United States Department of Agriculture

Natural Resources Conservation Service

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Subject: ARCH-Geophysical Field Assistance **Date:** 11 July 2007

To: Margo L. Wallace
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Purpose:
At the request of the Connecticut State Archaeologist, Connecticut State Police and local historians, ground-penetrating radar (GPR) and electromagnetic induction (EMI) surveys were conducted at archaeological and forensic sites located in Newtown, Wethersfield, Milford, Westport, and Norwich, Connecticut.

Principal Participants:
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Joe Bokowski, Detective, Division of State Police, Troop A, Southbury, CT
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Activities:
All field activities were completed on 20 and 21 June 2007.

Summary:
1. At the Newtown site, results from the EMI survey suggest the probable presences of anomalous features buried beneath a swale at the far southwestern extremity of the backyard (near a very steeply sloping and unnatural escarpment). GPR surveys conducted across this swale, though inconclusive, suggest the possible presence of deeply buried (> 5 m), metallic (inferred from patterns of signal reverberations)

features. However, without ground-truth verification, interpretations from these surveys are not definitive and in themselves are considered inconclusive.

2. In alluvial deposits along the Connecticut, the use of GPR to distinguish stratigraphic layers at depths ranging from 5 and 15 m is considered inappropriate, as radar energy is dissipated within depths of 5 meters and subsurface features are too poorly resolved with lower frequency antennas. The use of other geophysical techniques such as electrical resistivity or seismic is recommended.

3. At the Old Milford Cemetery, radar imagery detected several subsurface features that suggest possible gravesites. However, anomalies appearing on radar records were not definitive. No mass grave was detected with GPR. A more detailed GPR investigation of this portion of the cemetery may reveal additional subsurface feature that are worthy of archaeological investigations.

4. At the Upper Greens Farm Cemetery, GPR was used to locate the graves of four Audley family members that were buried between 1941 and 1963. However, at the Lower Green Farm Cemetery, GPR failed to reveal any noteworthy feature within the Munson plot where burial(s) occurred (circa 1830s).

5. GPR identified several subsurface anomalies near the proposed bike path at the Norwalk Cemetery. One conspicuous subsurface anomaly, whose amplitude, geometry, and depth suggest a potential gravesite, is recommended for excavation by archaeologists.

6. GPR is often reported as the most useful geophysical tool for the delineation of potential gravesites. However, results are mixed. Bevan (1991) observed that GPR provided "anomalous reflections that suggested gravesites where there were none, while failing to provide reflections from known graves". Because of the speed and near completeness of decay and weathering, remnants are seldom preserved for long periods in most Connecticut soils. Often, at older gravesites, the only remains are coffin nails, hinges, or soil discolorations caused by the interments. Unwanted background clutter from tree-throws, animal borrows, and stones and cobbles further compound the complexity of radar interpretations and masks many of the telltale signs of disturbances on radar records. As a consequence GPR seldom provides a definitive response. Further GPR archaeological investigations of gravesites in Connecticut are recommended to identify favorable soil environments for the use of GPR and identifiable features that can occur in graves.

It was my pleasure to work in Connecticut and to be of assistance to you and your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
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cc:
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Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (North Salem, New Hampshire).[1] The SIR System-3000 weighs about 9 lbs and is backpack portable. With an antenna, this system requires two people to operate. The principal antenna used in these investigations operated at a center frequency of 400 MHz. In addition, a 70 MHz antenna was used at the Newtown site, and the 70 MHz and 200 MHz antennas were used at the Wethersfield site.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc).[1] Each radar record was submitted to the following processing procedures: setting the initial pulse to time zero, color transformation, marker editing, distance normalization, and horizontal stacking. For each grid site, the processed radar records were combined into a three-dimensional pseudo-image using the 3D QuickDraw for RADAN Windows NT software (Geophysical Survey Systems, Inc).[1] Processed images were migrated and the gains were adjusted for display purposes. Once processed, cross sections and time slices were reviewed and selected images attached to this report.

At the Newtown Site, an EM31 meter (manufactured by Geonics Limited, Mississauga, Ontario) was used.[1] This meter is portable and needs only one person to operate. No ground contact is required with this meter. The EM31 meter weighs about 12.4 kg (27.3 lbs), has a 3.7-m intercoil spacing, and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter provides a theoretical penetration depth of about 6 meters in the vertical dipole orientation (McNeill, 1980).

The Geonics DAS70 Data Acquisition System was used with the EM31 meter to record and store both EC_a and position data.[1] The acquisition system consisted of the EM31 meter; an Allegro CX field computer (Juniper Systems, North Logan, UT) with Geomar's Trackmaker 31 software (Geomar Software, Inc., Mississauga, Ontario); and a Garmin Global Positioning System (GPS) Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack) (Garmin International, Inc., Olathe, KS).[1] When attached to the acquisition system, the EM31 meter is keypad operated and measurements can be automatically triggered.

To help summarize the results of the EMI survey, SURFER for Windows, (version 8.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulation shown in this report.[1] The grid of EC_a data was created using kriging methods with an octant search.

Ground-penetrating radar:
Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. This system operates by transmitting short pulses of very high and ultra high frequency electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of differing dielectric permittivity (E), a portion of the energy is reflected back to a receiving antenna. The receiving unit amplifies and samples the reflected energy, and converts it into a similarly shaped waveform in a lower frequency range. The processed reflected waveforms are displayed on a video screen and can be stored on a hard disk for future playback, processing, and/or display.

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g., bedrock, soil horizon, buried archaeological feature) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (v) are described in the following equation (Daniels, 2004):

$$v = 2D/T \qquad [1]$$

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to the equation (Daniels, 2004):

$$E_r = (C/ v)^2 \qquad [2]$$

where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and *v*.

Newtown Site:

Background:

A criminal case concerning a woman's disappearance in 1984 remains open with the Connecticut State Police. The State Police received information on the possible burial of four cars in the back yard of the woman's former home shortly after her disappearance. The cars were reportedly smashed, stacked (one upon the other), and buried with a backhoe in the backyard. At the request of the Connecticut State Police, geophysical services were provided to assist their investigation.

Both electromagnetic induction (EMI) and ground-penetrating radar were used in this investigation. EMI was used to rapidly reconnoiter and gain a broad picture of spatial apparent conductivity (EC_a) patterns across the yard. Areas identified with EMI as having anomalous EC_a responses were investigated in greater detail using higher resolution GPR. In a similar investigation, Nobes (2000) used EMI and GPR to locate a body that had been buried for 12 years in New Zealand. In the survey conducted by Nobes, the body was successfully located by an isolated EMI anomaly rather than by GPR anomalies.

Electromagnetic induction operates by inducing circular eddy current loops into the soil and measuring the magnitude of the electromagnetic energy in these loops. Under certain conditions (known as operating at low induction numbers), the magnitude of energy in these current loops is proportional to the EC_a of the earthen materials near the loops. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983).

Electromagnetic induction responds to the electrical conductivity of earthen materials. The electrical conductivity of earthen materials is influenced by the amount and type of salts in solution, amount and type of clays, porosity, and degree of water saturation. Variations in EC_a are produced by changes in the electrical conductivity of the earthen materials. Absolute EC_a values are seldom diagnostic in themselves. EMI interpretations are based on the identification of spatial patterns within data sets. Lateral and vertical variations in EC_a have been used to infer changes in soils and soil properties and the presence of buried artifacts.

EMI interacts well with highly conducting and permeable targets (McNeill, 1983). The EM31 meter has been used for mapping electrically conductive buried metal containers and hazardous wastes (McNeill, 1983). Metallic objects can generally be detected with the EM31 meter, provided they are not too deeply buried. However, a problem with all EMI sensors is target identification. EMI sensors detect, but do not identify buried features. As a consequence, all detected anomalies must be excavated to confirm interpretations.

Survey Procedures:

A *random walk* or *wild-cat* EMI survey was conducted with the EM31 meter at the Newtown site. The EM31 meter was operated in the deeper-sensing (0 to 6 m) vertical dipole orientation and in the continuous mode (measurements recorded at 1-sec intervals) with the DAS70 system. Using the NAV31W software program, both GPS and EC_a data were simultaneously recorded in a field computer. The meter was held at hip height and orientated with its long axis parallel to the direction of traverse. The survey was completed by walking at a uniform pace, in a random or back and forth pattern across the yard. Where possible, above ground features such as the house, vehicles and lawn furniture were avoided to reduce interference.

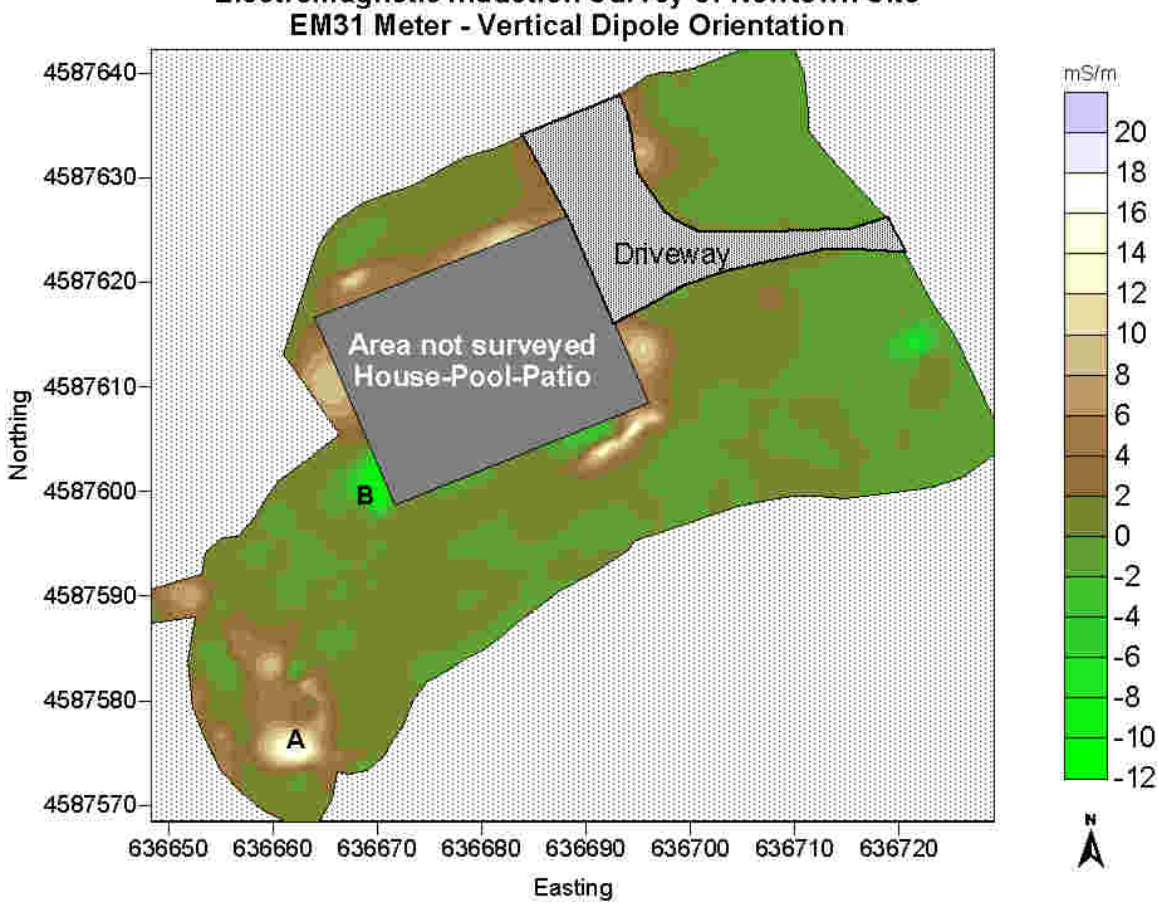
Results:

1. EMI Survey:

Figure 1 shows the spatial distribution of EC_a data collected with the EM31 meter in the deeper-sensing, vertical dipole orientation at the Newtown site. In Figure 1 the isoline interval is 2 mS/m. Soils and were electrically resistive at this site and measurements of EC_a were generally very low to negative. Based on 1079 measurements, EC_a averaged -1.3 mS/m with a range of -28.3 to 37.4 mS/m. One-half of the measurements were between -2.8 and -0.6 mS/m. Conspicuously high values of EC_a were measured along traverses that approached too closely to the house, pool and patio areas. In addition, a camper parked at the extreme northern end of a driveway extension caused anomalously high EMI responses. These anomalously high EC_a values are associated with metals used in these features.

Excluding areas located near the aforementioned features, values of EC_a are very low and relatively invariable across most of the yard. Exceptions occur along and near the escarpment that bounds the southwest portion of the yard. Here, EC_a is anomalously high. A small garden occurs in this area and metal lawn items did cause some interference in the north central portion of the anomalous areas. Across the remainder of the area with anomalous EC_a, no other metallic features were evident on the soil surface. As a consequence, the anomalously high EC_a responses across the remainder of this area are attributed to layers of conductive soil materials; contaminants; and/or small or deeply buried, metallic artifacts. Within the area with anomalously high EC_a, the most conspicuous sub-area has been identified in Figure 1 at "*A*". This anomalous area is located in a concave, linear swale or area of ground subsidence. Also shown in Figure 1 is an area with exceptionally low EC_a (see "*B*") that adjoins the patio area. This area is suspected to contain buried drainage tiles or septic lines. The EMI responses over both areas *A* and *B* are considered atypical and worthy of further investigation with GPR.

Figure 1



2. GPR:
Soils were relatively dry at the time of this investigation and a value of 7 was used for the relative dielectric permittivity (E_r). This value provides a propagation velocity of 0.1126 m/ns. This velocity was used to depth scale the radar imagery. This velocity was not verified in the field and should be considered an approximation.

Figure 2 is a representative radar record that was collected with the 70 MHz antenna. This radar record was collected along a transect line that traversed the linear swale identified as “A” in Figure 1. In Figure 2 all scales (depth and distance) are expressed in meters. The prevalence of linear reflectors suggests successive layers of outwash or fill materials. The deep penetration and excellent resolution of subsurface features suggests that the underlying materials have a low electrically conductivity and are likely relatively coarse textured. These characteristics were used to discount the inference made from the EMI survey that the anomalous area could be underlain by buried contaminants of conductive soil or fill layers. High amplitude reflection (colored white, grey, blue and pink) suggests highly contrasting materials separated by abrupt boundaries. Lower amplitude (colored red and black) suggest more similar and less abrupt or contrasting strata and materials. The reflectors evident in Figure 2 are believed to principally represent differences in the grain size distributions, density, and/or moisture contents of the stratigraphic layers.

In Figure 2, two anomalous reflectors with reverberated signals have been identified (see “A” and “B” in Figure 2). When attempting to classify or identify any subsurface target on radar records, the variability of ground conditions, as well as the physics of EM wave propagation and reflection must be taken into account. Deeply buried reflectors appear smaller than their actual physical size. Conductive targets (such as metals), because of stored energy, reverberate and create extended depth images. While the reflections identified at “A” and “B” in Figure 2, appear relatively small, they are relatively deeply buried (> 5 m) and do create signal reverberations (see high amplitude reflections, which reverberated with depth beneath these features). These reverberations suggest buried metallic objects.

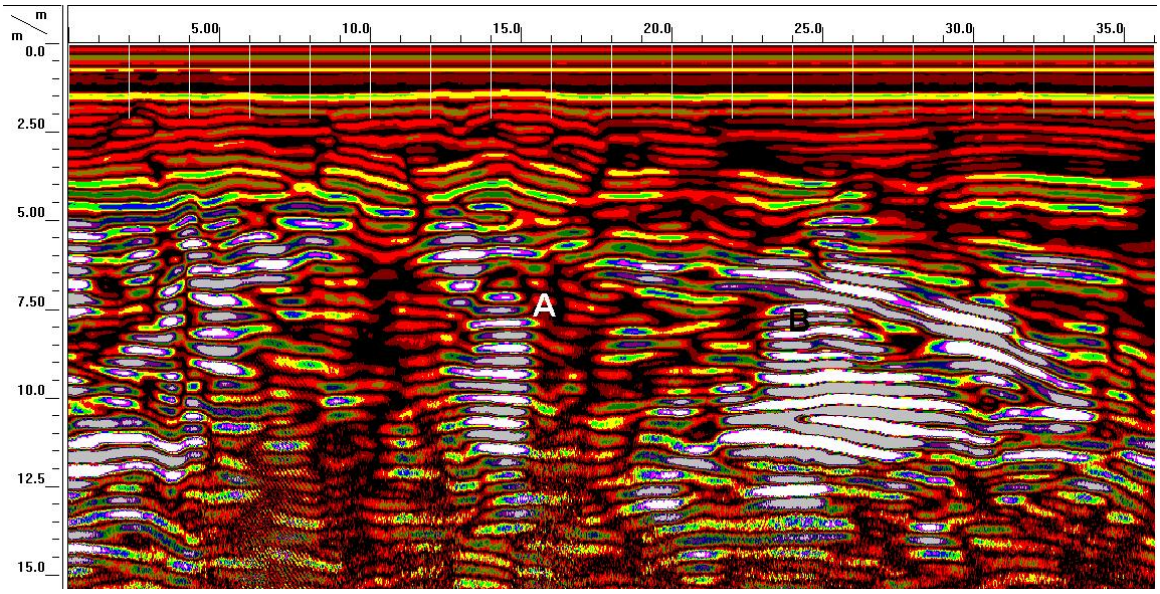


Figure 2. Representative radar record from a traverse line that bisected the anomaly identified at "A" in Figure 1.

Results from the EMI survey suggest the probable presences of anomalous features buried beneath a swale at the far southwestern extremity of the backyard (near a very steeply sloping and unnatural escarpment). GPR surveys conducted across this swale, though inconclusive, suggest the possible presence of deeply buried (> 5 m), metallic (inferred from patterns of signal reverberations) features. However, without ground-truth verifications, interpretations from these surveys are not definitive and are considered inconclusive.

Wethersfield Site:
The purpose of this investigation was to assess the potential of GPR to profile and identify stratigraphic layers in alluvial sediments along the Connecticut River in Hartford County. For this investigation, the desired depth of penetration ranges from 5 to 15 m. Both the 200 and 70 MHz antennas were used in this investigation. For the purpose of this investigation, the 70 MHz antenna provided the deepest penetration depths. The 70 MHz antenna is the lowest frequency available to USDA-NRCS. Lower frequency antennas provide greater depth of signal penetration, but lower resolution of subsurface features. GPR antennas have been designed to operate in a frequency range from about 30 MHz to 1.25 GHz.

Table 1. Taxonomic classifications of the soils identified in study sites.

Soil Series	*Taxonomic Classification*
Canton	Coarse-loamy over sandy or sandy-skeletal, mixed, semiactive, mesic Typic Dystrudepts
Charlton	Coarse-loamy, mixed, active, mesic Typic Dystrudepts
Hadley	coarse-silty, mixed, superactive, nonacid, mesic Typic Udifluvents
Haven	Coarse-loamy over sandy or sandy-skeletal, mixed, active, mesic Typic Dystrudepts
Hinckley	Sandy-skeletal, mixed, mesic Typic Udorthents
Enfield	Coarse-silty over sandy or sandy-skeletal, mixed, active, mesic Typic Dystrudepts
Pootatuck	Coarse-loamy, mixed, active, mesic Fluvaquentic Dystrudepts

The Wethersfield sites are located on the flood plain of the Connecticut River. Soil map units traversed with GPR included areas of Pootatuck fine sandy loam (soil map unit (MU) 102), and Hadley silt loam (MU 105) (see Figure 3 for locations of GPR traverse lines). The very deep, moderately well drained Pootatuck soils and the well drained Hadley soils form in alluvial sediments. The taxonomic classifications of these soils are listed in Table 1. The low clay content (typically < 6 % for Pootatuck soils and < 15 % for Hadley soils) and cation exchange capacity of these soils makes them suitable for GPR soil investigations (ftp://ftp-fc.sc.egov.usda.gov/NGDC/ssatlas/gpr/ma_ct_ri.pdf). However, these soils are highly stratified and, below depths of 80 inches, strata with higher clay contents that limit GPR penetration are possible.

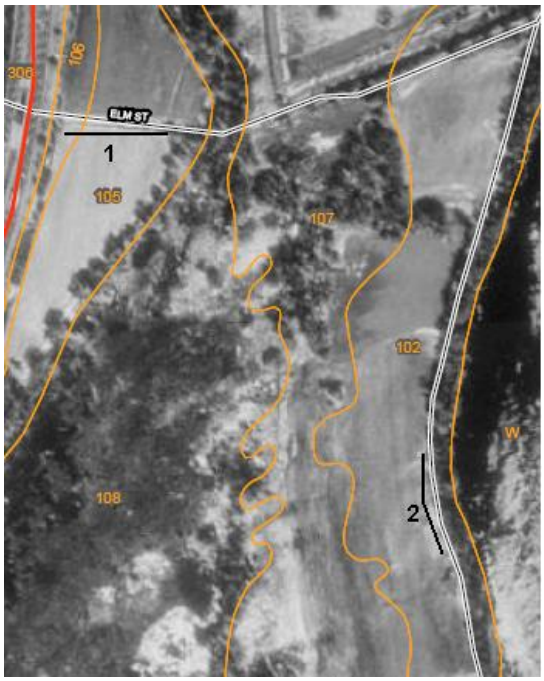


Figure 3. Soil map showing the locations of GPR traverse lines at the Wethersfield sites.

Figure 4 is a representative portion of a radar record that was collected at Wethersfield Site 1 with the 70 MHz antenna. On this radar record all scales are expressed in meters. Besides the standard processing techniques, this radar record has been extensively processed using high pass horizontal filtration, signal stacking, migration, and range gain adjustments techniques to help remove high levels of unwanted background noise.

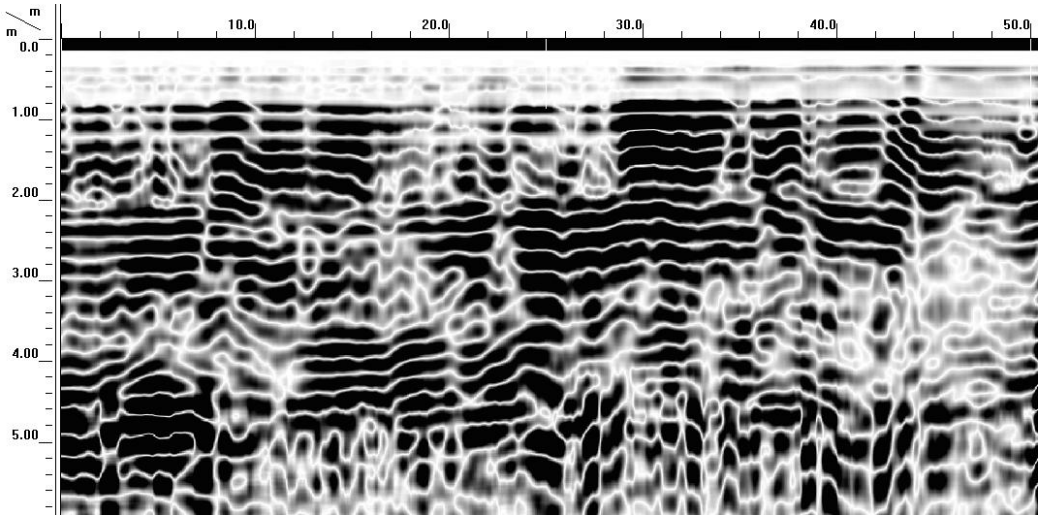


Figure 4. Portion of a highly-processed radar record collected with the 70 MHz antenna at Wethersfield Site 1.

The depth scale used in Figure 4 is based on an E_r of 14 and a velocity of signal propagation of 0.0796 m/ns (based on hyperbola matching techniques). Boundaries separating three major stratigraphic layers are evident at depth of about 0.90 to 1.0, 2.0 to 2.2, and 3.4 to 4.0 m on the radar record. These boundaries separate radar facies, each with distinct graphic signatures. Attenuation losses restricted penetration depths to about 5 m in these sediments. Compared with the GPR records obtained with the 70 MHz antenna at the Newtown Site (see Figure 2), which was collected over more favorable soils, the radar records from the Wethersfield sites are more poorly resolved and depth restricted.

In alluvial deposits along the Connecticut, the use of GPR to distinguish stratigraphic layers at depths ranging from 5 and 15 m is considered inappropriate, as radar energy is dissipated within depths of 5 meters and subsurface features are too poorly resolved with lower frequency antennas. The use of other geophysical techniques such as electrical resistivity or seismic is recommended.

Glastonbury Site:
A wildcat GPR survey was conducted in an attempt to locate a buried, stone boundary marker known to have existed in the general vicinity of this site. The site is located on the farm of Howard Horton. The GPR survey failed to locate the marker. Either the property boundary marker was not crossed with the antenna during the GPR survey or the stone marker may have been removed from the site.

Old Milford Cemetery, Milford Connecticut:
It is believed that 46 American soldiers, who were among 200 captured by the British in New York, died of smallpox in a temporary hospital set up in Milford in 1777. Based on an account written by a historian in the 1830s, the soldiers were not placed in coffins, but to avoid the spread of the disease were hastily and unceremoniously buried in a mass grave located in what is now known as Old Milford Cemetery. The location of the mass grave has not been confirmed, but a monument has been erected that memorializes the soldiers.

A 400 MHz antenna was used at Old Milford Cemetery. Based on the depth to a shallow (40 cm) reflector, the relative dielectric permittivity (E_r) through the upper part of the soil was estimated to be 6. This E_r results in a propagation velocity of 0.1217 m/ns. In this study, using this velocity of propagation and a scanning time of 40 ns, the maximum depth of penetration with the 400 MHz antenna was about 2.4 m. However, the velocity of propagation is spatial variable and generally decreased with increasing depth. Therefore, this depth scale should only be considered as an approximation.

GPR surveys were conducted in an area of Haven and Enfield soils, 0 to 3 percent slopes (MU 32A). The very deep, well drained Haven and Enfield soils form respectively in silty and loamy mantles that overlie sandy and gravelly outwash. Table 1 lists the taxonomic classifications of these soils. These soils range from very strongly acid to medium acid in reaction (pH 4.5 to 6.0), have low clay contents (in upper parts: 5 to 18 % and 3 to 12 % clay for Haven and Enfield soils, respectively; in lower parts: less than 6 % for both soils), low cation exchange capacity (0 to 6.7 meg/100 g), and were relatively dry at the time of this investigation.

Random or *Wildcat* radar surveys were conducted in the area surrounding the monument commemorating the soldiers (southwest corner of the cemetery). These surveys revealed no subsurface reflections that suggest a mass grave. In order to accommodate the larger number of bodies, a mass grave would have to be larger and deeper that the "*typical*" grave. An anomalous, shallowly (<45 cm) buried feature was detected near and along one of the side slopes to the monument. This feature was excavated, revealing a thin layer of flat stones.

A small, 10 m^2 grid was established in an open area to the east of the monument that contained no head stones. The grid was constructed using two equal length and parallel lines, which formed the opposing sides of a rectangular area. These two parallel lines were orientated in and east-west direction and defined a grid area. Survey flags were inserted in the ground at intervals of 50-cm along each of these two lines. For positional accuracy, GPR traverses were completed along a reference line, which was stretched and sequentially moved between corresponding flags on the two parallel grid lines. Pulling the 400 MHz antenna along the reference line completed a GPR traverse. Along the reference line, marks were spaced at intervals of 1 m. As the antenna was towed passed each reference point, a vertical mark was impressed on the radar record. Walking, in a back and forth manner, along the reference line, which was moved sequentially between similarly numbered flags on the two parallel survey lines, completed a GPR survey.

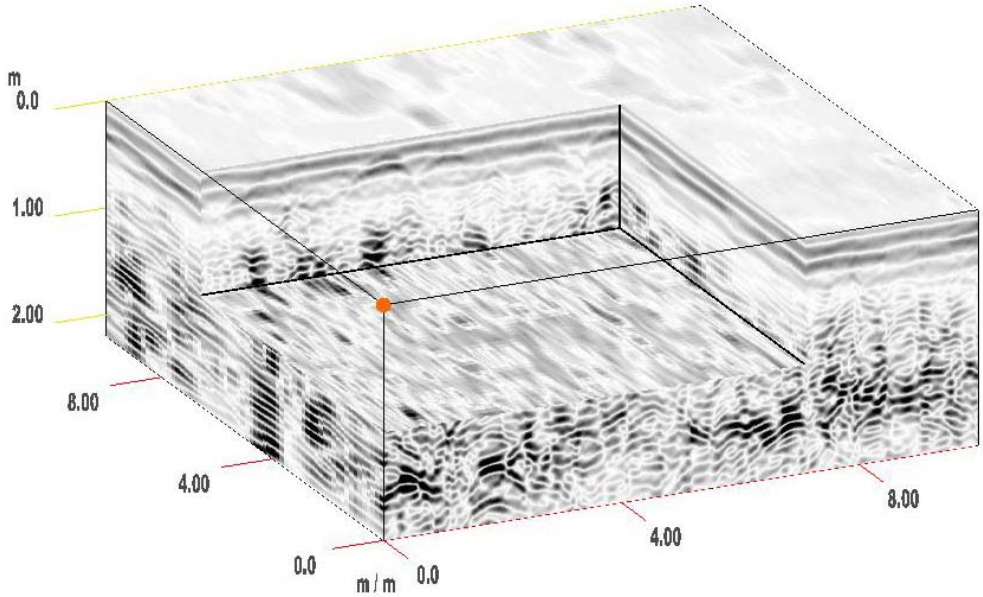


Figure 5. This three-dimensional cube display shows subsurface features within the grid area at Old Milford Cemetery. A 7.0 by 6.6 m inset has been removed to a depth of about 120 cm. High amplitude subsurface reflections along the back wall of the cutout cube suggest possible grave sites.

Figure 5 is a 3D cube display of Old Milford Cemetery grid area. The north-south line is essential parallel with the x-axis (foreground), with north towards the right. A 7.0 by 6.6 m section has been cutout of the cube to a depth of about 120 cm. While no evidence of a mass grave could be gleaned from a review of the 3D cube, several high-amplitude, linear anomalies were noted in the western (background) portion of the grid area. These linear anomalies occur between depths of 80 and 120 cm and are aligned with their long axes orientated in an east-west direction. Five of these anomalies are evident along the back wall of the cutout cube. While GPR detects, it does not identify subsurface anomalies. It is wishful thinking to believe that the high amplitude reflectors that are evident in Figure 5 represent burials. Features in the soil other than graves (such as large roots, animal burrow, and rock fragments) will produce similar reflections on radar records.

In recent years, a sophisticated type of 3D GPR data manipulation known as “amplitude slice-map analysis” has been used in archaeological investigations (e.g. Conyers and Goodman, 1997). In this procedure, amplitude differences within the 3D image are analyzed in "time-slices" to isolate differences within specific time (i.e. depth) intervals (Conyers and Goodman, 1997). Time-slice data are created by averaging the reflected radar energy horizontally between each set of parallel radar traverses within a specified time window to create a time-slice. The resulting time-slice image displays the spatial distribution of reflected wave amplitudes, which can be interpreted as representing lateral changes in soil properties or the presence of subsurface features.

A horizontal time-slice images made at a depth of 84 cm across the Old Milford Cemetery site is shown in Figure 6. In this image of the grid site, north is to the right. The general fabric of the underlying outwash appears as lower amplitude linear reflections that display a southwest to northeast orientation. Several isolated, high-amplitude linear reflectors that are aligned in essentially an east-west direction are evident in the western 2/3 (upper portion of plot) of the grid area. While these reflectors could represent several subsurface features (rocks, borrows, strata, soil inhomogeneities), being in a cemetery, the common depth, geometry, and orientation of some of these reflectors suggests possible gravesites.

As noted by Dr Nick Bellantoni (Connecticut State Archaeologist, personal communication July 9, 2007), the preservation of graves depends greatly on the pH of the soil. The more acidic the soil, the more quickly organic remains decay. Dr Bellantoni observed that “We have seen burials from the early 1900s, completely decomposed when the pH was 4.7 to 4.9, and we have seen burials preserved from the 1700s when the pH is above 5.5”. Preservation of skeletal remains is most favored in dry, alkaline, sandy soils (Dupras et al., 2006). The low pH of Haven and Enfield soils (pH 4.5 to 6.0) does not favor the preservation of burial remains.

The detection of burials with GPR often depends upon the materials used to contain the bodies. Bodies may be buried in sacks, body bags, wooden caskets, concrete vaults, or fiberglass, composite or metal coffins. Metal or lead coffins and burial vaults provided relatively large, long-lasting, and more contrasting interfaces that produce high amplitude, recognizable radar reflections. As also noted by Dr Bellantoni, “Coffin hardware will preserve, though many times rusted. However, the wood decomposes rather quickly in the soils of Connecticut. The best preservation is with metal coffins, which are patented as early as 1820s, but, are not common until the 1860s. We have seen the preservation of soft [body] tissue within metal coffins going back to the 1880s”. It is possible that some of the linear anomalies seen in Figure 6 represent burial remnants. However, ground-truth excavations by archaeologists are required to confirm interpretations.

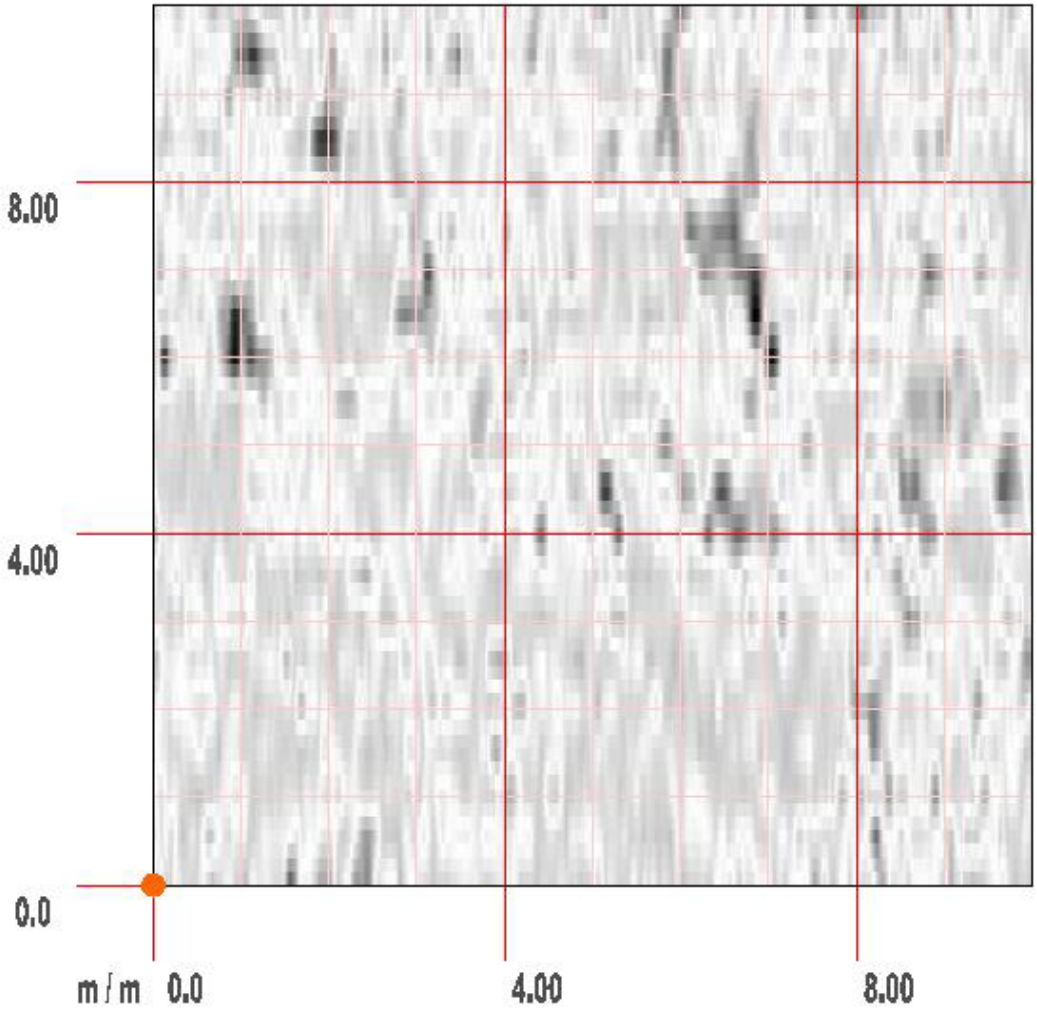


Figure 6. This amplitude slice map depicts radar reflections at a depth of 84 cm across the Old Milford Cemetery site.

A random GPR traverse was conducted across the portion of the cemetery that is near Prospect Street. This area is being considered for the development of an apartment complex. Figure 7 is a portion of that radar record. While the majority of the area scanned with GPR lacked noteworthy subsurface features other than those interpreted to be associated with naturally occurring soil horizons and geologic strata, this portion of the radar record shows two rather intriguing features (in Figure 7, see areas enclosed in boxes). The identities of these features are unknown, but their form does suggest possible burials. The radar imagery suggests down-turned and slumping, soil horizons over these high-amplitude features. In addition, these features appear to truncate the continuum of soil and stratigraphic layers. However, the imagery is not definitive and interpretations are inconclusive in themselves. A more detailed GPR investigation of this portion of the cemetery may reveal additional subsurface feature that are worthy of archaeological investigations. The use of GPR in combination with archaeological search procedures would provide greater assurance that no significant archeological features occurred within the proposed development site.

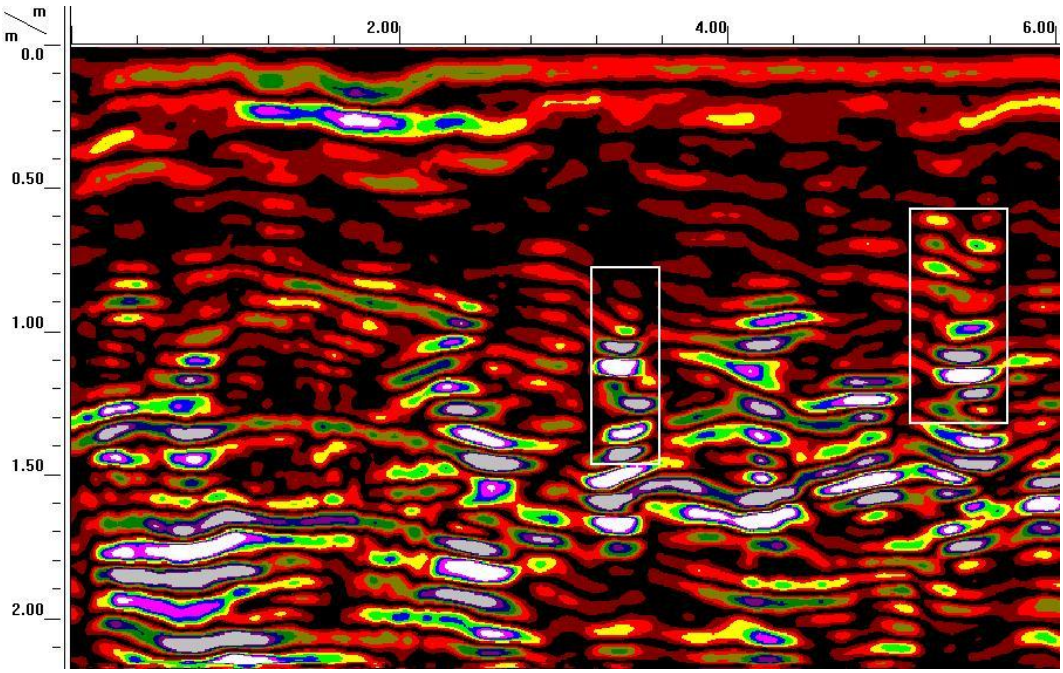


Figure 7. This radar record shows two, high-amplitude, segmented features that suggest possible grave sites.

Green Farms Cemeteries, Westport, Connecticut:

Upper Cemetery:

The exact locations and number of interments in the Audley family plot are of concern to cemetery officials responsible for the care and maintenance of the Upper Green Farms Cemetery in Westport, Connecticut. Headstones appear to mark the graves of four Audley family members that were buried in this plot between 1941 and 1963.

A small, 2 by 15 m grid was established across the family plots and into an adjoining area to the north. The grid area is located to the immediate west of the four head stones. The grid was located in an area of Charlton-Urban land complex, 3 to 8 percent slopes (MU 260B). The very deep, well drained Charlton soils form in loamy tills. Table 1 lists the taxonomic classification of this soil. This soil has low clay content (< 8 %) and was very dry at the time of this investigation. This soil is considered very well suited to GPR soil investigations. While the pH of Charlton soils range from very strongly acid to medium acid in reaction (pH 4.5 to 6.0), because of the recency of burials within the Audley family plot, the amount of decay and weathering that has occurred is considered insufficient to impair detection with GPR

Survey procedures used at both the Upper and Lower Green Farms Cemeteries were similar to those used at the Old Milford Cemetery. The exception to the GPR grid survey procedures used at the Green Farms Cemeteries was that radar traverses were more closely spaced. At the Green Farms Cemeteries, the interval between GPR traverse lines was 25 cm rather than 50 cm. Once again, pulling the 400 MHz antenna along the reference line completed a GPR traverse.

Based on hyperbola matching techniques, the relative dielectric permittivity (E_r) through the upper part of the soil was estimated to be about 2.6. This E_r results in a propagation velocity of 0.184 m/ns. In these surveys, using this velocity of propagation and a scanning time of 40 ns, the maximum depth of penetration with the 400 MHz antenna was about 3.7 m. However, the velocity of propagation is spatial variable and generally decreased with increasing depth. Therefore depths must be considered as approximations.

Figure 8 is a 3D cube display of the Audley family plot grid area. In this cube all depth and distance marks are in meters. The north-south line is essential parallel with the x-axis (foreground), with north towards the right. An 8.0

by 3.0 m section has been removed from the cube to a depth of about 120 cm. Four high-amplitude (black colored), linear features are evident on the base, fore-wall, and back-wall of the cutout cube. These features are oriented in an east-west direction, and represent the four known burials. A fifth possible interment is evident in the back-wall of the cutout cube between the X = 0.5 to 1.1 m distance marks (extreme southwest corner of the grid area). The GPR survey revealed no indications of burials in the northern 3 meters of the grid area.

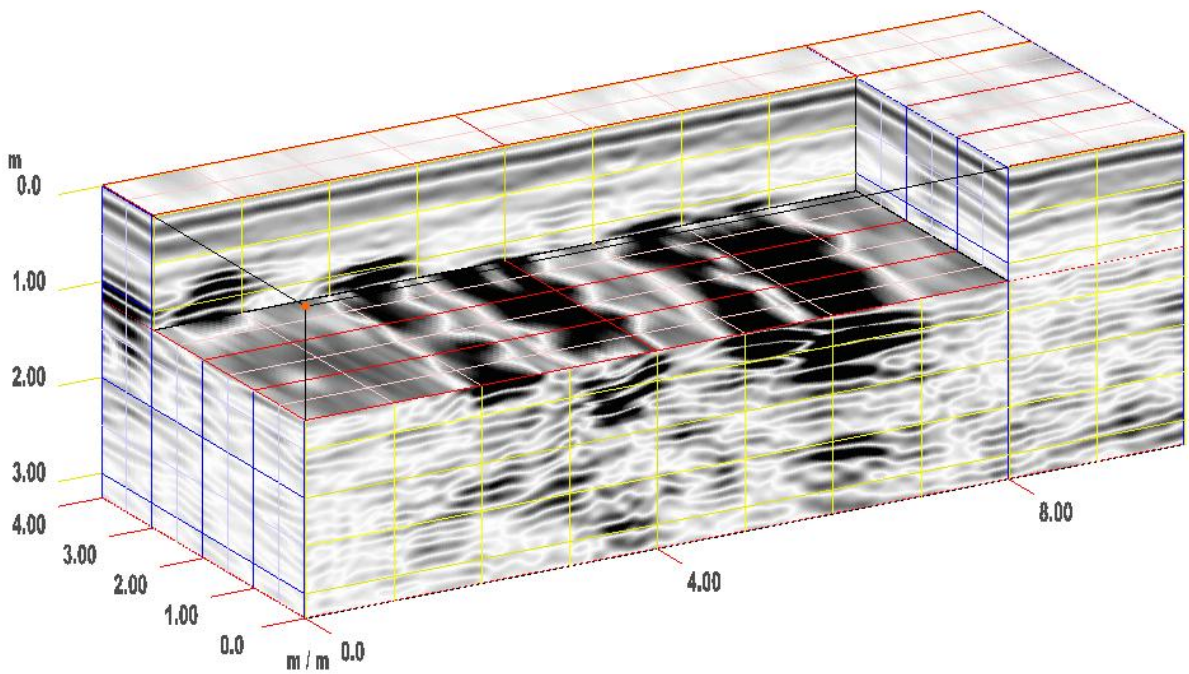


Figure 8. This three-dimensional cube display shows subsurface features within the grid area at Upper Green Farms Cemetery Westport, Connecticut. An 8.0 by 3.3 m inset has been removed to a depth of about 120 cm. Four conspicuous, high amplitude, linear subsurface reflectors identify the graves.

A horizontal time-slice image made at a depth of 125 cm across the Audley family plot site is shown in Figure 9. The distance marks are expressed in meters. In this image of the grid site, north is to the right. In this image, four high-amplitude linear reflectors that are aligned in essentially an east-west direction are evident in central portion of the grid area. The fifth potential burial is evident between X = 0.25 to 1.00 m, Y= 2.5 to 3.5 m.

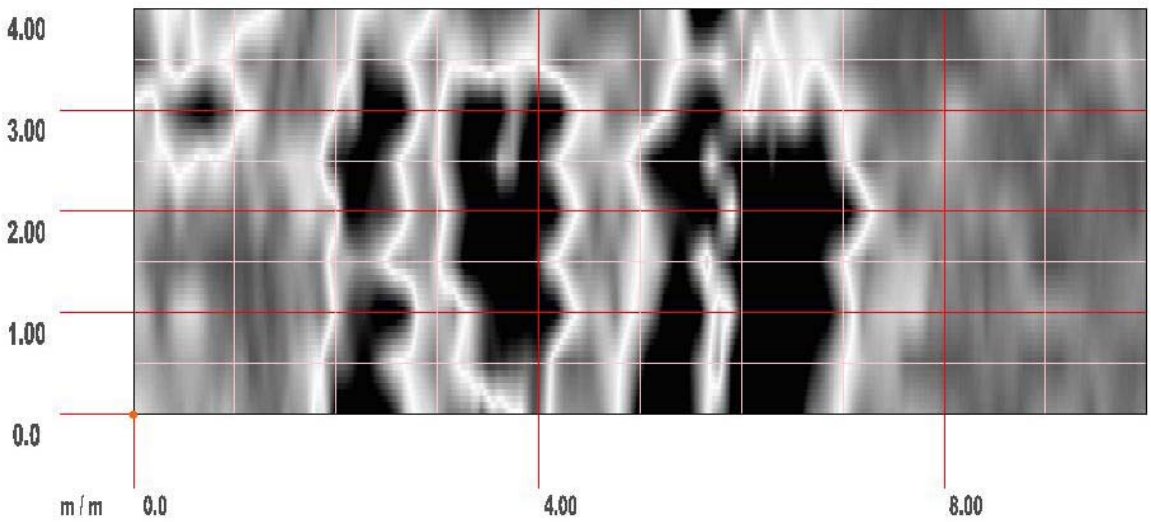


Figure 9. This amplitude slice map depicts radar reflections at a depth of 125 cm across the grid site at the Upper Green Farm Cemetery.

Lower Cemetery:
A weathered headstone marking the grave of the wife of Henry Munson lies near the southern boundary of the Lower Green Farm Cemetery. She died and was buried in 1836. Cemetery officials and local historians want to know whether Henry Munson was also interred in this plot.

A small, 4 by 4 m grid was established in the area that surrounds the headstone. The grid was located in an area of Canton and Charlton soils, 3 to 8 percent slopes (MU 60B). The very deep, well drained Canton soils formed in a loamy mantle that is underlain by sandy till. Table 1 lists the taxonomic classification of this soil. This soil has low clay content (< 8%) and was relatively dry at the time of this investigation.

The radar survey resulted in the detection of no noteworthy subsurface features. The high pH of these soils has presumably accelerated decay and weathering processes, which have removed all features of the burials that could be detected with GPR.

Memorial Park Cemetery, Norwalk, Connecticut:
The cemetery is located in Memorial Park in downtown Norwalk, Connecticut, near the intersection of US Highway 7 and I-95. The cemetery dates back to the early 1700s. Plans are being developed for a *Bike Trail* and a parking lot just outside the cemetery. Clearing and land leveling are progressing in an area of the park that adjoins the cemetery. Concerns have been expressed over the potential disturbance and removal of graves that are possibly located outside the present cemetery boundary. These areas may contain the graves of individuals that were not permitted to be buried within the cemetery's boundaries (indigent, slave, and Indian graves).

A preliminary radar traverse and a small, 4 by 15 m grid were established near a portion of the proposed bike path in the northwestern portion of the cemetery. The grid was located in an area of Hinckley-Urban land complex, 3 to 15 percent slopes (238C). The very deep, excessively drained Hinckley soils formed in water-sorted materials on terraces and outwash plains. This soil ranges from extremely strongly acid to medium acid (pH 3.5 to 6.0) in reaction, and has very low clay content (typically < 8 % in the upper part and < 3% in the lower part). While Hinckley soil is very well suited to GPR, its acidic reaction does not favor the preservation of burials. In addition, the content of rock fragment ranges from 5 to 25 percent for cobbles, and 0 to 5 percent for stones. These rock fragments complicate radar interpretations as their reflections are easily confused with reflections from burials.

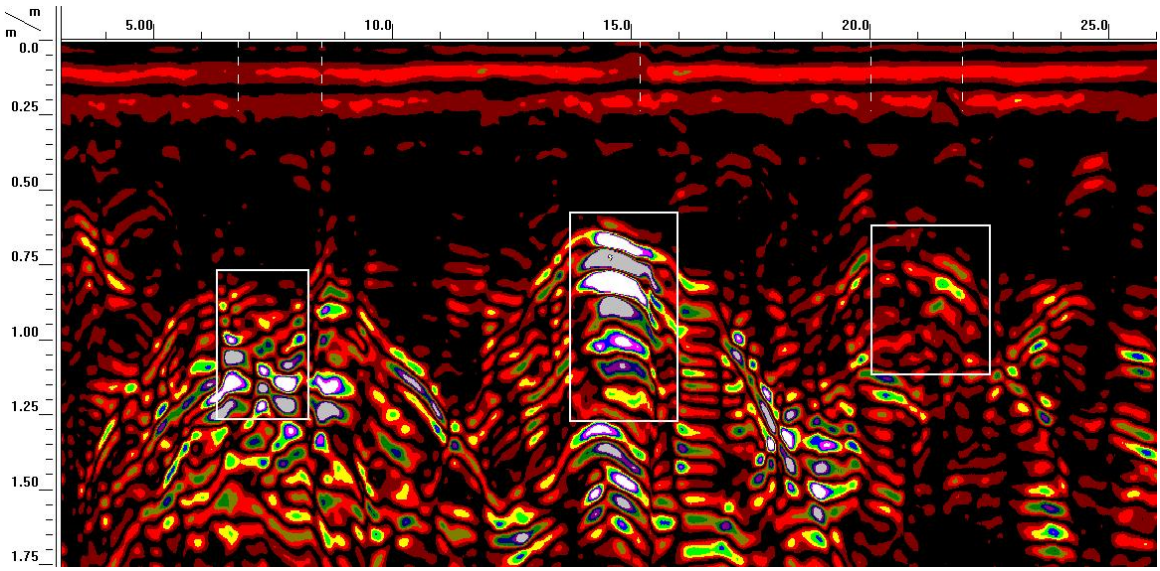


Figure 10. *This radar record shows three anomalous features within the Memorial park Cemetery.*

A 400 MHz antenna was used in this investigation. Based on hyperbola matching techniques, the relative dielectric permittivity (E_r) through the upper part of the soil was estimated to be about 9.6. This E_r results in a propagation velocity of 0.096 m/ns. In this study, using this velocity of propagation and a scanning time of 40 ns, the maximum depth of penetration was about 1.9 m.

An opening radar traverse was conducted along a line that contained a headstone flanked by two linear depressions. The orientation of the traverse was essentially north-south and was located in front of and parallel to the long axis of the headstone, and orthogonal to the long axes of the two linear depressions. Figure 10 is the radar record from this traverse. On this record, depth and distance scales are expressed in meters. The vertical, segmented, white-colored lines at the top of the radar record represents the approximate locations of the two depressions (the two more closely spaced lines) and the headstone (the single line). In Figure 10, three conspicuous groupings of subsurface reflectors have been enclosed in boxes. Below the 14 to 15 m distance marks, a high-amplitude (colored white and grey) reflector occurs. As this reflector occurs directly in front of the headstone, it is presumed to represents a burial. Arching patterns of moderate (colored yellow and green) and high amplitude reflections occur beneath each of the depressions. Rather abrupt vertical breaks in the continuity of subsurface reflectors appear on each side of these reflectors. These reflectors are inferred to represent potential grave sites.

A small grid was established along a portion of the line designated for the Bike Path. The purpose of this investigation was to see if there are any subsurface reflections that could be associated with burials along this portion of the path. Survey procedures used at the Memorial Park Cemetery were similar to those used in the preceding investigations. For this survey, the interval between GPR traverse lines was 50 cm. Once again, pulling the 400 MHz antenna along the reference line completed a GPR traverse. Along the reference line, marks were spaced at intervals of 1 m.

Figure 11 is a 3D cube display of the grid area in the Memorial Park Cemetery. In this cube all depth and distance marks are expressed in meters. The north-south line is essential parallel with the x-axis (foreground), with north towards the right. A 14.4 by 3.0 m section has been removed from the cube to a depth of about 85 cm. The pseudo-image shown in Figure 11 contains a large number of subsurface features, many of which form hyperbolic patterns (see back wall of cutout cube) that suggest potential burials. However, most of these reflectors do not have the dimensions of a potential gravesite and are therefore presumed to represent rock fragments, animal burrows, and or larger tree roots. However, between X = 13 to 14 m, a linear reflector(s) occur, whose amplitude, geometry, and depth suggests a potential gravesite. Based on radar interpretations, this would be the site recommended for excavation by archaeologists.

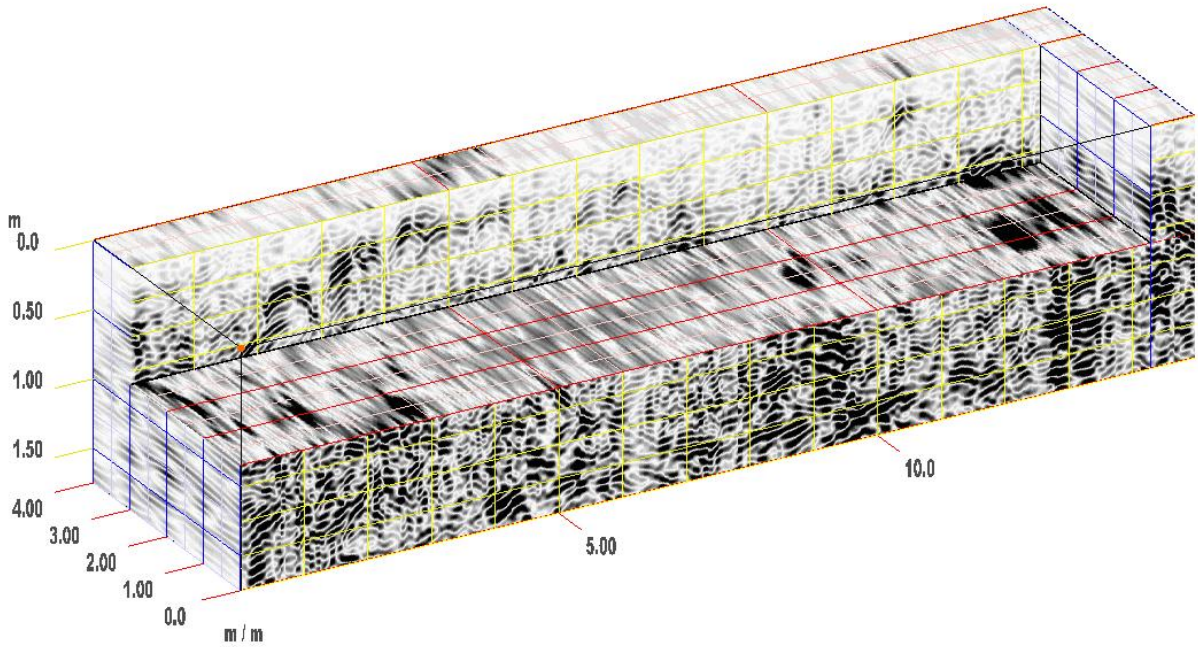


Figure 11. *This three-dimensional cube display shows subsurface features within the grid area in the Memorial Park Cemetery. A 14.4 by 3.0 m inset has been removed to a depth of about 85 cm.*

A horizontal time-slice image made at a depth of 84 cm across the grid area is shown in Figure 12. The distance marks are expressed in meters. In this image of the grid site, north is to the right. Several, closely spaced, high-amplitude linear reflectors are evident in northern portion of the grid area, between the 12.5 to 14.5 m distance marks. Multiple GPR reflectors form distinct, thin, linear trends or patterns across this time-sliced image. These linear features differ in signal amplitude and have a decidedly east-west orientation. These reflectors are believed to represent the contacts of steeply-inclined outwash strata with the horizontal time-slice. While many of these reflectors are believed to represent the inclined stratification in the substratum of Hinckley soil, the reflector identified by "A" displays a unique geometry that suggests a potential burial.

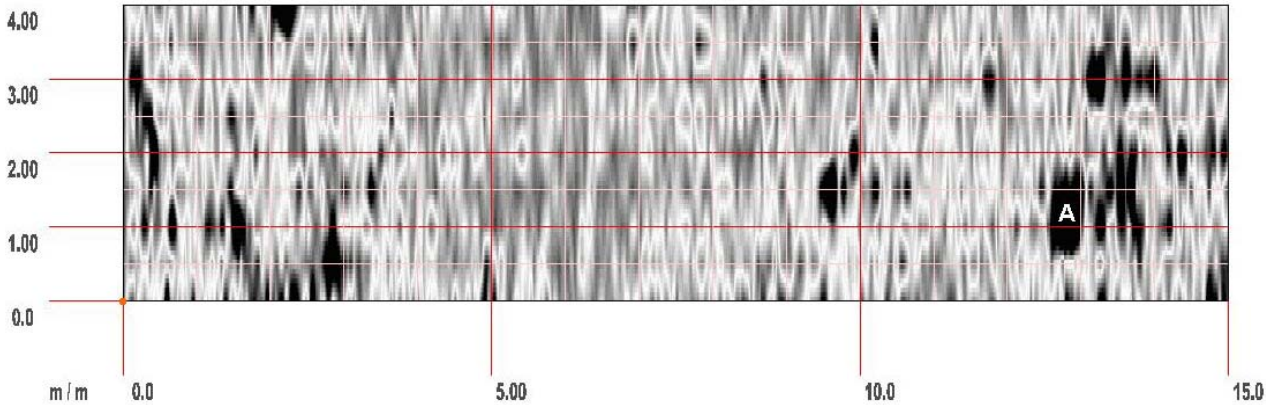


Figure 12. This amplitude slice map depicts radar reflections at a depth of 84 cm across the grid site at the Memorial Park Cemetery in Norwalk.

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