (such as rocks or metals) also influence GPR. Most archaeological research has focused on recent cemeteries where there is a pattern of relatively deep (1-2 m), roughly rectangular, adult sized (approx. 2 x 1 m) graves. The GPR patterns of informal graves, which include other shapes and /or sizes, are less well understood and may be less obvious to interpret in the data.

8.3 Step 2. Understanding the fundamentals of GPR and unmarked graves

To be able to identify graves using GPR, it is essential to understand the basic principles of the method. Our understanding of how GPR signals operate in burial contexts comes from three sources: 1) field research where GPR data is collected from known burials, 2) simulations of GPR using software, and 3) geophysical theory and scholarship.

Field research is the collection of GPR data from known burial settings. Most published research has focused on modern, formal cemeteries in temperate zones. As GPR becomes more widely applied in IRS landscapes, the understanding of how GPR works in a wider variety of situations will advance. The larger the sample of known examples (larger range of contexts and grave patterns), the better our ability will be to define the traits of different kinds of burials in different conditions.

Simulation involves the use of software (e.g., *GPRmax* or *GPRSIM*) to mimic GPR reflection patterns of simulated targets in modelled conditions (See Figure 21). With simulations we can create hypothetical geological conditions and various targets, generating a set of traits we should expect from GPR reflections of different kinds of graves. This work is in its early stages.

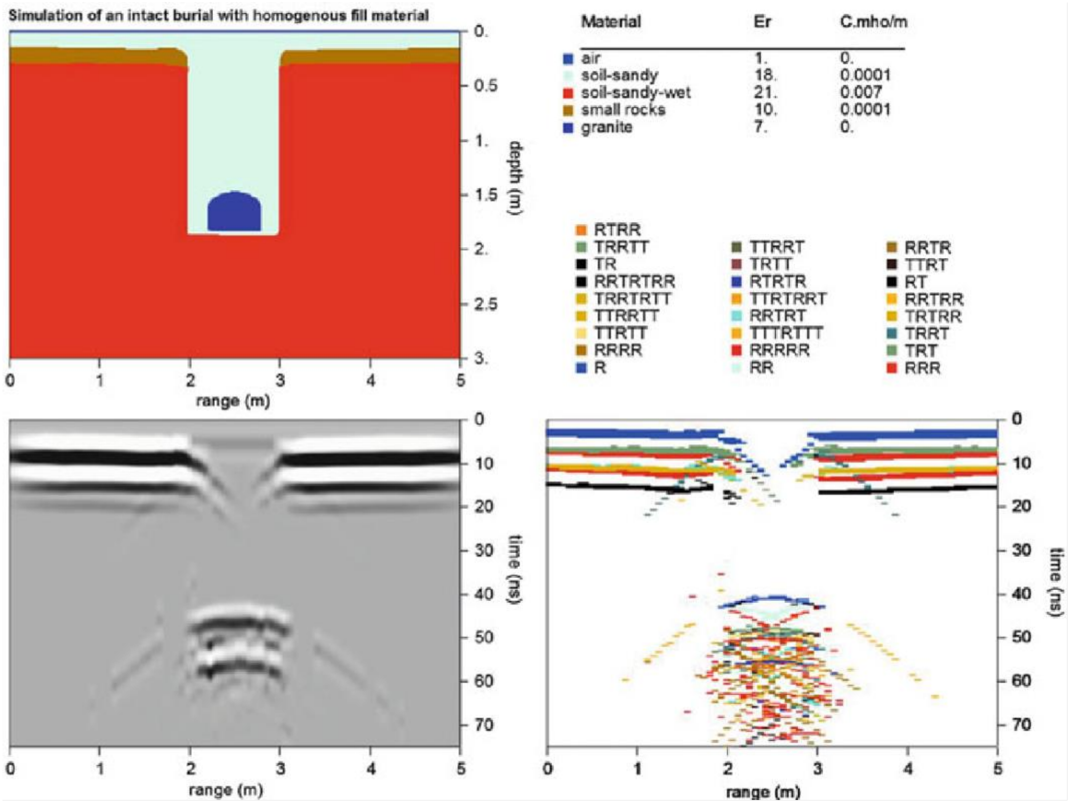


Figure 21. Example of a modelled grave in GPRSim software (Figure from Goodman and Piro 2013:160, Figure 8.1). The top left image shows a simulated grave in the software. The lower left is the resulting radargram that the software creates.

8.3.1 Geophysics

The behaviour of a GPR signal travelling through the ground can be complex. Its movements are dictated by the signal's wavelength (λ) / frequency (f) (which are inversely related). The lower the frequency, the greater the depth a GPR signal can travel through the ground. Conversely, with higher frequencies, the signal will be able to travel less distance but detect smaller features at a higher resolution. If GPR is configured for deeper penetration, it will only detect bigger objects. Most cemetery surveys use frequencies of between 100 and 1000 MHz, allowing for depths of a few metres and detection of objects smaller than a metre.

GPR detects subsurface patterns because some materials in the ground reflect signals back to the device which the device records. Two principal effects cause signal returns: 1) materials cause the radar wave to reflect off a surface like a mirror, and 2) when passing between different materials, the radar wave changes velocity, and some of the signal is reflected back to the device. Both effects occur in GPR and produce patterns in a reflection profile that we interpret as materials, objects, and features.

In formal cemeteries, GPR can be used to detect graves confidently for several reasons: 1) there are few anomalies of similar size/shape in such landscapes, 2) graves frequently occur in patterns such as rows, assisting the identification of individual graves, and 3) the rectangular planes of grave shafts produce characteristic reflective patterns visible in the vertical images (radargrams). Because of these properties, interpretation of burials in cemeteries using GPR data can often be straightforward.

IRS landscapes present more complex environments because there are many unknown variables. Burial shafts may lack standard rectangular shapes, they may not be arranged in patterns such as rows, and they may exist in geologically complex sediments. This combination of unknown factors means that graves will be harder to identify, and the background signal may be noisier. Since we currently lack a wide variety of GPR data samples from contexts with unmarked graves, interpretation continues to be a work in progress.

8.4 Step 3. Interpreting GPR Burials from Traits

The specific GPR traits associated with burials are varied and it is unclear if these characteristics are consistent across different geological contexts. However, a trait-based approach to GPR interpretation is emerging that allows researchers to identify specific GPR features associated with graves. As noted above, geophysical theory and simulations can assist, especially as the sample GPR results from known unmarked burials increases. Grave traits are interpreted with the use of two visual aids, radargrams and amplitude maps, although radargrams are the primary source of interpretations (Figure 22).

8.4.1 The Radargram

Radargrams visualize a linear sequence of radar scans of the ground (collected as one moves the GPR machine across the ground surface). The radargram shows the amplitude of the reflected signal as a visualization ‘in profile’, as though seeing the subsurface from the side. Radargrams are both the source of data for amplitude maps and most useful in identifying buried features.

8.4.2 The Amplitude Map

When GPR lines are collected in grids, the results can be presented and viewed in 3D. They are typically shown in a series of plan-view (‘birds-eye’) maps at different depths, called amplitude maps. From this vantage, graves within cemeteries typically have characteristic patterning both as roughly rectangular anomalies and as arrangements of anomalies in rows. In such contexts, the amplitude map may appear to be confirmation of graves in GPR. However, data from radargrams should be cross-referenced for identification.

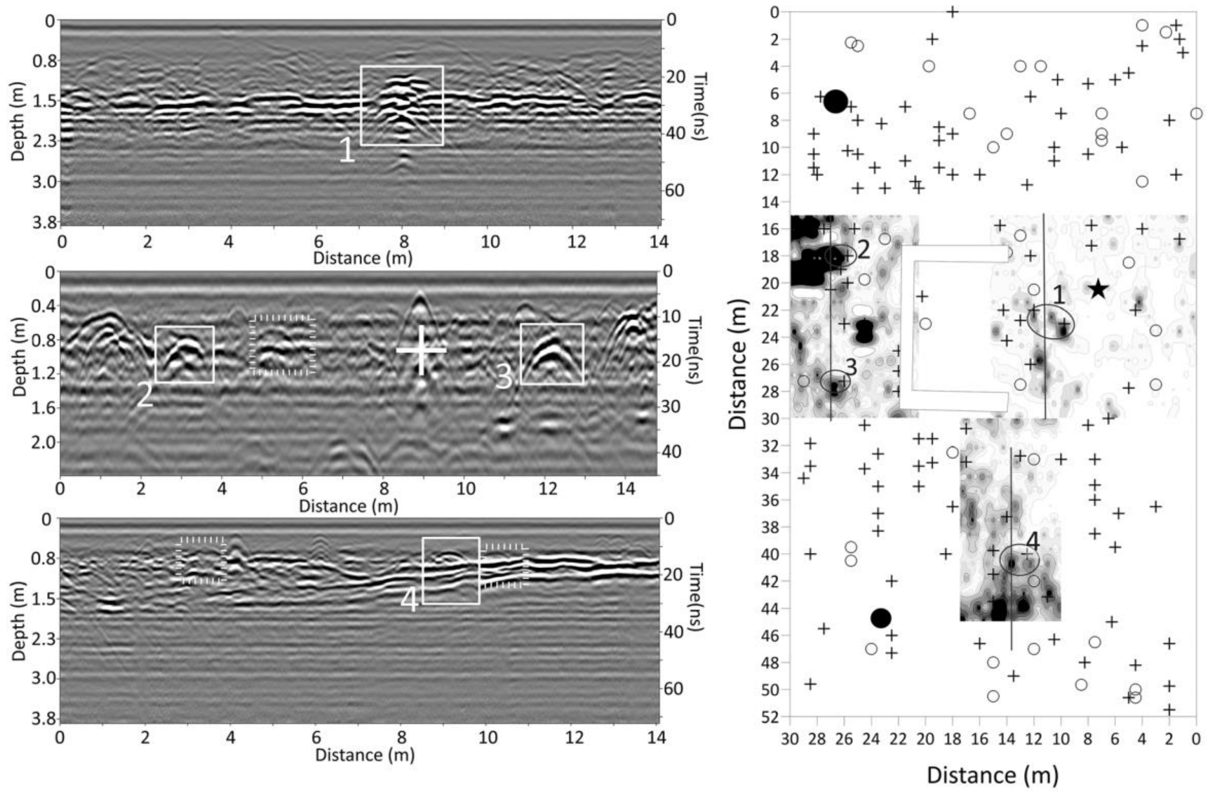


Figure 22. Combining reflection profiles with 2D amplitude maps. Left: Three profiles (radargrams) from different parts of a cemetery. Hyperbolic shaped reflections (diffractions) indicating probable graves are highlighted by white boxes and numbers. These numbers correspond with positions on the amplitude map of the cemetery. Right: The survey plot has been overlaid by profile interpretations: + are probable graves, o are possible graves, the black star denotes a grave identified with two techniques, and the black circles represent obstructions. Three 2D amplitude maps are included in the survey area. Notice that the amplitude changes (darker = high amplitude) correspond with our numbered 'graves.' *(Figure from Wadsworth et al. 2020: Figure 5).*

8.4.3 Burial Traits in GPR

A recent assessment of GPR applications to detect unmarked burials (Martindale et al 2021) identifies at least 23 different GPR signal patterns (traits) found in radargrams of known burials from 73 different published sources. Since many of these characteristics are only documented in a few of the analyses, the identification of GPR traits associated with burials remains a complicated problem.

However, these challenges are not insurmountable, and guidance will improve with both the application and interpretation of GPR surveys and ongoing methods evaluations (both field tests and simulations). At this stage, we have determined that the two most common traits that burials display in radargrams are stratigraphic discontinuities and hyperbolic shapes.

Stratigraphic discontinuities are patterns of horizontal difference (or low amplitude reflections) representing the grave shaft in the surrounding sediments (see the break in the horizontal lines across the top of the lower images in Figure 21). They appear in most radargrams that intersect a grave but are most visible in radargrams that intersect a rectangular grave shaft at right angles. Traits are often most visible at the lowest depth of the grave.

Hyperbolic shapes (Figure 23) are convex shapes that appear in radargrams above and within rectangular grave shafts, particularly across the width of the grave. They are likely caused by the difference in physical properties between the material filling the grave shaft and the surrounding material, which causes the GPR waves to reflect from the bottom and walls of the shaft and concentrate in a curved shape above.

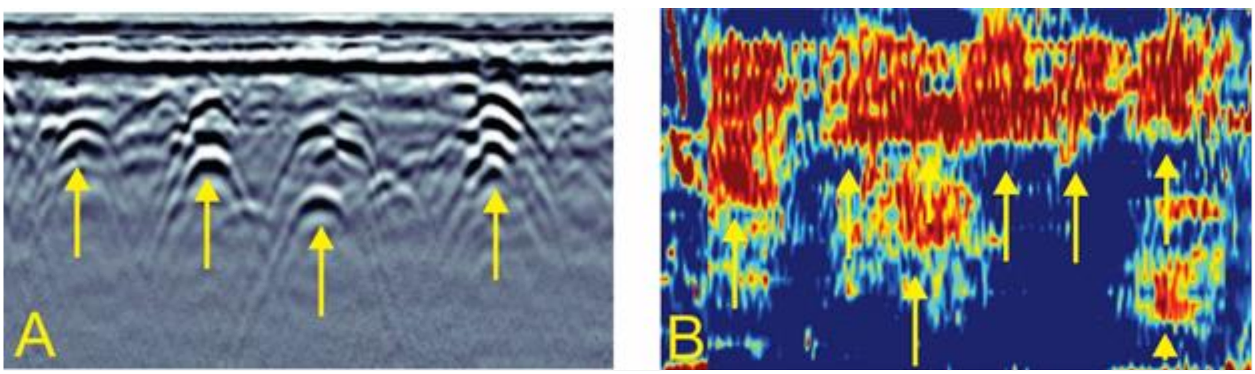


Figure 23. A) Examples of graves as observed in a radargram. Yellow arrows denote identified diffraction hyperbola. The difference between the areas in and above the diffraction hyperbola and the areas between the arrows (relatively homogenous background/lack of grave reflections) can be thought of as evidence of stratigraphic discontinuities. B) Amplitude map showing the same graves identified in A but in plan view.

Despite the identified challenges, we can note the following:

- In cemetery contexts, burials are frequently visible in amplitude maps as rectangular anomalies representing the grave shaft. However, there are known examples of burials that do not appear as clear anomalies in amplitude maps suggesting that identification should always be cross-referenced with radargram data.

- The most common traits of a burial in GPR are stratigraphic discontinuities and hyperbolic shapes. Our experience suggests that these traits are most visible when survey grids are oriented parallel/perpendicular to grave orientation, when possible.

In sum, there are several GPR signal patterns that are indicative of graves, but these vary and our knowledge of the range of variation is incomplete. The suite of potential traits that occur are affected by local geological patterns and burial treatments and contents. More refinement of our methods of interpretation will benefit the application of GPR to the identification of burials outside of cemetery contexts and in informal and clandestine locations.

8.5 Summary

This document has attempted to underline the importance of step-by-step and methodologically grounded interpretations of GPR data. Because of variable conditions, no single strategy can be applied to every context, and this will be reflected in the associated GPR technical report. For communities that are hiring outside specialists, the following is a list of information and items that should be included in a GPR technical report:

1. Map(s) showing the location of survey grids in relation to other features at the site.

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

3. A detailed methodology that explains how the data were collected, processed, and then interpreted. This should include an example of Raw, Processed and Interpreted radargrams and/or amplitude maps.

4. An explanation of interpretations, including annotations on radargrams and amplitude maps with precise descriptions and examples of patterns.

5. Explanation of “confidence” terms used in the report. These can include “probable”, “possible” or “likely”.

6. Maps locating the identified features in relation to visible surface features and location coordinates.

7. Copies of all forms of data should be included with the report for archival purposes. This includes a full set of collected and processed data files, as well as all radargrams and amplitude maps.

9. Magnetometer: Recommended Data Collection Procedures for Locating Unmarked Graves

Edward Eastaugh

9.1 Introduction

Magnetometer survey is one of several magnetic geophysical techniques that measure differences in the Earth's magnetic field and/or differences in the magnetic properties of the ground. These differences can occur for numerous reasons, including instances where the ground is disturbed, as is the case when a grave is dug and refilled. This is because topsoil (the layer of earth closest to the surface) usually has slightly higher magnetic properties than the underlying subsoil, as it contains more and different forms of iron minerals. When a grave is dug and refilled, the topsoil and subsoil are often mixed together, and as a result the soil in the grave shaft has different magnetic properties than the surrounding area. These differences are tiny and need specialized instruments to detect them (Figure 24). Metal detectors are not appropriate for this type of survey as they are not sensitive enough and usually only penetrate to a maximum depth of 30cm.

Identifying graves through magnetometer survey, like any remote sensing approach, is challenging. The potential success of a magnetometer survey will depend on a number of factors. The most important is the degree to which the fill of the grave differs from the surrounding subsoil. Usually, the difference is very small, so sometimes identifying the grave is impossible and other approaches are needed. In relatively shallow graves, a magnetometer might be able to detect pieces of iron in the grave, such as coffin nails or hardware, but it is usually impossible to distinguish these from other pieces of buried metal that occur as by-products of occupation over time. Magnetometer survey will therefore, in most instances, be used as a supplemental survey technique to ground-penetrating radar (GPR) to improve confidence in the results.

Magnetometer survey will also play an important role in situating the results of GPR, particularly in instances where large areas need surveying. This is because magnetometer survey is one of the fastest geophysics approaches available, which allows for large areas to be surveyed quickly. Magnetometer surveys can identify the remains or foundations of old buildings and other features that are remembered by survivors or identified in archival records but may no longer exist above ground. Locating where these buildings and features are on the landscape will be invaluable in helping to guide GPR investigations to areas of greatest potential.

Like most geophysical techniques, magnetometer survey does not disturb the ground. Indeed, most magnetometers are carried above the ground and are passive, meaning that they simply measure tiny changes in the Earth’s magnetic field rather than emitting energy into the ground to measure a response.

9.2 Planning

While magnetometer 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. Some instruments take readings more rapidly, while others might have multiple sensors, which can double or quadruple the speed of the survey. Generally, magnetometer surveys are most efficient when done by three people (one instrument operator and two assistants to move the survey ropes), though some instruments allow for fewer individuals. We estimate that a crew of three technicians can cover an area anywhere between half to a whole football field in one day, depending on conditions and instrument used.

There are a variety of magnetometers available 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. Fluxgate gradiometers (Figure 24) and alkali-vapour magnetometers are often preferred in archaeology, as they allow for rapid, high density data acquisition and many of the commercially available instruments allow for a set up with multiple sensors. Other instruments are also suitable but may be slower or more difficult to handle. Much will depend on what is locally available. The most important factors to consider are sensitivity and speed of the instrument. Instruments that are capable of rapid, high density data acquisition to a minimum of 0.1nT (nT= nano tesla, the unit of measurement of the magnetic field) are essential for grave detection.

Figure 24. Two of the more commonly used magnetometers used in archaeology. The Geoscan FM256 fluxgate gradiometer (left) and the Bartington Grad 601 twin sensor (Right) *Photo Credits:* E. Eastaugh (L) and P. Renouf (R)

9.3 Data Collection

Magnetometer survey is performed by carrying, pushing, or pulling a magnetometer back and forth within grids that have been laid out over the ground. Tapes and ropes are used to guide the operator in this process and to ensure the entire area is covered.

The recommended methodology for data acquisition will differ depending on the goals of the survey. As noted above, archaeologists often differentiate between two types of survey methodology: reconnaissance and formal. Reconnaissance 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). Formal surveys are used to cover smaller areas at higher resolution to map the distribution and number of individual features (e.g., graves) within them. Given the general rapidity of magnetometer survey compared to other remote sensing techniques, communities may wish to forgo reconnaissance survey and consider investigating the entire area with a higher resolution formal survey, once they have established that the approach is applicable.

9.4 Data Collection Protocols

9.4.1 Reconnaissance

- Survey grids should be laid out with a total station theodolite or GNSS/GPS

- Grid corners should be located with a GNSS/GPS to within 5 cm accuracy.

- A minimum point sample density of 0.5m x 0.25 m is recommended (e.g., readings recorded every 0.25 m along traverses spaced 0.5 m apart).

- Data collection within grids using either zigzag (Z-pattern/bi-directional) or parallel (unidirectional) traverses is recommended (Figure 25).

9.4.2 Formal

- Grids should be laid out with a total station theodolite or GNSS/GPS.

- Data collection within grids using parallel (unidirectional) traverses is recommended to reduce collection errors such as traverse striping and staggering.

- Minimum traverse spacing of 25cm with inline sample density of 12.5 cm or less (e.g., 6.25cm).

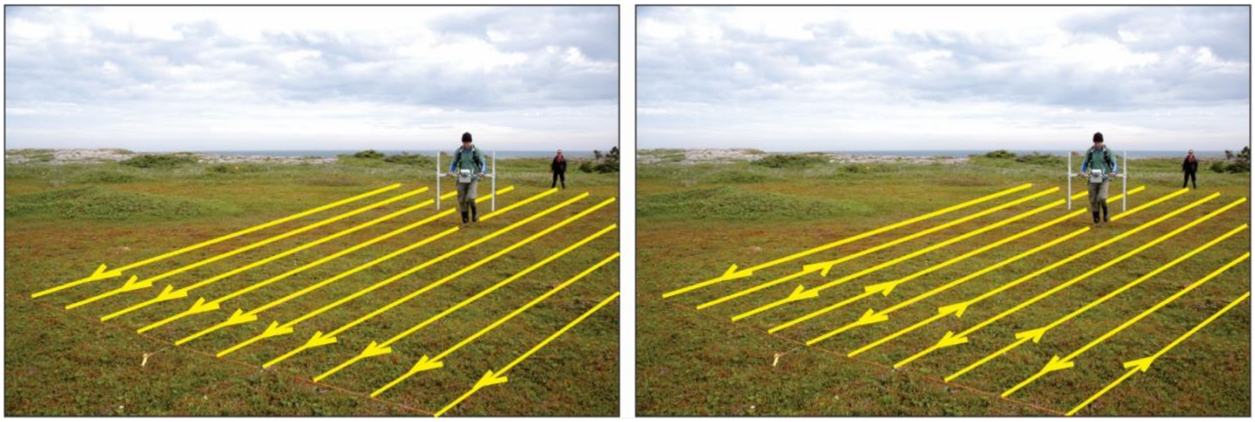


Figure 25. Magnetometer survey showing parallel (unidirectional) survey methodology (left) and zigzag (bidirectional) survey strategy (right)

While many magnetometer instruments can be configured to allow data collection with an integrated GPS, most 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, causing areas to be missed entirely. The CAA therefore recommends that all magnetometer surveys are conducted within grids. Common grid sizes for magnetometer surveys are 10 m, 20 m, and 30 m squared. It is sometimes helpful to conduct surveys within rectangular shaped grids to avoid inadvertently confusing the orientation during processing. However, some instruments do not allow for this, and errors can be avoided by accurate note taking.

Unlike GPR, targets of interest are best surveyed at approximately 30 degrees to their orientation (if known), as some processing functions can remove responses from buried features (particularly those that are linear) when crossed in line with their orientation. However, in practice, the alignment of features is often unknown prior to the survey. Grids are more often set up in relation to obstacles or field orientations on the ground. More importantly, as magnetometer survey is likely to be used alongside a GPR survey, it would be more expedient to use the same grid as the GPR survey, which should be set up perpendicular (90 degrees) to the orientation of the grave(s) (if known). 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.

9.5 Data processing, interpretation, and presentation

Once the survey is completed, the survey data needs to be processed in computer software to generate plots for interpretation and presentation. Options include commercial geophysics software (e.g., Terrasurveyor, Geoplot) and free open-source software (e.g., Snuffler). The ease of use and functionality will differ between choices.

The processed plots look very much like air photographs taken from above (Figure 26). Processing magnetometer data can require numerous steps as the Earth's magnetic field changes constantly, resulting in numerous natural effects in the data that need filtering out. Data collection inconsistencies are also common due to the sensitivity of the instruments. It is important that the processing steps are done in the correct order as each filter will affect subsequent steps.

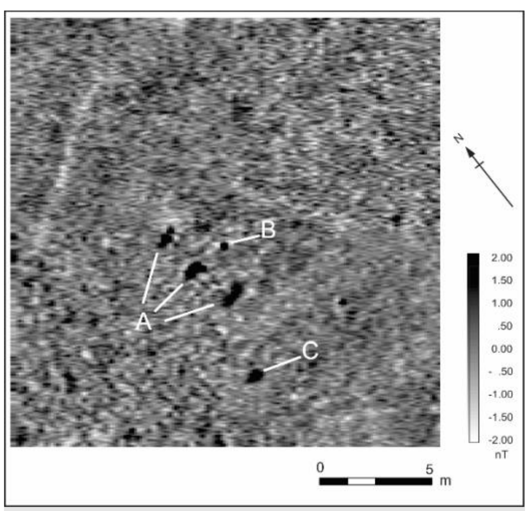


Figure 26. Example of gradiometer results showing the location of 3 unmarked graves of 19th century European sailors (A) in Mercy Bay, NWT. The results also identified the foundation of the original grave marker (B) and an archaeology test pit (C) from an earlier investigation.

Data processing should follow the sequence of steps recommended by the instrument manufacturer and software used. These might include, but are not limited to: 1) a review of the raw data, 2) clipping data to remove noise spikes that affect statistical calculations of subsequent processing steps, 3) neutralising major responses (e.g., fence lines and services), 4) removal of data collection defects (e.g., traverse stripping or staggered data), 5) iron spike removal to remove very large responses caused by near-surface metal (caution is needed as iron coffin fixtures and nails may be the only indicator of the presence of a burial), and 6) final enhancement of data plots including interpolation, which artificially increases the number of data points to give the data plot a smoother appearance (Figure 27).

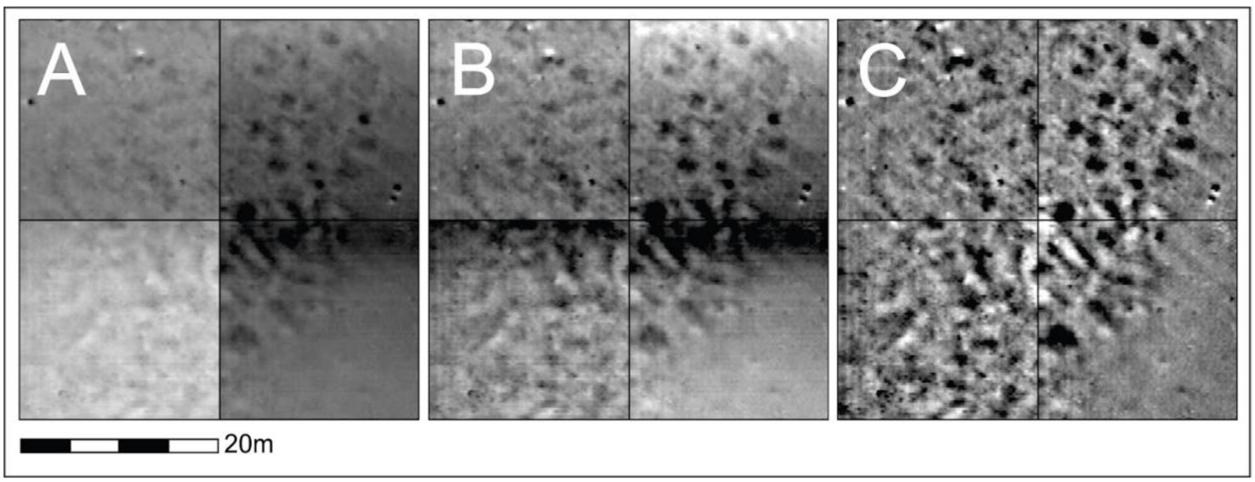


Figure 27. Example showing how some of the processing functions change and enhance the data plots to aid interpretation (Note: Processing terminology may differ between software). A: Raw results showing mismatch of responses between and across grids due diurnal variation (natural changes to the Earth's magnetic field during the day). B: Results after Zero Mean Grid function applied to help match grid data and C: Final results after “Zero Mean Traverse” and “clipping” applied to remove slope effects in data and to enhance the contrast of features of interest.

Magnetometer survey data can be difficult to interpret and should be done by trained individuals. For example, the shape and size of the magnetic response that results from a buried feature or object may look completely different to its actual form. A small iron object such as a nail results in a positive and negative magnetic response which is observed in the data as a black and white image, the shape of which depends on the orientation of the object (Figure 28) but none of which look anything like a nail. The size of the nail’s magnetic response will also be much larger than the nail itself and might measure up to one metre on the plot. Buried features, in particular metal pipes, or fences running along property boundaries can produce enormous responses that appear many metres wide, “washing out” any of the subtle detail that might be produced by graves and making the survey useless in those areas.

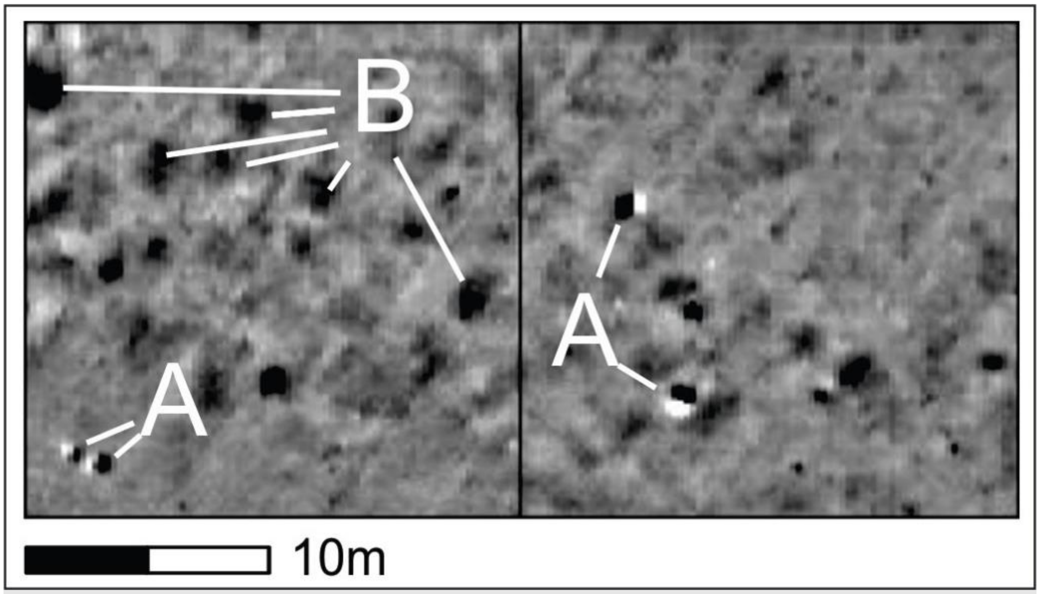


Figure 28. Example of gradiometer results with responses resulting from small iron objects buried in the soil (A). Note that while they are likely less than 10 cm in size, they appear over 1 m wide in the plot, almost as large as the archaeological pits (B) which were the focus of the survey.

Interpretation of geophysics results also inevitably includes 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 will be based on numerous factors such as shape and size of the anomaly, its magnetic response and prior experience. This is where having other sources of evidence, such as other remote sensing techniques 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 and explain the rationale for the interpretations.

10. Conductivity Survey: Recommended Data Collection Procedures for Locating Unmarked Graves

Edward Eastaugh, William Wadsworth and Jonathan Fowler

10.1 Introduction

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 29).

Figure 29. Conductivity survey with Geonics EM38Mk2, Grand-Pré, Nova Scotia
Photo Credit: J. Fowler

Identifying graves through conductivity survey is challenging and should be performed by specialists. 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.

10.2 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.

Government of Canada well records, which contain useful localized soil information, are here: https://open.canada.ca/data/en/dataset/c1a624a7-fbd4-4bc8-8e65-41b294443123

Government of Canada borehole data are here: https://open.canada.ca/data/en/dataset/15f4d926-0606-5d3f-9726-763ffa6b8c5f

Many conductivity meters have been configured so that they can estimate the vertical changes in the soil column, allowing you to evaluate the difference in the field.

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. 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 cover an area about half the size of a football field 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 during survey by identifying differences in the grave fill compared to the surrounding soil. These differences will be apparent relatively close to the 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 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 favored by archaeologists is the Geonics EM38. Geonics is a Canadian Company, so it will also likely be one of the easier instruments to access.

10.3 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 zigzag) traverses, where the operator walks back and forth along the transects. Zigzag traverses are often preferred as they cut the survey time in half, thereby saving time and money. However, some conductivity instruments (including the 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.

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 calibrating 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.

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 can mean that areas are 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, allowing any features of interest identified within them to be 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 (Figure 30). 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 visualization 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 organizing the data to enable data transfer between software programs can be complicated and takes time. The offset between recorded values and the location of features in the ground also needs to be taken into account.

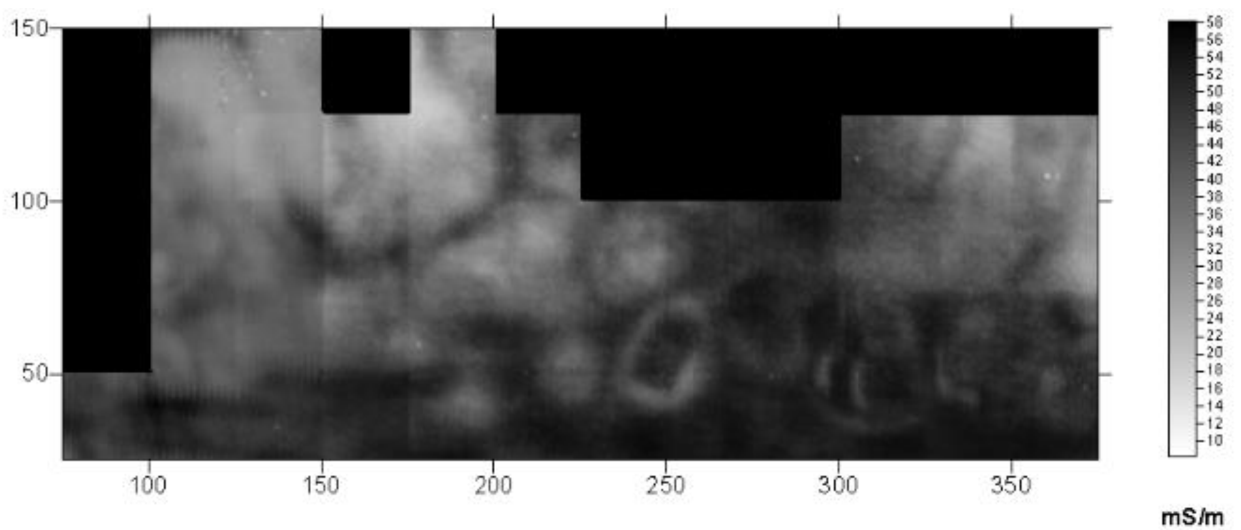


Figure 30. An example of conductivity survey results showing a series of plowed down house platforms, Hollywood Site, Mississippi
Figure from: Clay 2005, Conductivity (EM) Survey: A Survival Manual
https://www.researchgate.net/publication/242118324_Conductivity_EM_Survey_A_Survival_Manual)

11. Resistivity Survey: Recommended Data Collection Procedures for Locating Unmarked Graves

William Wadsworth and Edward Eastaugh

11.1 Introduction

Electrical resistivity techniques have long been used in archaeological and forensic contexts. Like other geophysical methods, this technique can produce both maps and profiles of an archaeological site, highlighting possible features or structures. It measures the ability of the Earth's near-surface (usually < 5 m in archaeology) to resist an electrical current moving through it.

A wide variety of instruments are available with different ways of conducting resistivity survey, however the core principles remain the same. The method works by sending an electric current, generated from a battery, into the ground via metal electrodes. The computer measures the voltage between any two electrodes and then calculates the resistance in ohm-metres (Ω m-the unit of measurement for electrical resistance) between these two electrodes. Once a measurement has been made from many electrodes, the specialist interprets the shape, character, and depth of any observed anomalies and determines whether they can be related to possible archaeological features. For example, metal objects conduct electricity well and can produce low resistivity values if they are large enough.

The physical properties of the ground, such as soil type and composition (e.g., sand, silt, clay), porosity, and ability to hold water, all affect the grounds' ability to conduct an electric current. The same is true for buried features such as walls or grave shafts. These will have different electrical properties depending on their physical composition. It does not matter if the resistance of the feature you are trying to identify (e.g., a grave) is higher or lower than the surrounding soil. It just needs to be different to be detectible.

Resistivity surveys have been used to locate graves in cemeteries. The technique is very good at identifying voids which have high resistivity due to the presence of air, as well as changes in sediment compaction and moisture levels indicating increasing or decreasing resistance, respectively. It is also well suited for high clay/conductive soils, environments that GPR often finds challenging. In cemeteries, some authors have found that high resistivity values denote grave shafts, while low resistivity values within graves may indicate metal (such as coffin plates or hardware). It is clear that graves may be represented by many different characteristics in resistivity data, so it is important to adapt the search and interpretation methods accordingly.

Here we present some key points to consider in resistivity surveys. Like the other techniques presented in this document, it is important to remember that resistivity surveys locate changes in the physical properties of the subsurface that could be related to cultural and natural disturbance events and **not the objects themselves, like human remains**. Therefore, interpreting this type of data requires caution, discretion, and expertise.

11.2 Planning

There are two main types of resistivity survey: 1) area survey that maps a large area with a focus on a particular depth range and 2) electrical resistivity tomography (ERT) that images a vertical transect through the earth along a profile (Figures 31 and 32). Both methods have advantages and disadvantages and the cost/time required can be different. In Europe, resistivity area surveying is quite popular and conducted with a variety of instruments including frames with variable probe arrays that are moved by hand (Figure 31) and electrode cart systems with fixed electrode widths. Such devices cover larger areas quickly and produce large area maps but have limited ability to document variation in subsurface properties across a range of depths. Conversely, ERT systems take longer and are more stationary. They require the operator to place a line or grid of metal electrodes and allow the computer to calculate the ground resistance over a period of time (Figure 32). Once those calculations are done, these electrodes are removed from the ground and planted at the next survey location (this can be done in a grid with consistent intervals). While relatively slow, ERT can produce both maps of sites and detailed profiles of the subsurface, with variable depths/resolutions depending on the electrode spacing (Figures 32 and 33). Both techniques have the potential to identify graves under reasonable conditions.

When planning for a resistivity survey, it is important to remember that the depth and resolution of the data collected is determined by the spacing of the electrodes. The more widely spaced the electrodes, the deeper the electric current can propagate through the subsurface. However, widely spaced electrodes result in lower spatial resolution. The maximum data resolution is directly equivalent to the minimum electrode spacing. For ERT surveys, widely spaced electrodes also result in more area being covered per line (possibly decreasing the time necessary to survey a site). Additionally, there are different electrode configurations (which electrodes are sending and receiving the current – Figure 34) that will result in different types of data collected. As a result of all these factors, many authors recommend shorter electrode spacing (~25 cm) to get as clear and detailed a profile/map of potential graves and grave shafts as possible. Regardless of this variation in data collection, how you design your survey will depend largely on the equipment you have available. Note that if you are likely to need the equipment for a relatively short period (weeks rather than years) renting will almost certainly be more economical than buying.

Figure 31. Area survey in progress. The Geoscan RM15 configured in twin probe array. Two pairs of probes are used. The first "mobile" pair are attached to the frame and moved systematically across a survey area to take measurements. The second "remote" pair, which record the background resistance, are out of picture at the end of the 50 m orange cable. The beam holding the two probes at the bottom of the frame can be modified to take up to 9 probes, allowing vertical profile measurements similar to an ERT survey. *Photo credit:* E. Eastaugh

Figure 32. Electrical resistivity tomography survey in progress. Profiling ERT equipment pictured in the foreground with IRIS Syscal Junior Switch-48 resistivity meter, marine battery, metal electrodes and cable. 48 electrodes were spaced 0.5 m apart spanning a profile of 23.5 m. Six 23.5 m profiles, spaced 1 m apart, were collected at a known cemetery. Dipole-dipole and Wenner electrode arrays were used to collect the resistivity profiles. In the background are different GPR systems. *Photo Credit*: W. Wadsworth

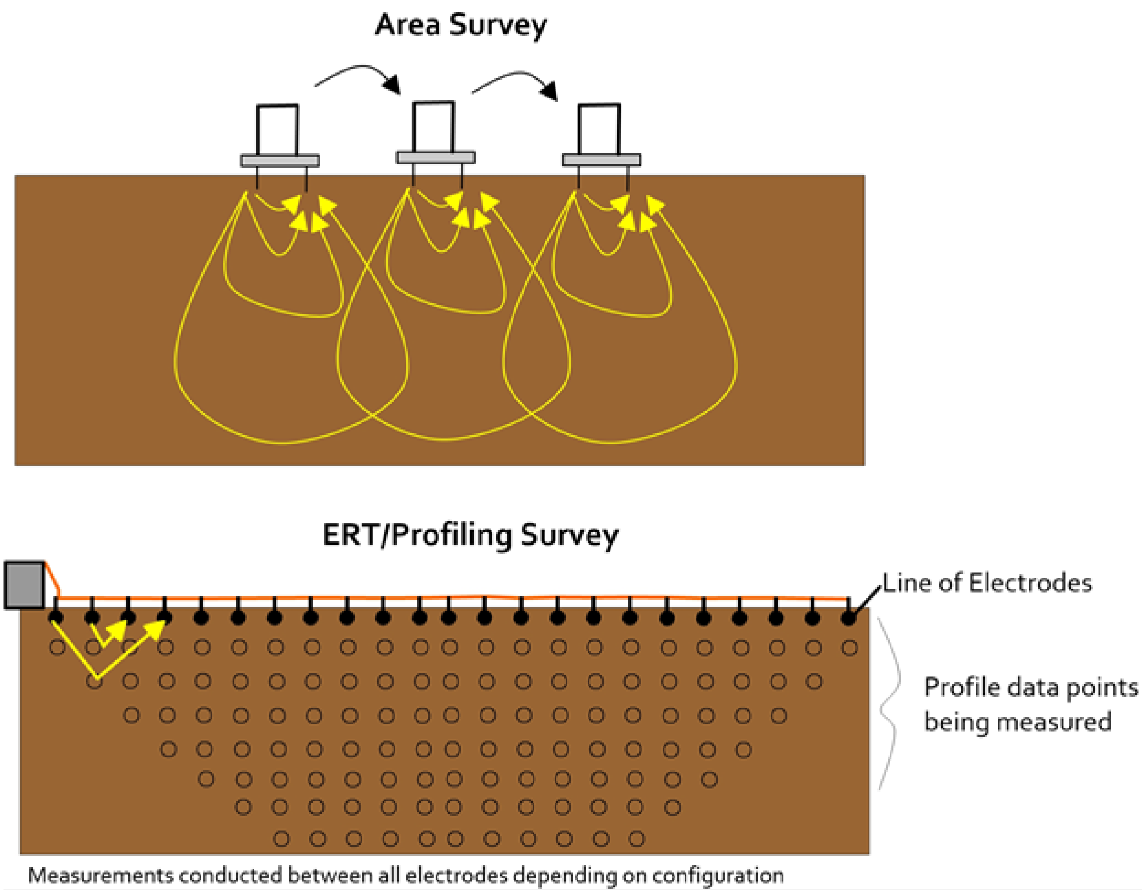


Figure 33. Schematic diagram of how both area surveys and ERT survey the subsurface. *Top:* Area surveys (also see Figure 31) send and receive electrical current from a fixed frame. Repeated measurements are taken by physically moving the frame to a new location to record the new data points. *Bottom:* Profiling surveys (also see Figure 32) send and receive electrical current from many electrodes that are manually placed along the ground's surface. The resistivity meter will send electrical current in various patterns between the electrodes to record a profile with many data points (o). This diagram shows the initial readings of a dipole-dipole ERT survey. To collect another profile, the entire system must be removed and placed at a new location. *Figure by:* W. Wadsworth.

It is also important to remember that resistivity is helpful in cases where other geophysical techniques (such as GPR) fail. Notably, resistivity is a reliable technique in high clay/saline environments and in areas with lots of obstructions and vegetation (*environments that typically prohibit GPR*). However, the technique is not effective in dry environments (where GPR excels). While resistivity will not replace GPR as the 'go-to' technique for locating graves (given its extensive setup and operating time), it remains a great addition to unmarked grave projects and an important technique in certain environments.

11.3 Data Collection Protocols

Data collecting protocols will vary significantly depending on the methodology and instrument used. Area survey systems (Figure 31) often have limited profiling capabilities, and thus have limited options for electrode configuration. Which configuration you use is determined by the location and characteristics of your target, field/environmental constraints on laying electrodes, and the practical limitations of your specific equipment. In ERT surveys, electrode placement (Figure 33) and how the current is transmitted between them has a significant impact on the resolution and sensitivity of the data collected. Common electrode configurations/geometries include Wenner, Schlumberger, pole-dipole, dipole-dipole, pole-pole, and gradient, all of which can be used for ERT/ profiling (Figure 34). Interested readers can learn about the different configurations here: [Surveys — GPG 0.0.1 documentation (geosci.xyz)](https://gpg.geosci.xyz). Dipole-dipole is used extensively for shallow geophysical work, such as archaeology.

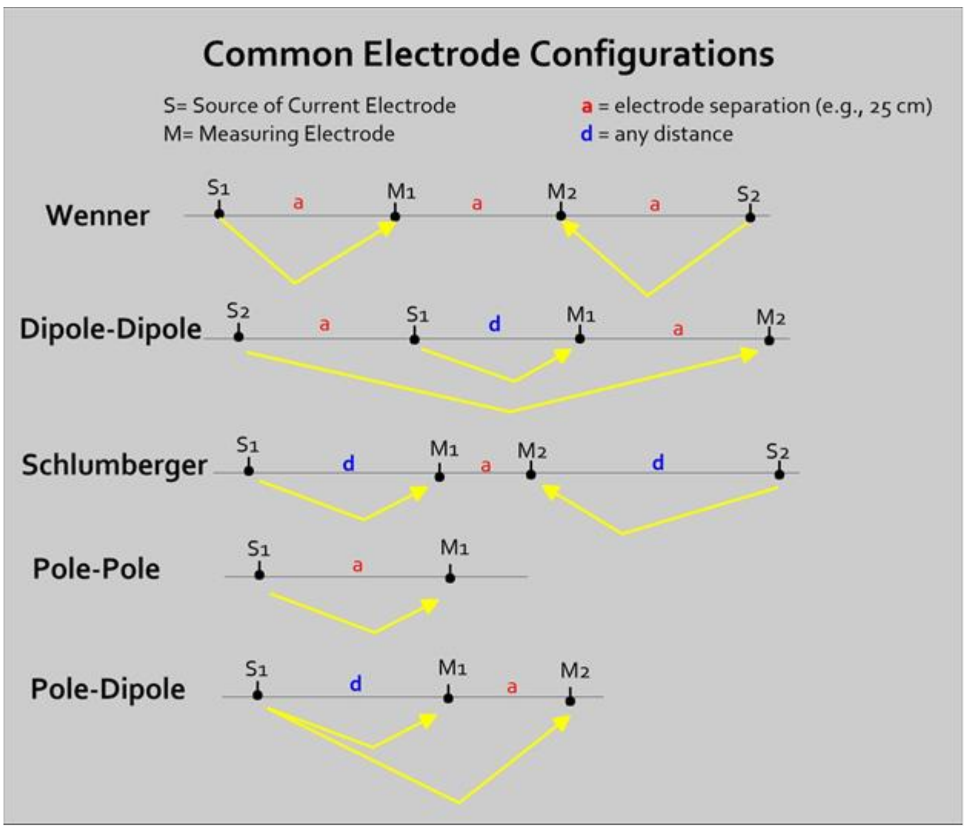


Figure 34. Common electrode arrays/configurations. Yellow lines denote the electrical current that transmits between a source and measurement electrode. The different patterns produce different types of resistivity surveys, some of which are better for profiling. Diagram remade from the open-source textbook, Geophysics for Practicing Geoscientists (https://gpg.geosci.xyz/).

For area surveys, grids are established over the area of investigation in much the same way as for GPR survey. For the Geoscan RM15 two pairs of probes are used, usually configured in a twin probe array. The first “mobile” pair of probes are attached to a frame and are moved systematically across a survey area (Figure 31). Also connected to the frame (by a 50m cable) is a second “remote” pair of probes that are left in a stationary position to record background resistance. Data points are collected by inserting probes into the ground at regular points along transects marked by tapes. To identify graves, we recommend taking readings every 25 cm along traverses spaced 25 cm apart. Transects can be walked bi-directionally (e.g., zigzag), if the instrument is left in the same orientation. This shortens the time needed to survey, though it is still relatively slow compared to other techniques. We estimate that it takes approximately 2 hours to survey a 20m by 20m or 400 m^2 area at this resolution. This process can be speeded up by connecting more probes to the mobile frame, though the resulting instrument is often clumsy to use and only works in ideal field conditions.

For ERT surveys, multiple electrodes are set up in an equidistant straight line across the ground (Figure 32). Often these are centered above the area or feature of interest. Depending on how many electrodes you have available, it is best to space them at either 25 cm (ideal) or 50 cm (acceptable) intervals. Each of these electrodes is connected to a cable that connects to the resistivity meter. The meter is pre-programmed with different electrode arrays that run resistivity tests between the electrodes. It’s important that the cables, electrodes, and meter are not touched or changed until it has finished its calculations. You may need to improve the initial contact resistance between the electrode and the ground by moistening the insertion point around your electrodes with water. You can also collect 3-D resistivity data by spacing electrodes in a grid pattern or collecting individual resistivity lines in a grid pattern. This is done much the same way you collect individual profiles. After you collect an individual line, you must manually move each electrode a specified distance to the next profile. This is a time-consuming process, and again it is best to limit the space between your profiles. Under optimal conditions, if you spaced each electrode 25 cm apart, and each profile 25 cm apart, you would collect very high-resolution data that could be used to identify potential graves. Given that it is often only possible to get a few profiles done in a day, you may wish to increase this distance to 50 cm or a metre. However, this will decrease resolution and possibly overlook graves.

11.4 Data processing, interpretation, and presentation

Once the resistivity survey is completed, the data needs to be processed in computer software that generates plots and profiles for interpretation and presentation (Figure 35). Interpretation is complex and best done by specialists. File outputs are often xyz files in ASCII format. Like other geophysical techniques, data processing is usually undertaken to reduce noise (interference) and improve interpretability. Data can be presented and processed in 1-D, 2-D, or 3D forms. To transform resistivity data into 2-D profiles (and then plotted into 3-D grids), the data must undergo a process called *inversion*. Most commercially available inversion software (such as Res2DInv) will automatically calculate the best resistivity model possible for the electrode configuration with minimum user input. Once this is done, processed resistivity data can be gridded and visualized in different software options such as Surfer or a GIS.

Resistivity survey data is often difficult to interpret. While more robust than other forms of geophysical data, it is often more challenging to interpret than GPR data. As a result, interpretations should be made by trained specialists, and step-by-step explanations of the different processes and logic models applied to the data should be outlined. For example, grave shafts/pits may have low resistance when their pores are filled with fluid and sediments are less compacted. However, if the structure of the grave is intact, or a coffin is present, graves may appear as highly resistant due to the air inside the coffin (air has high resistance). There are different markers for a grave in resistivity data, therefore (as always) it is best to include other types of remote sensing data and community information to inform interpretations.

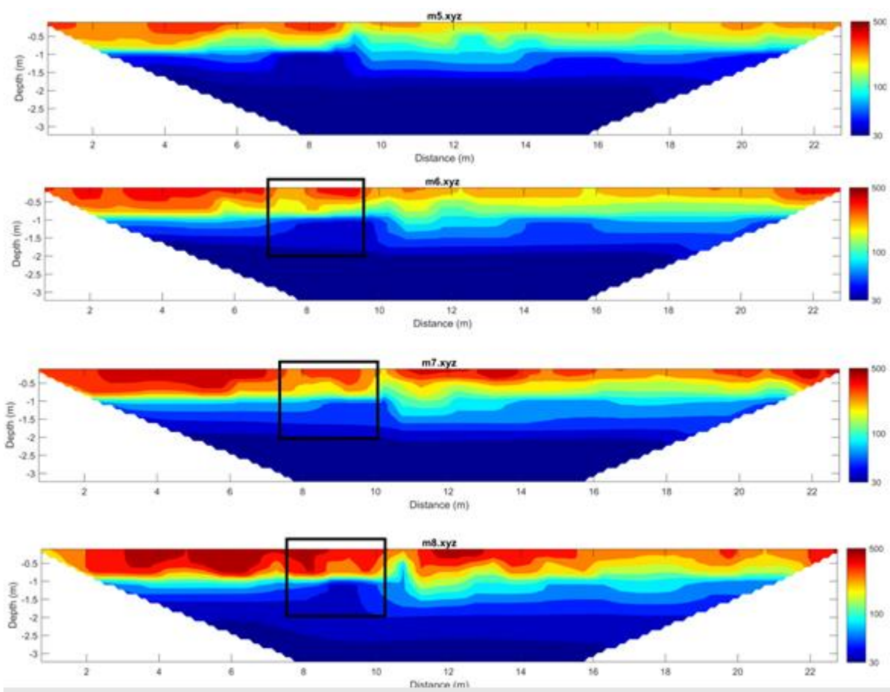


Figure 35: Four 24 m resistivity (ERT) profiles spaced one meter apart following inversion. Highlighted is an identified grave in the profile spanning 2 m (or 3 profiles) that shows a range of Ω m values and a rectangular shape. This specific feature was also surveyed with GPR and the two datasets both suggested a grave was located at this location.

12. Recommendations for Reporting Remote Sensing Results

Edward Eastaugh

12.1 Introduction

The communication of remote sensing investigation findings typically proceeds with a formal presentation of results and a written final report to communities. Given the complex nature of locating missing children, we suggest caution in the release of preliminary results of remote sensing work (see Communication of Remote Sensing Investigation Results in the CAA's Guide Unmarked Graves Investigations).

12.2 Written Reports

A final report should include the following:

- A brief site description indicating underlying soil types and geology, ground conditions and vegetation, description of built architecture, past disturbances including previous archaeological investigations and known underground services that might impact the results.
- The survey methodology should provide a description of the instrumentation and survey procedures used. This will vary between instrument type but should include parameters such as 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.
- Photographs, if appropriate, of each survey area showing the ground conditions.
- Copies of unprocessed raw data for archiving.

- 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.

- Depth estimates of features should be included with GPR and inversion ERT data.

- The interpretation should distinguish anthropogenic (human activities) 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 colour 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.

12.3 Oral Communication of Results

Oral summaries are a helpful addition to written reports, when sharing results with communities. Keep in mind the following when planning oral presentations:

- Both in-person and video presentations (live or recorded) can be effective

- It is important to ensure that mental health supports are in place when sharing results in person, and video presentations should point people to available supports that they can access if needed

- As much as possible, community presentations should avoid jargon. Where it is impossible to avoid technical terms, be sure to define them.

13. Glossary

Altimeter	An instrument used to measure the altitude of an object above a fixed level
Amplitude	The maximum departure of a wave from the average value; the length and width of radio waves
Amplitude Maps	An image produced by rendering a horizontal slice through a 3D dataset
Anomaly	Something that is different from what is expected, an irregularity
Anthropogenic	Something resulting from human activity
Array	An ordered series or arrangement
Barometric Altimeter	An instrument measuring altitude by calculating the location's air pressure (air pressure decreases as altitude increases)
Baseline	Data or information obtained prior to or at the onset of a study that serves as a basis for comparison with data collected at a later point in time; in survey this means the main line of a grid that observations and points are measured/recorded in relation to
Borehole log	A detailed record of the specific ground conditions and their location within a borehole
Cartesian	A coordinate system that transfers data points on a sphere (e.g., the Earth) onto a 2D surface (e.g., a map). Once on a 2D map, grid reference numbers on x and y (or East-West and North-South) axes can be used to locate specific places or objects on the map
Calibration	The process of configuring an instrument to provide results within an acceptable range

Conductivity	The ability of a material to conduct an electrical current. It is the reciprocal of resistivity
Datum	A fixed starting point from which all measurements are taken
DEM	Digital Elevation Model: a computer-generated representation of the bare ground surface excluding trees, buildings, and any other surface objects
Electromagnetic Wave	A wave that is created as a result of vibrations between an electric field and a magnetic field
Electrode	A conductor that makes contact with a non-metallic part of a circuit (e.g., the soil)
Feature	In archaeology a feature is physical evidence of past human activity that is not portable, e.g., a grave, building foundation or wall
Geophysics	An interdisciplinary physical science that applies knowledge and techniques of physics, math, and chemistry to understand earth's environmental and structural phenomena
Geophysical	Relating to the physics of the earth
Gimbal	A pivoted support that permits rotation of an object about an axis
GIS	Geographic Information System: a type of database containing geographic data combined with software tools for managing, analyzing, and visualizing those data
GNSS	Global Navigation Satellite System: a constellation of satellites that broadcast their location in space and time to ground receivers. Receivers can calculate the precise location of a point of interest based on the distances to 3 or more satellites.
GPR	Ground Penetrating Radar (GPR) is a form of remote sensing that works by sending electromagnetic (EM) waves from an antenna into the ground at different

	frequencies to detect differences in soil moisture and compaction
GPS	Global Positioning System: is one of a number of satellite constellations that fall under the umbrella term GNSS. GPS and GNSS are often used interchangeably.
Igneous	Relating to or involving volcanic processes
Interpolate	Interpolate, in the context of geophysics, is a data processing function that removes or (usually) increases the number of data points to give the resulting image a smoother appearance.
Inversion	A reversal of position, order, form, or relationship
Magnetometry	Measures differences in the Earth's magnetic field and/or differences in the magnetic properties of the ground
Odometer	An instrument used for measuring distance of a moving vehicle or machine
Point Cloud	A set of data points in space within a defined coordinate system
Polarity	The orientation of magnetic poles in space
Profile	In archaeology, a profile is a vertical cut through the ground, in which the soil layers are visible. In geophysics, a profile is a visualization of the subsurface properties of a vertical "slice" through the ground. For example, GPR and Resistivity data can be viewed as profiles.
Radargram	A visual representation of the combined reflected electromagnetic waves from a radar survey. A radargram is a GPR profile
Reconnaissance	The act of exploring; using remote sensing this means roaming over a target area looking for signals in the interface
Resistivity	Electrical resistance to the passage of a current (the reciprocal of conductivity)

Stacking	The process of averaging a set of repeated instrument readings in order to reduce noise and improve interpretation
Theodolite	A precision optical surveying instrument for measuring angles between designated visible points in the horizontal and vertical planes
Total Station	A survey instrument that combines the functions of a theodolite with a transit level and electronic distance meter (EDM)
Transect	A straight line or narrow section through an object or natural feature on the earth's surface along which observations are made or measurements taken
Transit Level	An optical surveying instrument that consists of a telescope with a built-in spirit level that is mounted on a tripod. Used to establish a straight reference line, measure horizontal and vertical angles and measure distances.
Velocity	The speed at which something moves in one direction, calculated by dividing distance moved by time taken to complete the movement. Often expressed in m/s (metres per second)

14. Bibliography

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