GPR Applied to Archaeological Investigations for Transportation Projects in California, Kansas, and Missouri

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Abstract

The ground penetrating radar technique is a preferred non-invasive technique to screen sensitive areas for human remains and targets of archaeological interest. While geophysical methods are no substitution for established archaeological field protocols, recent advancements in instrumentation and processing software allow large areas to be screened in a relatively short amount of time, compared with traditional archaeological fieldwork.

Case histories will be presented from California, Kansas, and Missouri demonstrating the application of ground penetrating radar techniques applied to various archeological investigations. 2D GPR data were acquired in the City of Leavenworth to screen for unmarked burials outside the recorded boundaries of a late 19th/ early 20th century cemetery that will lie within a proposed right-of-way. A 3D GPR screening of a proposed road expansion was conducted to screen a sensitive property believed by some to be the resting place of a 19th century freed slave. GPR, magnetic, and electromagnetic techniques were utilized at a portion of the Los Angeles Crematorium slated for MTA tunnel development.

Introduction

Most transportation engineers rely on some fashion of archaeological impact report when designing new transportation right-of-ways or expansion. Large transportation projects including areas with historical significance or sensitivity may not be planned with adequate budgetary concerns for detailed archaeological excavation. This generally involves a detailed historical documentation research, when available, and may require careful excavation. A properly planned geophysical survey is a cost-effective means of screening these sensitive areas prior to earthwork or excavation. Three case histories are discussed highlighting projects where a geophysical survey was incorporated to screen proposed right-of-way alignments for unmarked burials.

Greenwood Cemetery

In May of 2003, a geophysical investigation within the Greenwood Cemetery in Leavenworth, Kansas was requested by Bucher, Willis & Ratliff Corp. BWR's Limit Street improvement proposal indicated that the southern edge of the roadway would need to be expanded to accommodate increased traffic associated with recent nearby development. Part of the proposed expansion area lay within the northern perimeter of Greenwood Cemetery.

Historical data from the cemetery suggests that the property was in service for over one hundred years, with the most recent headstones indicating the cemetery had closed in the 1950's. Representatives from city government and historical societies recalled that the markers for many graves have been moved without obtainable documentation. Also, at various times throughout the last century, relatives of those interned at Greenwood were moved to perpetual care facilities, again often without records indicating who, or when, those graves had been moved. Therefore, there are many headstones currently in place at the existing cemetery that do not properly represent a burial site. There was also a concern that there may be graves at the cemetery without markers. Bucher, Willis & Ratliff contracted GEOVision, Inc to screen this zone for unmarked burial sites.

Ground Penetrating Radar (GPR) was chosen as the primary tool of geophysical investigation for this project. GPR has been used for a number of engineering, environmental, forensic, and archeological applications and was considered to be the best tool for this particular task, as it responds to both buried remains and the disturbed soil associated with the burial. The technique is non-destructive and non-invasive, to minimize impact to the survey area.

The ground penetrating radar system used for this project consisted of a SIR-10B with a 400MHz antenna manufactured by Geophysical Survey Systems Inc. Short duration electromagnetic (EM) pulses are transmitted via a ground-coupled radar antenna into the subsurface to detect changes in the electrical properties of the soil. These changes can be the result of disturbed sediments, an object or void beneath the surface, or increased moisture content of the soils. As the EM waves propagate through one medium into another, the EM pulses are reflected from electrical discontinuities in the subsurface back to a receiving antenna, much the same as sonar or ultrasound. The computer controlling the GPR measures the time it takes for the EM pulse to be transmitted downward into the subsurface and then reflected back to the surface. The propagation velocity of these EM waves in the subsurface is determined by the dielectric properties of the medium.

Upon inspecting the site, where most of the gravestones faced east, it was decided that lines oriented north to south would maximize the probability of crossing over any unmarked graves. To further increase the data coverage, line spacing was set at 2.5 feet between the lines, so that any graves set at an odd orientation would also be crossed. Normally before conducting a GPR survey, an established grid is marked on the ground with surveyors paint. However, due to the size of the site, and numerous grave markers and trees, an alternate method was used. Using the northern chain link fence as a baseline, the northern edge for the survey grid was marked using surveying paint at five foot intervals. The southern edge of the grid was measured 70 feet from the fence and marked with stake chasers such that the survey marks could be aligned. For each GPR line, a surveyor's tape was stretched between the two endpoints, and used to maintain a straight pathway. North-south oriented lines were collected with the tape exactly on the endpoints, while south-north lines were collected between the endpoints.

The location of this survey grid and all significant surficial features were later surveyed and are shown on the attached site map (Figure 1).

Figure 1: Site Map with Geophysical Interpretation – Greenwoods Cemetery, Livermore, KS

Data collection

GPR data were acquired semi-continuously as the antenna was slowly hand-towed along north to south survey lines spaced 2.5 feet apart (Figure 2). Data were collected at 60 scans per second; giving an average data coverage of about 60-80 scans per foot (5-6 data points per inch), depending on how fast the antenna was being pulled. GPR data was also collected along several east-west profiles adjacent to the chain link fence. Control points were placed on the GPR records at 10-foot intervals using a marker switch on the antenna. As the antenna was being towed along the survey lines, the GPR data were viewed in real time on the SIR-10 color monitor to maintain acquisition quality. All GPR field records were appropriately annotated with line name and station range and saved to the SIR-10's hard disk for later processing. All field copies of GPR data are archived, retained in the project files and forwarded to BWR.

There are a number of potential challenges interpreting GPR data collected in this type of environment. Interpreting radar records requires that the data be reasonably free of electronic noise, both instrument and site-specific. Of particular concern for this study was the elevated moisture content of the soils after the heavy downpour of rain the previous night. Attenuation of the GPR signal is related to soil conductivity, which is primarily a function of clay content, moisture content, and dissolved solids in the pore water. Small percentages of clay in subsurface soils can rapidly increase the attenuation of GPR signals. Water-bearing soils or clays in soils reduce the efficiency of GPR to adequately image deep and/or subtle features. Another issue derived from the numerous trees on the property. A tree root can be seen as a strong reflector in the GPR data, strong enough that it may mask the presence of a deeper subsurface feature such as a grave. Also, the presence of tightly-packed or branching roots can actually be misinterpreted as a grave-like anomaly. Care was taken to compare all noted GPR anomalies against the surveyed site map, to isolate areas where tree-root interference might be significant.

Grave identification with GPR

Identifying graves in a GPR record can be a complicated process. A number of different identifying patterns were looked for, including hyperbolic diffraction curves, subsidence features, or possible indication of preferential moisture flow through disturbed soil.

When a propagating EM field encounters a continuous feature (such as an interface between two different soils, or between soil and bedrock), it will be reflected back to the surface and imaged as a lateral feature. When the same EM field encounters something less laterally-consistent, such as a grave buried within the soil, or a tree root, the EM energy will be diffracted and imaged as a hyperbolic reflection (Figure 2). These diffraction hyperbolas mark the edges or top of a target (such as the tops or corners of a casket or sides of a vault) are the primary identifier used to locate grave-like anomalies.

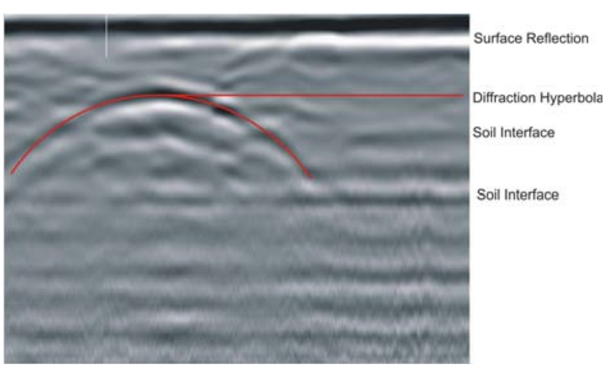

Figure 2: Example GPR Profile Collected at Greenwoods Cemetery Exhibiting

Hyperbolic Diffraction

Subsidence features were not unexpected for some of the older graves. With time, wooden caskets may have collapsed under the weight of the topsoil, eliminating any diffraction hyperbolas that normally would be associated with a casket. However, the disturbed soil might be shown as a depression in the lateral soil. A third GPR anomaly that might be indicative of a grave would be a distorted GPR signal due to a localized increase in moisture content. These types of anomalies are difficult to classify as being “grave-like” anomalies because they could be a result of general subsurface soil stratigraphy (soil structure).

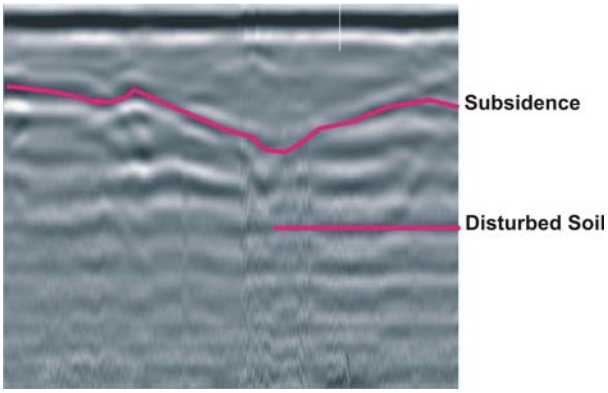

Figure 3: Example GPR Profile Collected at Greenwoods Cemetery exhibiting Subsidence and Disturbed Soil Features

For the purposes of this survey, it was assumed that the graves would be between 3-7 feet in length, and thus should intersect more than one GPR traverse. Locations of all GPR patterns were noted and sorted by type (hyperbola, subsidence, distortion of signal, and roots) and plotted as XYZ files and input as a layer on the AutoCAD drawing. Localized anomalies were given less “weight” than anomalies that were laterally consistent across several GPR lines. Using this identifying scheme, the GPR method was able to successfully locate a number of graves marked by a headstones, as well as a number of subsurface anomalies that could be interpreted as graves, but have no accompanying marker.

Figure 1 shows a composite map of all subsurface anomalies located on the GPR grid. Anomalies believed to be caused by graves are marked in black and denoted by blue rectangles. Anomalies believed to be caused by tree roots are marked in green and denoted by small green dots. Subsidence features are marked in red and have the symbol “X“.

There are two regions of densely-distributed GPR anomalies marked on the interpretation maps as A-1 and A-2 and shaded in grey. This area was relatively clear of trees or grave markers. Most likely these anomalies are the result of roots from excavated trees or large cobbles. However, it should be noted that these anomalies could be caused by unmarked graves, or a combination of graves, roots, and/or cobbles.

There was no geophysical evidence of unmarked graves in the area ten feet immediately south of the chain link fence. This area was previously designed as a pathway or road for the cemetery, and there is no indication from the geophysical data that graves are located in that region. GPR anomalies were noted in the northwest corner of the lot, but are believed to be the result of numerous tree root systems. Based on the CAD maps supplied by BWR showing the proposed road expansion, this area falls into the zone that will be occupied by the future retaining wall. Any excavation or construction more than 10 feet south of the chain-link fence was interpreted as likely to encounter graves, both with and without markers.

Reputed Freed-Slave Grave, Kansas City, MO

A geophysical survey was conducted in January of 2005 at a residence in Kansas City, Missouri. The purpose of the geophysical survey was to screen a portion of the property for a potential unmarked freed slave grave. A historical documentation search indicated that a possible informal burial site lay in the path of a proposed roadway expansion right-of-way.

To demonstrate the effectiveness of the technique, several GPR profiles were collected over burial locations at a nearby cemetery to demonstrate the ability of ground penetrating radar to image graves in similar soils. GPR was successful in locating graves both with and without an accompanying marker. However, depth of penetration was relatively poor (saturated clays limited the ability of the GPR to image deeper than 4 ft).

GPR equipment used during this investigation consisted of a GSSI SIR-3000 GPR system with a 400 MHz antenna. Data were collected as the operator walked along east-west (E-W) and north-south (N-S) survey lines spaced 1 feet apart, using the 2 foot grid endpoints for lateral control. GPR data were acquired semi-continuously (32 scans per second), as a 400-MHz antenna was hand-towed along the survey lines. A surveyors' chain was used for spatial control along each profile.

Data was processed in the field using commercial software, and further processed using a combination of commercial and in-house processing programs. Individual 2D profiles were processed before being combined and resampled into 3D time slices. A 12-inch slice was generated for every 6 inch interval. Figures 4 and 5 are sample GPR volume slices. This dataset was obviously affected by cultural artifacts (the linear GPR anomalies are interpreted as being utilities) and clutter, a condition caused when there are many objects of various sizes, shapes, and materials (such as cobbles within clay of variable moisture content). However, the specific area of concern was relatively free of artifacts, and after reviewing the historical documentation in conjunction with the results from the GPR investigation, it was determined that no further archaeological excavation would be necessary.

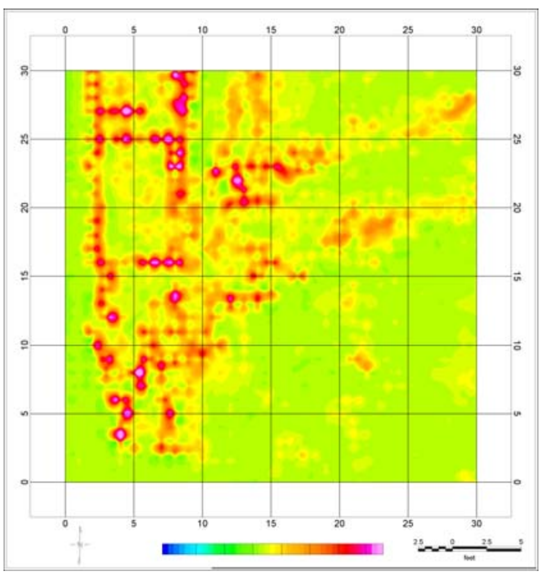

Figure 4: GPR Volume Slice 6-18 inches, Brighton Ave, Kansas City, MO

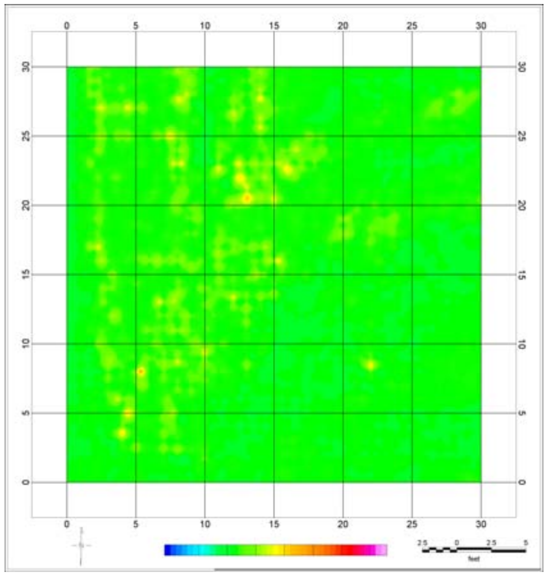

Figure 5: GPR Volume Slice 24-36 inches, Brighton Ave, Kansas City, MO

Los Angeles Crematorium

During initial excavation for the proposed $760 million Gold Line Eastside Extension in Los Angeles, California, construction halted when workers uncovered what appeared to be human remains. Remains were not wholly intact (i.e. medically-amputated limbs), and an emergency archaeological investigation was ordered. The archaeological investigation conducted by Cogstone Resource Management indicated that metallic plot boundaries (stakes), stone markers and bone fragments had been recovered, as well as a partially-intact wooden casket. An environmental impact report dated 1992 described the construction area as not having been used for burial of remains. The archaeological consulting firm requested a geophysical survey in the project area in an effort to locate any other similar targets, if possible.

The geophysical investigation was conducted in August 2005 at the Los Angeles Crematorium in Los Angeles, California. The purpose of the geophysical survey was to screen a portion of the property, approximately 300 x 60 ft, for unmarked graves or remains. Techniques used during this investigation included the ground penetrating radar (GPR), magnetic, and electromagnetic (EM) methods.

Data collection and techniques

Ground penetrating radar (GPR) was selected as the primary geophysical technique for this investigation. GPR equipment used during this investigation consisted of a GSSI SIR-3000 GPR system with a 400 MHz antenna and attached survey wheel. At typical sites in southern California, depth penetration of a 400-MHz antenna is limited to about 3 to 5 feet, whereas a 200-MHz antenna may reach as deep as 5-10 feet, depending on site conditions. However, the 200 MHz antenna has less resolution than the 400 MHz antenna. GPR data were collected with the SIR-3000 as the operator walked along east-west and north-south survey lines spaced 1-2 feet apart. GPR data were acquired semi-continuously (12 scans per foot), as a 400-MHz antenna was hand-towed along the survey lines. The attached survey wheel was used for spatial control.

The magnetic and electromagnetic instruments were used in an attempt to locate steel plot boundary markers. The magnetometer used during this investigation consisted of a Geometrics G858 optically pumped cesium-vapor magnetometer (G858). This instrument measures the intensity of the earth's magnetic field in nanoteslas (nT) and, optionally, the vertical gradient of the earth's magnetic field in nanoteslas per meter (nT/m). The vertical magnetic gradient is calculated by measuring the total magnetic field with two sensors at different heights, subtracting the top sensor reading from the bottom sensor reading, and dividing by the sensor separation. Buried ferrous metallic objects give rise to anomalies in the earth's magnetic field. These anomalies are generally dipolar with a positive response south and a negative response north of the object. The dimensions and amplitude of a magnetic anomaly are a function of the size, mass, depth, and magnetic properties of the source. Magnetometers can typically locate a vertical metallic stake to depths of about 6 feet providing background noise levels are not too high and the target is not extensively corroded. Larger metallic objects can be located to greater depths. Magnetometers are not able to detect nonferrous metals such as aluminum or brass. Measurements of the earth's total magnetic field and vertical magnetic gradient were made at 0.1-second intervals as the operator walked along west to east and south to north (W-E and S-N) survey lines spaced 5 feet apart. The 0.1-second sampling interval resulted in an average station spacing of about 0.5 feet.

EM equipment used during this investigation consisted of a Geonics EM-61 high-resolution digital metal detector (EM-61). The EM-61 is a high-resolution, deep sensing, time domain EM metal detector. The EM-61 has a single transmitter and two receiver coils. The bottom coil is the transmitter during the current on-time and receiver during current off-time. The top-coil, mounted 40 cm above the bottom coil, is a receiver coil only. The transmitter and receiver electronics controls are mounted in a backpack and a hand-held data logger is used to store field measurements. During operation a half-duty cycle waveform is applied to the transmitter coil. During the off-time the receiver coils measure the decay of eddy currents, in millivolts (mV), produced in subsurface metallic objects by the pulsed primary EM field. The top coil is gained in such a manner that the instrument response to a metallic object lying on the surface will be approximately equal at both the top and bottom coils. The effects of surface debris can, therefore, be suppressed by calculating the differential response (subtraction of the bottom coil from top coil response). Positive EM-61 anomalies centered over the source are typically observed over buried metallic objects. Above ground metallic objects will often give rise to a negative differential response, as the top coil response is larger than the bottom coil response.

Results

Color-enhanced contour maps of GPR 3D plan view, vertical magnetic gradient response, and EM-61 bottom coil data are shown in Figure 6, 7 and 8, respectively. The color bar indicates the amplitude of the measured quantity with the blue tones indicating average "background" values of the measured quantity and green and red tones representing high amplitudes. Many anomalies in the EM data were field checked to determine if a source of metal at the surface caused the anomaly. A number of surface metallic features, such as the fence and aboveground piping caused anomalies in the geophysical data. There are several linear EM anomalies interpreted as being caused by buried active or abandoned pipes. The pipes were traced using an EM utility locator.

A sample 2D GPR profile is presented as Figure 9. This figure is fairly representative of the entire data set collected at this location. The soil in this profile appears to be fairly disturbed, and shows many isolated anomalies appearing as hyperbolas in the unmigrated GPR record. The sheer number of these anomalies, and the frequency with which they appear in the GPR data, indicates that the soil is either non-uniform fill, with many cobbles, or containing debris or remains fragments throughout the upper 2 ft of soil. However, even the “clutter” encountered during this survey was of value: ongoing archaeological investigations for this proposed rail alignment have recently uncovered over 100 stone markers indicating Chinese burial sites.

Due to the unexpected discovery of partial human remains on the property, MTA was set back eight weeks and $200,000. These markers had been moved from their proper location and were not currently marking a burial location. For sensitive sites such as these, the recommendation of the authors is that any appropriate geophysical investigation be performed prior to any invasive testing or construction activities. After completion of this study, representatives from MTA requested a short letter report providing suggestions for future archaeological investigations. Some months later, Cogstone Resource Management was awarded a project whose RFP specified many of the suggestions provided as a result of the LA Crematorium project, including GPR screening.

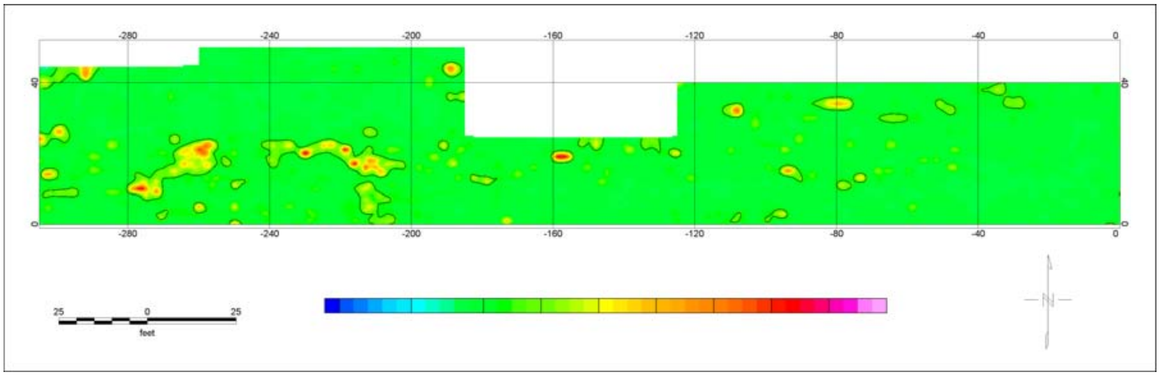

Figure 6: Sample GPR Volume Slice (24-28 in) Collected at the LA County Crematorium.

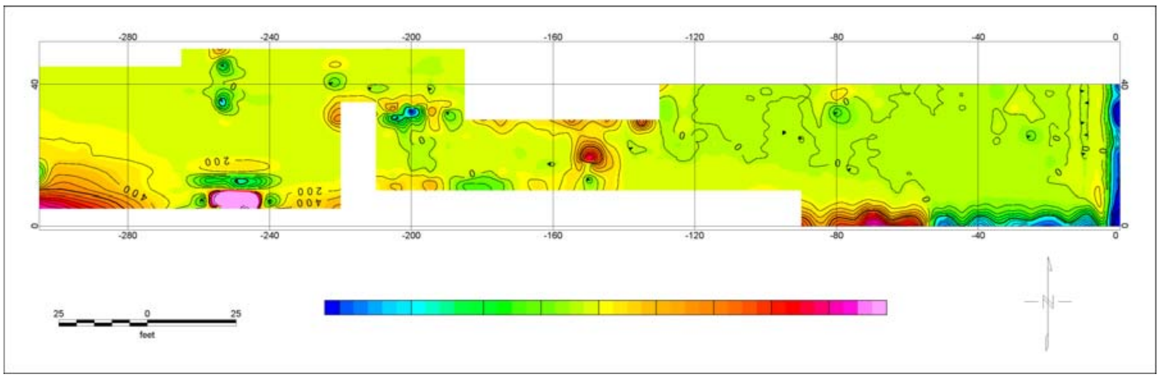

Figure 7: Vertical Magnetic Gradient Response, LA County Crematorium

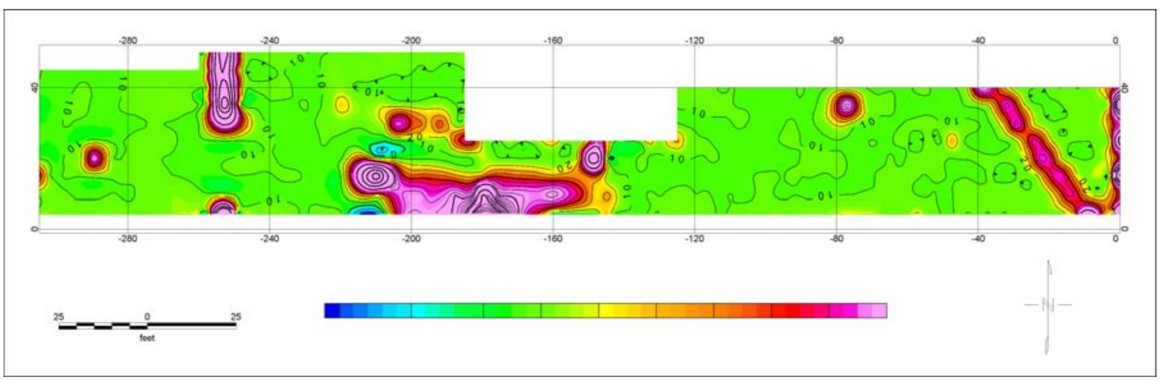

Figure 8: EM-61 Differential Response, LA County Crematorium

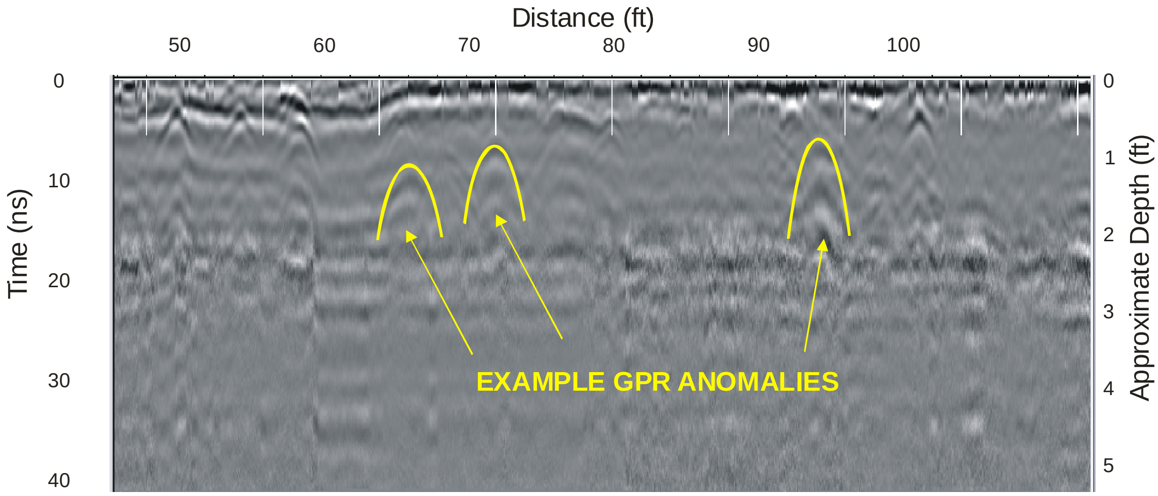

Figure 9: Sample 2D GPR Data Collected at the LA County Crematorium

Conclusion

The ground penetrating radar survey conducted at the Greenwood Cemetery in Leavenworth, Kansas located marked and unmarked graves. Soil moisture content and tree roots may mask subsurface anomalies. Anomalies deriving from tree roots, subsidence structures, and graves were located and mapped appropriately on the attached site maps. The area ten feet immediately south of the northern fence line was clear of radar anomalies, and interpreted as having no unmarked graves.

The widening of Brighton Avenue in Kansas City, Missouri involved a site screening using GPR over a suspected freed-slave grave location. Based on the data acquired at this site, there was no conclusive evidence supporting the existence of buried remains. However, this technique was evaluated at a nearby cemetery of similar age and shown to be effective at identifying burial locations.

The geophysical investigation conducted at the Los Angeles Crematorium was less-successful identifying potential archaeological artifacts or specific remains than the previous examples. However, this project was under significant scrutiny by historical special-interest groups, and GPR was considered a useful measure in the overall archaeological investigation by providing locations of anomalies and subsurface piping.

Geophysical techniques provided a cost-effective means to prescreen areas of suspected grave locations, so that more detailed archeological methods may be constrained to probable locations, as well as limit costly delays due to unexpected excavations.

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