

United States Department of Agriculture



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Subject: Soils – Geophysical

Date: 29 July 2011

To: Jay Mar
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Purpose:

To provide geophysical training and assistance to the MLRA Soil Survey office staff in Tolland, Connecticut.

Principal Participants:

Mary Beth Baker, Curator, Stonington Lighthouse Museum, Stonington, CT
Bonnie Beatrice, Friends of the Office of State Archaeology (FOSA), Storrs, CT
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Nelson Merchan, UConn Mentorship Student, Wooster School, Danbury, CT
Jerry Roberts, Director, Connecticut River Museum, Essex, CT
Rebecca Romero, UConn Mentorship Student, Platt High School, Meriden, CT
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Debbie Surabian, MLRA Soil Survey Party Leader, USDA-NRCS, Tolland, CT
Marissa Theve, Soil Scientist, USDA-NRCS, Tolland, CT
Amy Trout, Curator, Connecticut River Museum, Essex, CT

Activities:

All activities were completed during the period of 18 to 21 July 2011.

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Summary:

1. Training was provided on the setup and calibration of the EM38-MK2 meter, on electromagnetic induction (EMI) field procedures, and on data processing and interpretations. The newly developed RTmap38MK2 software program was demonstrated and used in field surveys.
2. At the site of the former Samuel King House in Suffield, Connecticut, neither ground-penetrating radar (GPR) nor EMI provided clues as to the location of this former structure, which dates back to the late-1600s. Both geophysical tools did, however, indicate the presence of modern cultural features.
3. At the Reverend Guy Manse site in Suffield, Connecticut, EMI provided a very rapid and effective tool for locating and identifying buried cultural features associated with the Manse and three other former structures. To cover larger areas, the use of EMI is recommended over GPR. Once smaller “areas of interest” have been identified with EMI, GPR can be more effectively used to provide higher resolution of subsurface features within these smaller areas.
4. At the Connecticut River Museum in Essex, Connecticut, both GPR and EMI were used to better understand the subsurface and detect the presence of archaeological features. Data revealed several anomalous features and spatial patterns, which were associated with the town’s original bulkhead, differences in fill and sub-grade materials, modern buried utility lines, and saltwater intrusion. However neither geophysical method provides undisputable evidence supporting the presence of a buried bulkhead. The Connecticut River Museum is gathering information on this site in an effort to have it placed on the National Register of Historic Places.
5. At the Danielson site, GPR provided archeologists with an effective measure of the dimensions of a “hidden” chamber. The chamber’s narrow and hidden entrance in the basement of the nearby house suggests a potential hiding place for escaped slaves using the Underground Railroad.
6. At a site in Waterford, a reconnaissance EMI survey of a large (1-acre) wall-enclosed area was carried out in an attempt to isolate an early to mid-1800s cemetery site and define its boundaries. The geophysical method was used to reduce the size of the area needed for any further and more detailed archaeological investigations. While no conclusive spatial patterns were evident, two areas, based on recurring anomalous EMI values, were recognized as the most promising locations for further archaeological investigation.
7. An attempt was made to locate the site of the original Stonington Lighthouse. During the EMI survey, several participants entered the Stonington Lighthouse Museum and took a picture of a map, which showed the original lighthouse’s location. Later, Jacob Isleib used GIS to overlay and georeference the historic map on modern imagery of the site. Jacob’s work indicates that the original lighthouse site is located further south than the areas surveyed along the point of land.
8. The use of EMI as a reconnaissance tool for archaeological investigations covering large areas was introduced as an expedient method to reduce time and costs, and focus more detailed GPR surveys and archaeological excavations. While apparent conductivity (EC_a) data are commonly measured with EMI, the collection and interpretation of apparent magnetic susceptibility (χ) data was stressed in these investigations. Apparent magnetic susceptibility data provide additional and complementary information at sites surveyed with EMI. Further studies on the effective use of EMI and the collection of χ data over known and unknown gravesites of different ages are encouraged.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work with you and be of assistance to you and your fine staff.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:

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Technical Report

Jim Doolittle

Background:

“NRCS considers cultural resources in its conservation planning for the same reason it protects the natural resources — the soil, water, air, plants and animals — on your property. Keeping natural resources in balance helps provide the basis for a healthy and profitable farm environment; keeping cultural resources provides the basis for understanding our human past. The stewardship of these nonrenewable resources is an important link in the conservation ethic that underlies the NRCS mission. Several Federal, state, and local laws have been enacted to preserve cultural resources. The most important of these is the National Historic Preservation Act of 1966. Under this and other legislation, Federal agencies, including the U.S. Department of Agriculture's Natural Resources Conservation Service, are required to protect cultural resources.” (<http://www.nrcs.usda.gov/technical/ECS/culture/mission.html>).

Equipment:

An EM38-MK2 meter (Geonics Limited; Mississauga, Ontario) was used in the reported studies¹. The EM38-MK2 meter operates at a frequency of 14,500 Hz and weighs about 5.4 kg (11.9 lbs). This meter requires no ground contact and only one person to operate (Figure 1). The meter has one transmitter coil and two receiver coils, which are separated from the transmitter coil at distances of 1.0 and 0.5 m. This configuration provides nominal exploration depths of about 1.5 and 0.75 m in vertical dipole (VDO), and about 0.75 and 0.40 m in the horizontal dipole (HDO) orientations. In either dipole orientation, the EM38-MK2 meter provides simultaneous measurement of both quadrature phase (apparent electrical conductivity (EC_a)) and in-phase (apparent magnetic susceptibility (χ)) components, within two distinct depth ranges. Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2007).



Figure 1. Jacob Isleib, Soil Scientists on the Soil MLRA Soil Survey Office 12-6 Staff, conducts an EMI survey across grounds of the Old Southington Lighthouse, Southington, Connecticut.

¹¹ Manufacturer's names are provided for specific information; use does not constitute endorsement.

A Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced data collected with the EM38-MK2 meter.² An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both GPS and EMI data². The newly developed RTM38MK2 program (Geomar Software, Inc., Mississauga, Ontario) was used with the EM38-MK2 meter to display and record both GPS and EMI data on the Allegro CX field computer.² The RTmap38MK2 system provides immediate tracking and viewing capabilities on the Allegro CX computer. With these capabilities, the operator can visually correlate spatial EC_a or χ patterns with soil, landform and cultural features as surveys progress. In addition, with this software, sites can be more uniformly covered (avoiding skipping areas) and unnecessary overlap of survey lines is prevented.

To help summarize the results of the EMI surveys, the SURFER for Windows (version 9.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulations shown in this report.² Grids were created using kriging methods with an octant search.

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).² The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 400 MHz antenna was used in the investigations.

The RADAN for Windows (version 6.6) software program (developed by GSSI) was used to process the radar records shown in this report.² Processing used included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, range gain adjustments, and migration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

Calibration of GPR:

Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, bedrock) 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 equation [1] (after Daniels, 2004):

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

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to equation [2] (after Daniels, 2004):

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

C is the velocity of light in a vacuum (0.3 m/ns). Typically, 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. The dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in substantial increases in the relative permittivity of soils (Daniels, 2004). Using a 100 MHz antenna, Daniels (2004) observed that the relative dielectric permittivity of most dry mineral soil materials is between 2 and 10, while for most wet mineral soil materials, it is between 10 and 30.

² Manufacturer's names are provided for specific information; use does not constitute endorsement.

No ground-truth verifications of the velocity of propagation were attempted during this study. As a result, depth scales were approximated using hyperbolic velocity matching that was carried out during processing. Hyperbolic velocity matching provided rough estimates of average relative dielectric permittivity and the velocity of propagation at each site where the radar was used.

Amplitude Slice Analysis:

In recent years, the use of digital signals and sophisticated signal-processing software have enabled the enhancement of radar signals and improved pattern-recognition on radar records in some soils. Some of the signal processing methods used to improve the interpretability of subsurface archaeological features appearing on radar records are discussed by Sciotti et al. (2003) and Conyers and Goodman (1997). One advanced signal processing method that is commonly used in archaeological investigations is *amplitude slice analysis* (Conyers and Goodman, 1997). In this analysis, a three-dimensional (3D) pseudo-image of a small grid area is constructed from the computer analysis and synthesis of a series of closely-spaced, two-dimensional (2D) radar records. Amplitude differences within the 3D pseudo-image are analyzed in "time-slices" (or depth-slices) that examine changes within specific depth intervals in the ground (Conyers and Goodman, 1997). In this process, the reflected radar energy is averaged horizontally between adjacent, parallel 2D radar records and in specified time (or depth) windows to create a time-slice (or depth-slice) image. Each amplitude time-slice shows the spatial distribution of reflected wave amplitudes, which may indicate changes in soil properties or the presence of subsurface features. In many instances, 3D GPR imaging techniques have been used to distinguish and identify potential targets and to reduce interpretation uncertainties.

EMI-Magnetic Susceptibility:

Typically EMI focuses on the electrical properties (EC_a) of earthen materials and neglects the magnetic properties. Apparent magnetic susceptibility (χ) also can have measureable effect, but its effects will be significantly less than the effects of EC_a , and will not as a rule be noticed in data sets. In most areas, it is generally assumed that the profiled earthen materials are non-ferromagnetic and have very low or immeasurable apparent magnetic susceptibility.

Magnetic susceptibility is a physical property of soils and earthen materials that is responsive to the presence of ferromagnetic materials. Soils with manifested magnetic properties are generally dominated by ferromagnetic minerals, maghemite, magnetite, and/or titanomagnetites (Mullens, 1977). In most terrains, magnetic susceptibility is very low. However, magnetic susceptibility has been observed to vary with slope positions (de Jong et al., 2000), soil drainage (Maier et al., 2006), vegetation (Dearing et al., 1996). In addition, high values of magnetic susceptibility have been associated with human occupation (Dalan and Banerjee, 1996) and industrial pollutants (Fialová et al., 2006; Magiera et al., 2006).

Survey Procedures:

Pedestrian surveys were made with the EM38-MK2 meter across all sites. The meter was operated in the deeper-sensing, vertical dipole orientation (VDO). The meter was operated in the continuous mode with measurements recorded at a rate of 1/sec. The long axis of the device was orientated parallel to the direction of traverse. Measured values of apparent conductivity (EC_a) were not temperature corrected to a standard temperature of 75° F. Depending on site conditions and the availability of time, either random traverses or detailed grid surveys were completed on sites with GPR.

Results:

Suffield Historic Homesteads

Samuel King House:

Both GPR and EMI were used in an attempt to identify remnants of an older structure (circa 1680) that was supposedly situated (41.9721 North Latitude, 72.6146 West Longitude) between an existing house and North East Street (State Highway 149) in Suffield, Connecticut. The site is located in an area of

Wethersfield loam on 3 to 8 % slopes (87B). The very deep, well drained Wethersfield soils (coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts) formed in glacial till. The low clay content of Wethersfield soils results in a low apparent electrical conductivity. This property is associated with low radar signal attenuation rates and relatively deep penetration; factors leading to highly suitability soil conditions for most radar applications.

Figure 2 is a representative radar record from this site. The horizontal and depth scales are expressed in meters. The depth scale is based on hyperbolic velocity matching that was carried out during processing. Hyperbolic velocity matching resulted in an average dielectric permittivity of 8 and a velocity of propagation of 0.10612 m/ns. This velocity of propagation was used to depth scale radar records collected at this site.

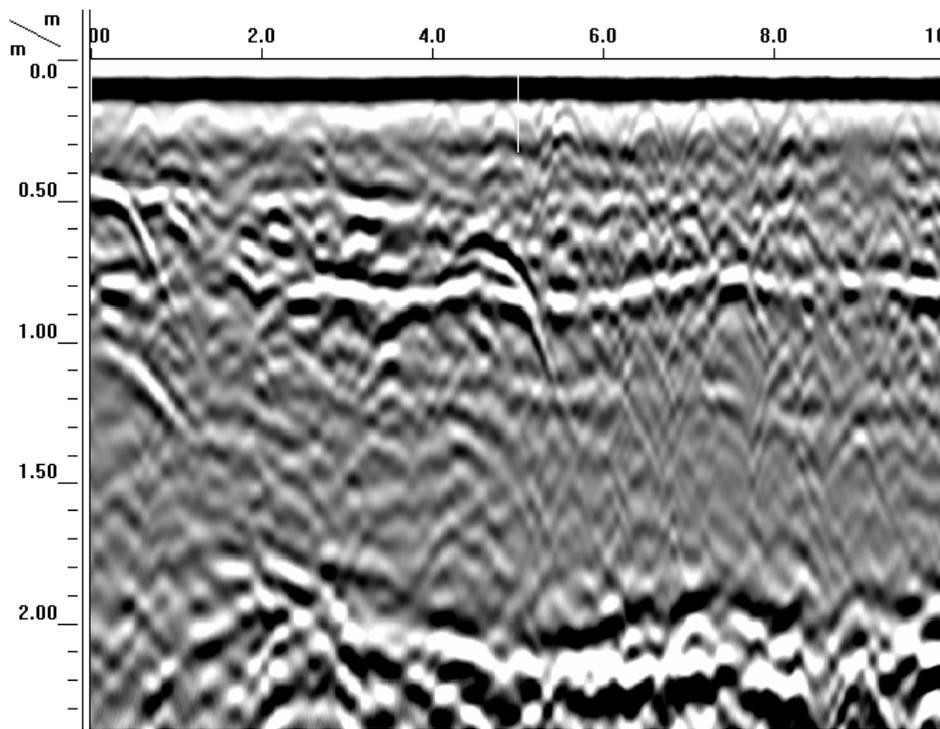


Figure 2. This radar record from the front lawn of the Samuel King House site was collected with a 400 MHz antenna. The two very conspicuous planar reflectors represent the interfaces between contrasting soil layers.

On the radar record shown in Figure 2, two continuous, planar reflectors are evident. One occurs at depths of about 60 to 80 cm, the other at depths of about 175 to 200 cm. Though not observed, these interfaces are believed to represent soil horizons. This radar image, which contains several point reflectors and two conspicuous planar reflector, is not representative of Wethersfield soils, which formed in till. Radar records collected over till are characterized by numerous, chaotically-spaced point reflectors and the absence of planar reflectors.

In Figure 2, near the 5 m distance mark, a short, white-colored, vertical line has been impressed on the upper part of the radar record. Beneath this line, at an estimated depth of about 60 cm, a noticeable hyperbolic reflection is evident immediately above the planar reflection from a soil horizon. As this feature was noticed on repeated radar traverses across the front lawn, it is believed to represent a buried pipe. The large number of low-amplitude hyperbolic reflections in the upper part of this record is attributed to small soil inhomogeneities, rock fragments, and tree roots.

The radar record shown in Figure 3 was collected immediately in front and parallel with the house at this site. On this radar record the horizontal and vertical scales are expressed in feet and inches, respectively. The two major interfaces that are evident on the radar record shown in Figure 2 are evident on this record as well. In Figure 3, the radar antenna appears to have been pulled at different rates of advance. This has resulted in the elongation of reflectors as the antenna's rate of advance was slowed or stopped (see "A" in Figure 3). No subsurface reflectors were observed on any radar record from this site that would suggest remnants of a former structure.

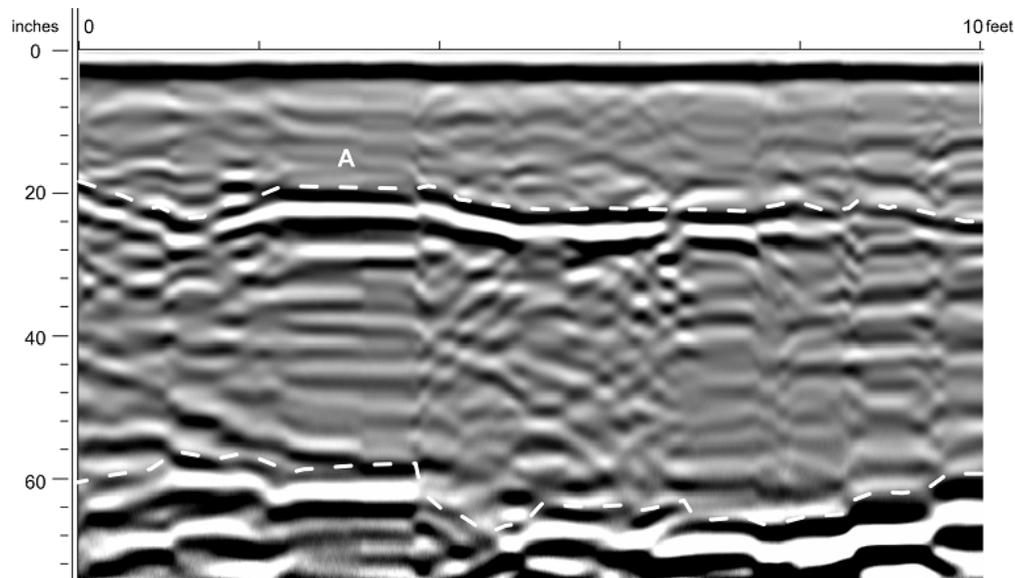


Figure 3. This radar record was collected immediately in front and parallel with the existing house at the Samuel King House site. On this radar record the horizontal scale is in feet and the vertical scale is in inches. The two very conspicuous planar reflectors noted in Figure 2 are also evident on this radar record.

Figure 4 contains plots of the EC_a (upper plots) and χ (lower plots) data collected with the EM38-MK2 meter over two soil depth intervals at the Samuel King House site. The existing house is located to the immediate west (left) of the survey area in the vicinity of "A" in Figure 4. In all plots, the higher values in the eastern portion of the survey area were initially attributed to road salts. However, as the values increase with increasing exploration depths, a buried utility rather than road salts, which would be concentrated near the surface, is suspected. Higher values near "A" are attributed to artifacts buried beneath the area immediately in front of the existing structure. As the homeowner indicated that a former porch extended outward from the house, these anomalous values are attributed to remnants of this former structure.

At the site of the former Samuel King House neither GPR nor EMI provided clues as to the location of this former structure. Both geophysical tools did indicate the presence of modern cultural features. Remnants from the former structure are believed to be either not present or, if present, lack sufficient contrast in physical properties (dielectric permittivity, apparent conductivity, or apparent magnetic susceptibility) to be detected with either GPR or EMI.

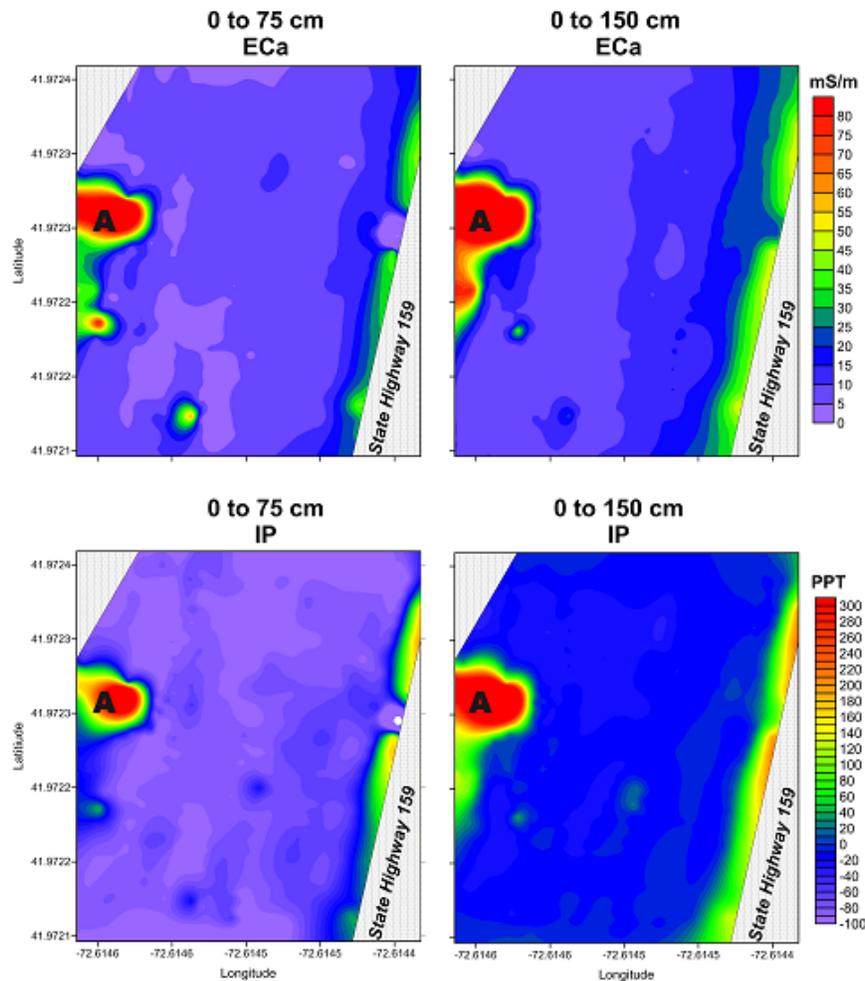


Figure 4. These plots of apparent conductivity (upper plots) and apparent susceptibility (lower plots) were generated from data collected with the EM38-MK2 meter operated in the VDO at the Samuel King House site. The depth of effective exploration is shown above each plot.

Reverend Gay Manse –Suffield Academy:

A reconnaissance EMI survey was conducted near the Reverend Gay Manse, in an attempt to identify buried remnants of several older structures (circa 1740) that were situated (41.9846 North Latitude, 72.65 West Longitude) along Main Street in Suffield, Connecticut. The former structures include the Suffield House Hotel, a livery stable, and two private homes (all removed from the site over twenty years ago). The site consists of two lawns that are located in an area of Broadbrook silt loam on 3 to 8 % slopes (82B). The well drained Broadbrook soils (coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts) formed in a mantle of silty materials that overlie lodgment till. The soils are very deep to bedrock and moderately deep to a densic contact. The comparatively low clay content of Broadbrook soils results in a low apparent electrical conductivity. This physical property results in low radar signal attenuation rates, which afford relatively deep exploration depths and high suitability soil conditions for most radar applications. Because of time limitations and intermittent rains, GPR was not used at this site.

Figure 5 contains two plots of both the apparent conductivity (upper plots) and apparent magnetic susceptibility (lower plots) data that were collected with the EM38-MK2 meter at the Reverend Gay Manse site. The effective depth of exploration is identified above each plot. The survey area is divided into two segments: a southern segment, which contains the front lawn to the Gay Manse, and a northern

segment, which is the site of the three former structures. Both segments are bounded on the west by Main Street. The driveway to the Gay Manse separates the two segments. The approximate location and dimensions of the Reverend Gay Manse has been identified with a black-colored rectangle in each plot.

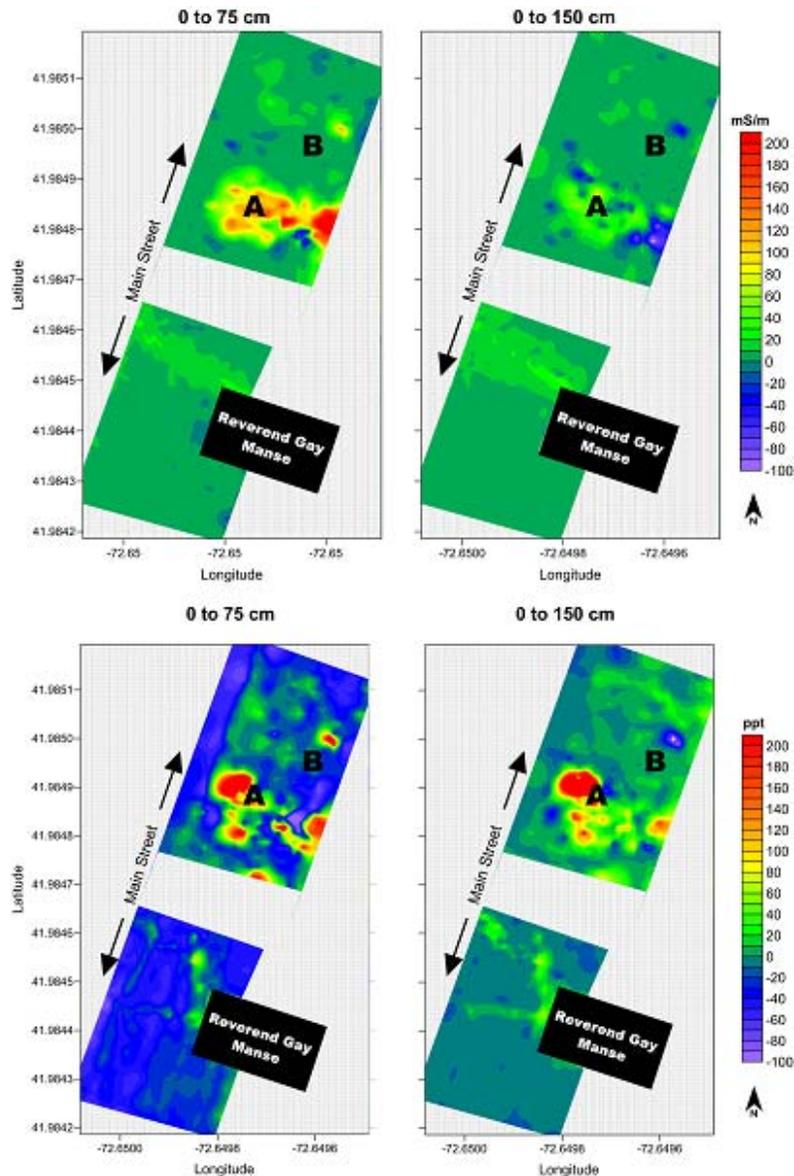


Figure 5. These plots of apparent conductivity (upper plots) and apparent magnetic susceptibility (lower plots) were generated from data collected with the EM38-MK2 meter operated in the VDO at the Reverend Gay Manse site in Suffield. The depth of effective exploration is shown above each plot.

The survey segment that contains the front lawn to the Reverend Gay Manse has comparatively low and invariable EC_a . In all of the plots shown in Figure 5, a linear feature can be seen trending from Main Street to the northwest corner of the Manse. As this linear feature terminates near meters attached to the Manse, the spatial patterns are presumed to represent buried utility lines. In the plots of the χ data (lower plots), this linear feature is more pronounced, but appears narrower. Also in plots of χ data, an additional linear feature can be seen extending outwards from near the front doorstep of the Manse directly towards

Main Street. As this feature is more clearly expressed on the data collected with the deeper-sensing, 100-cm intercoil spacing, it is presumed to be more deeply buried and suggestive of a buried water or sewage line. In the χ data collected with the shallower-sensing, 50-cm intercoil spacing (lower left-hand plot in Figure 5), with close scrutiny, a poorly expressed linear feature can be detected that closely parallels Main Street. This pattern may represent the effects of soil compaction caused by foot traffic.

The northern survey segment contains several obvious and noteworthy features. In all plots shown in Figure 5, the zone of conspicuously higher EC_a and χ values that extend outwards from “A” is believed to represent remnants of the former Suffield House Hotel. As this zone is more apparent in the shallower plots of both EC_a and χ data, a majority of the contributing underlying materials are presumed to be shallowly buried. However, as contrasting and conspicuous spatial patterns are also evident on the deeper-sensing plots, the presence of more deeply buried artifacts and possibly a basement cannot be ruled out. Also evident in all plots shown in Figure 5, are the fairly conspicuous and contrasting spatial patterns near “B”. Knowing the history of this site, the features producing these patterns are presumed to be the remnants of one of the former houses. Though weakly expressed, the χ data (Figure 5, lower plots) seems to define a large, seemingly rectangular zone in the northern segment, which, perhaps, defines an area of extensive cultural disturbances.

The use of electromagnetic induction at the Reverend Guy Manse site in Suffield, Connecticut, provided a very rapid and effective tool for locating and identifying “areas of interest” over a relatively large area. Spatial patterns appearing on plots of EC_a and χ data were associated with the Manse and three former structures. Follow-up investigations with GPR can be used to provide higher resolution data of subsurface features within the small, selected areas identified with EMI at this site.

Essex Riverfront - War of 1812

During the War of 1812, a British fleet anchored and blocked traffic at the mouth of the Connecticut River. Under the command of Captain Richard Coote, five boats manned by sailors and marines oared up the Connecticut River, raided the maritime-town of Potapoug (present day Essex) and burned over 27 ships in the harbor. At the time of the raid, Potapoug was a major center of shipping and shipbuilding center.

Archaeological investigations that were carried out in 1989 near the Connecticut River Museum revealed portions of a buried bulkhead, which is historic records indicate was from three to four hundred feet long. As this buried bulkhead defines the approximate location of the town's waterfront during the War of 1812, the Connecticut River Museum is interested in locating and determining the extent of this feature. Based on the 1989 archaeological dig, the bulkhead is located close to the fence line that borders the parking area behind the Connecticut River Museum. Using the 400 MHz antenna, two detailed radar grid surveys were conducted across paved portions of the parking area.

The survey sites are located in an area of Udorthents-Urban land complex (306). These mostly anthropogenic soils have been extensively altered by human activities. The parking area is underlain by fill materials of unknown origins and compositions. Though not confirmed by ground-truth observations, a dielectric permittivity of 5 was used to scale the radar imagery. This E_r is representative of fairly dry, coarse-textured materials. However, as the site consists of fill materials and is very near open water, variations in clay and moisture contents and E_r are expected. As a consequence of these differences, the depth scales used in the accompanying images should be considered only approximations of the actual depths.

Two survey grids were established across the parking area (around 41.3514 North Latitude, 71.3849 West Longitude). Grids were established adjacent to one another with Grid 2 located to the north of Grid 1.

Grids were restricted to the paved parking area. The western border of each grid was near a north-south trending property line. The northeast corner of Grid 1 was located adjacent to the sidewalk and parallel with the northern boundary of the Museum's lawn. Grid 1, the southernmost grid, had dimensions of 11 by 11 meters. A series of 23 parallel radar traverses were completed at 50-cm intervals across the grid area in alternating north to south, south to north directions. Each traverse line was 11 meters long with reference points spaced at 1 meter intervals along the line. Grid 2, the northernmost grid, was established immediately north of a small concentration of manhole covers in the parking area. Grid 2 had dimensions of 21 by 8 meters. A series of 17 parallel radar traverses were completed at 50-cm intervals across the grid area in alternating south to north and north to south directions. Each traverse was 21 meters long with reference points spaced at 1 meter intervals along the line.

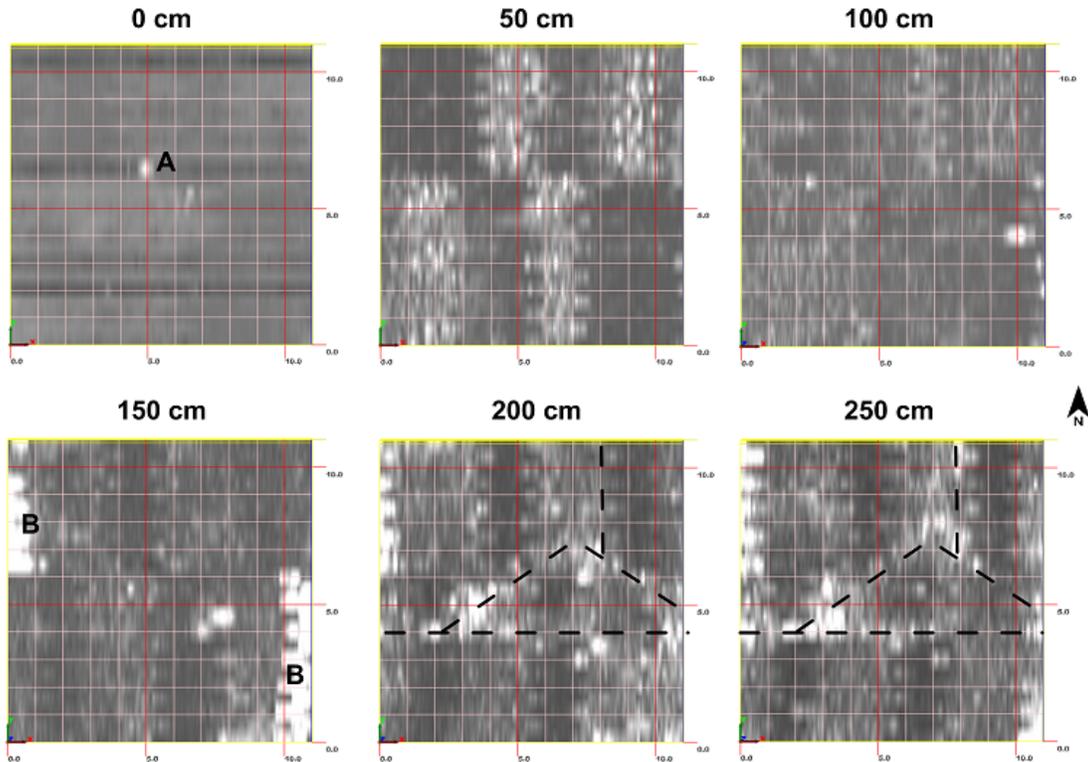


Figure 6. Six, time or depth slice images of Grid 1 from the Essex site are shown with horizontal slices graphically removed at depths of 50-, 100-, 150-, 200-, and 250-cm. Views are from directly overhead of the grid area looking down.

The results of the GPR surveys are displayed in the time sliced images shown in Figures 6 and 7. Figure 6 contains six time-sliced (or depth-sliced) images of Grid 1. In each of these images, the Museum's lawn is to the east (right), and property-line fence is to the west (left). The pseudo images shown on these plots are believed to represent mostly modern cultural features. The anomaly on the 0 cm slice is a manhole cover. A unique pattern of alternating high- (white-colored) and low- (black-colored) signal amplitude rectangles are evident on the 50-cm slice. The subsurface features that are responsible for these rectangular features are presently unknown. However, it is likely that this pattern is associated with the design and construction of the parking area. The spatial pattern evident on the 50-cm slice suggests potential differences in subgrade materials, soil compaction, or the presence of alternating strips of separation filter fabric. The alternating strips of high amplitude reflections, which are evident on the 50-cm slice, dampen underlying reflector signal amplitudes that are seen on all deeper time-slice images.

In Figure 6, on the 150-cm slice, two rectangular zones consisting of high amplitude signals are labeled (see “B”). These two conspicuous zones are most likely produced by buried cultural features, which parallel the eastern and western borders of the grid site. On deeper depth-slice images, the patterns appearing in the northwest corner of the 150-cm slice, though not as well expressed, persist. This feature(s) may represent the buried bulkhead, but ground-truth observations are needed to confirm any interpretation.

In Figure 6, on the 200- and 250-cm depth slices, three segmented lines have been drawn. Taken more liberties than warranted, high amplitude reflections that follow linear traces have been connected to create these lines. These lines suggest the locations of buried utility lines that are known to occur beneath the parking area. It must be reemphasized that the depths appearing on all the pseudo-images of this site are mere approximations, which should be verified with ground-truth cores.

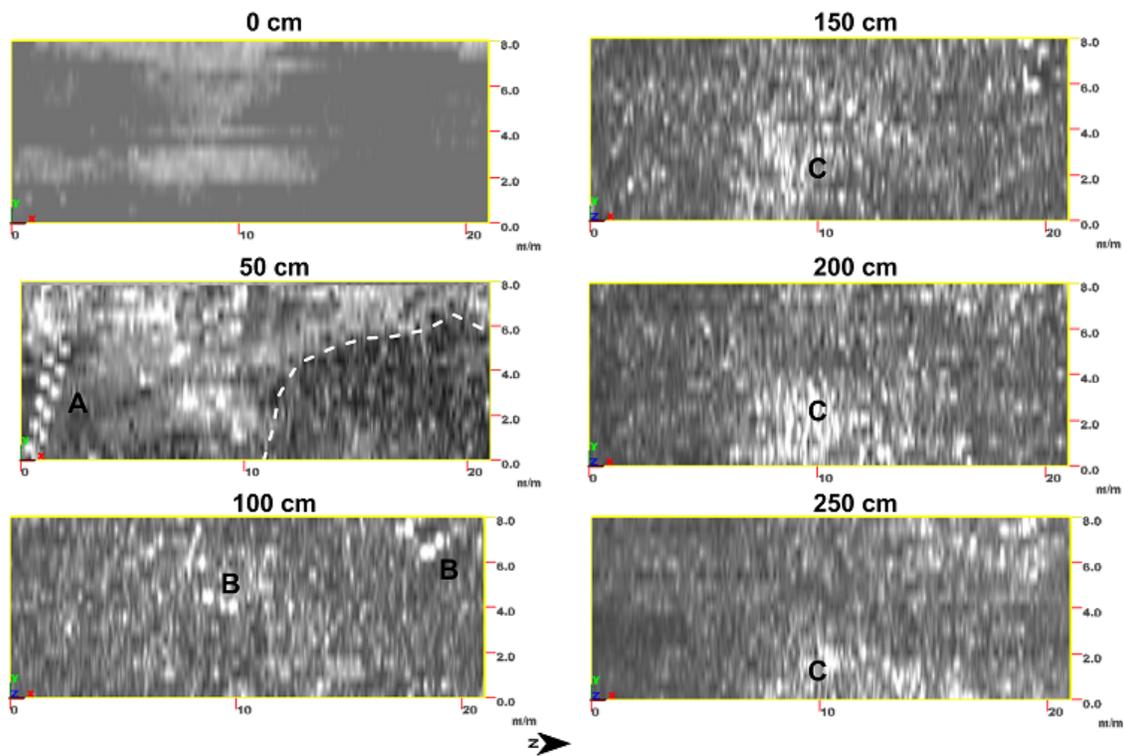


Figure 7. Six, time or depth slice images of Grid 2 from the Essex site are shown with horizontal slices graphically removed at depths of 50-, 100-, 150-, 200-, and 250-cm. Views are from directly overhead of the grid area looking down.

Figure 7 contains six time-sliced images of Grid 2. In each of the images, north is to the right and the property-line fence is to the west (top). On the 50-cm slice, a suspected, buried utility line is evident to the left of “A”. On this slice, a segmented white-colored line has been drawn to indicate the approximate boundary of different fill materials. These materials are differentiated based on difference in reflected signal amplitudes and spatial patterns. On the 100-cm slice, two areas, which contain multiple, high-amplitude point reflectors, have been identified at “B”. In the 150-, 200-, and 250- slices, an area of high amplitude signals have been identified at “C”. With increasing depth, this area appears to migrate towards the east and coastline.

While the grid surveys provided information on subsurface materials and features that lie beneath the parking area, no conclusive information can be gleaned from the radar 3D pseudo-images that suggest the presence of the buried bulkhead. At this site and for this application, 2D radar records, which are easier to collect and process, are perhaps more informative of the cultural features buried at this site. However, once identified, 3D GPR will provide greater information on the geometry of some of these features.

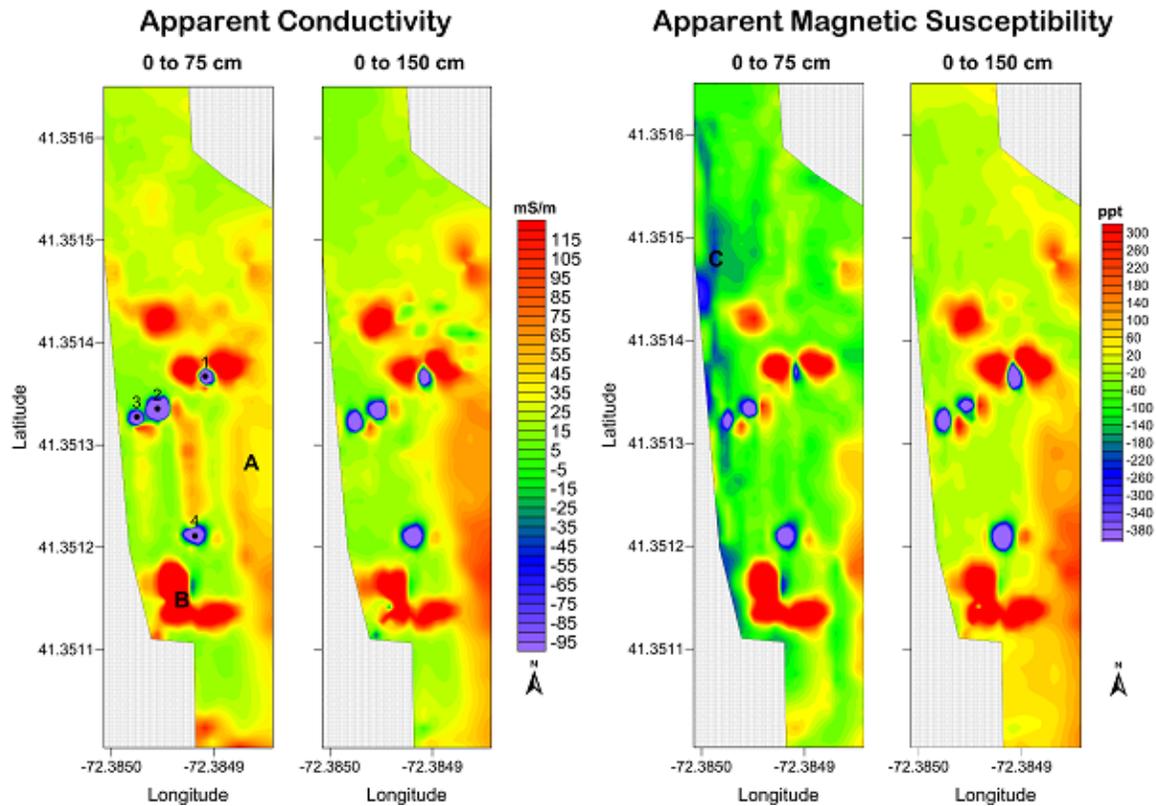


Figure 8. These plots of apparent conductivity (two left-hand plots) and apparent magnetic susceptibility (two right-hand plots) were generated from data collected with the EM38-MK2 meter operated in the VDO at the Essex Riverfront site. The effective depth exploration is shown above each plot.

An EMI survey was also conducted across the Essex site. Compared with GPR, the EMI survey was less labor intense and faster. Figure 8 contains four plots of the data collected with the EM38-MK2 meter at this site. In the plot of the EC_a data representing the 0 to 75 cm depth interval (left-most plot), four manhole covers have each been identified by a spot symbol (•) and numbered. These same features are evident on the other plots shown in Figure 8. When the meter is directly over these manhole covers a high negative anomaly is produced. However, as the meter approaches and retreats from the covers, high positive anomalies are produced on either side of the cover. These positive anomalies can be seen flanking most of the manhole covers.

In Figure 8, in the plot of the EC_a data representing the 0 to 75 cm depth interval, a broad zone of higher conductivity (labeled “A”) extends up and down the east side of the survey area. As this area is nearest the coast line, the higher conductivity is attributed to salt water intrusion. Also in this plot, the symbol “B” signifies a large cultural anomaly, which is believed to have been produced by an additional manhole cover and related underlying features. In this and other plots, narrow lineations of higher EC_a suggest the possible presence and tracks of buried utility lines.

In Figure 8, in the plot of the apparent magnetic susceptibility data representing the 0 to 75 cm depth interval, several lineations of low amplitude signals are evident along the western border of the site. While the feature(s) responsible for these anomalous patterns is unknown, their presence along the west border of the site, the area in which the buried bulkhead was uncovered, does tantalize the imagination.

At the Essex site, both EMI and GPR worked well and provided ample subsurface interpretive data, which can be used to help characterize the site. However neither geophysical method provides conclusive evidence supporting the presence and extent of a buried bulkhead.

Hidden Chamber, Danielson:

During renovations to a house located on Reynolds Street in Danielson, Connecticut, a hidden chamber was discovered behind a narrow passage in a basement wall. The purpose, use, and dimensions of this hidden chamber are unknown; however, thoughts of a possible 19th-century safe house for escaped slaves using the *Underground Railroad* logically follow. The house is located in a delineation of Udothents-Urban land complex (306). A small, detailed GPR grid survey was conducted over a portion of the grounds located immediately behind the house that are believed to overlie this suspicious structure.

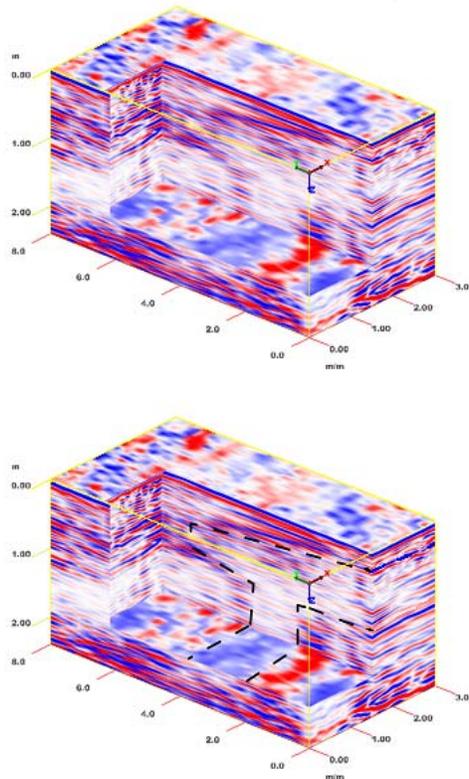


Figure 9. These two 3D pseudo-images show the subsurface immediately behind a house in Danielson, Connecticut. A 1.5 by 6.5 m inset cube has been graphically removed to a depth of about 180 cm in each pseudo-image. In the lower images, segmented lines have been used to define the outline of the hidden chamber. The house is located to the immediate right of the pseudo-image.

The dimensions of the grid were 3 by 8 meters. A series of 32 parallel radar traverses were completed at intervals of 25 cm across the grid area. Each traverse was 3 meters long with reference points spaced at 1 meter intervals along the line. Figure 9 contains two 3D pseudo-images of the grid area. In each pseudo-

image a 1.5 by 6.5 m inset cube has been graphically removed to an estimate depth of about 180 cm. No ground-truth observations were made to determine the relative dielectric permittivity or velocity of signal propagation through the soil. An arbitrary dielectric permittivity of 5 and a velocity of signal propagation of 0.1342 m/ns were used to scale the radar imagery. As a consequence, the depth scale used in the accompanying images should be considered as only approximations of the actual depths.

In Figure 9, contains two 3D pseudo-images of the grid site. The location of the house is to the immediate right of the x-axis (front-right side) of the 3D pseudo-images. The outline of the air-filled chamber is evident on both pseudo-images. On the lower pseudo-image, segmented black-colored lines have been used to assist the visualization of the hidden chamber. On both 3D pseudo images, spurious reflections from other subsurface features and the chamber's surfaces produce some unwanted background noise and clutter. However, the general absence of reflectors can be used to approximate the general location of the air-filled chamber. It must be noted that the vertical dimensions of the air-filled chamber are not to scale. This is because of the increased velocity of propagation through air and the increased distance a radar pulse will travel in a given unit of time within the air-filled chamber. The chamber's vertical dimensions are actually larger than portrayed in these 3D pseudo-images. What is truly exciting is what appears to be a shaft in the chamber's floor. This shaft is evident on the floor of the inset cube between the 2 and 4 m distance marks on the Y-axis (front left-side).

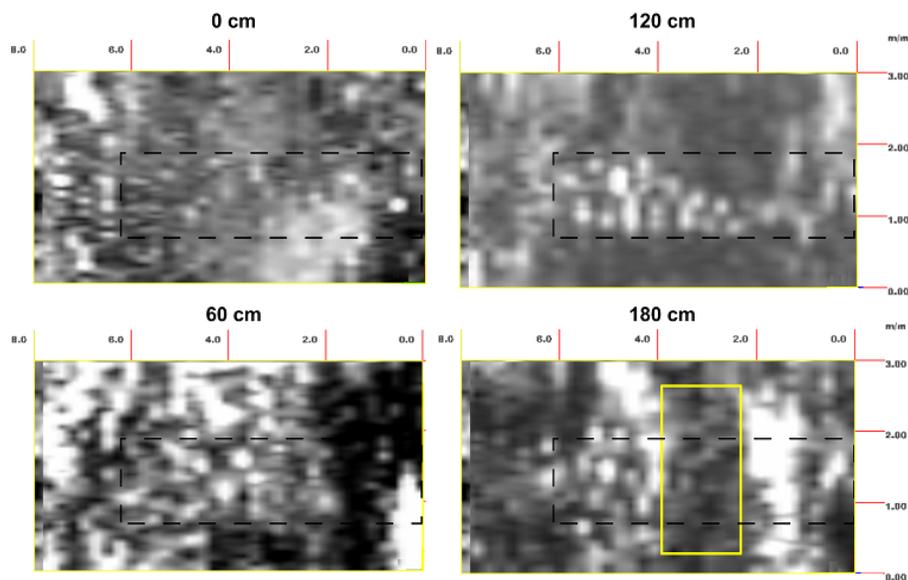


Figure 10. Four, time- or depth-slice images of the hidden chamber in Danielson, Connecticut, are shown with horizontal slices graphically removed at approximate depths of 0-, 60-, 120-, and 180-cm. Views are looking downwards from directly overhead of the grid area. The house is located to the immediate right.

Figure 10 contains four time-sliced pseudo-images of the subsurface underlying the Danielson grid site. In each of these images, the house is located to the immediate right. On each image, segmented black-colored lines outline the interpreted location of the hidden chamber. While the ceiling of this buried structure is difficult to discern, its floor is clearly expressed on the 120-cm slice. It must be reiterated that the vertical scale is an approximation. Because of the faster passage of radar pulses through the air-filled cavity of the chamber, the depth to the chamber's floor is greater than shown (1.2 m). On the 180-cm slice, yellow lines outline the location of the suspected shaft in the hidden chamber's floor. Here, two

parallel, high amplitude (colored-white) reflectors separate a low amplitude area that is the suspected shaft. The low amplitude signals within the shaft indicate that is probably air-filled.

Waterford Cemetery

Town deeds recognize a former cemetery in an unkempt and neglected area of former farm land (41.3278 North Latitude, 72.1679 West Longitude) along Rope Ferry Road in Waterford. The deed mentions a cemetery, known as the *Caukins' Family Plot*, which dates back to the mid-1800s. Between 1890 and 1975, the land was used for dairy. The site of the cemetery is enclosed by stonewalls. The area enclosed by the stone walls (about 1 acre in size) is considered by the State Archaeologist as being too large for a family cemetery plot. While the presence of a former cemetery was not challenged, no vestiges are evident within the walled area. The site and nearby farm building are being considered for possible placement on the National Register of Historic Places and there is growing interest in documenting the cultural and archeological resources of Waterford.

The wall-enclosed area is located in a delineation Woodbridge fine sandy loam on 3 to 8 % slope (45B). The very deep, moderately well drained Woodbridge soils (coarse-loamy, mixed, active, mesic Aquic Dystrudepts) are moderately deep to dense till. The extensive size, uneven surfaces, and dense underbrush of this site made it unsuitable for GPR. A reconnaissance EMI survey of the site was therefore carried out within the wall-enclosed area in an attempt to isolate the actual cemetery site and define its boundaries. If successful, EMI would reduce the size of the area needed for further and more detailed archaeological investigations.

Figure 11, contains plots of the apparent conductivity (left-hand plots) and apparent magnetic susceptibility (right-hand plots) collected with the EM38-MK2 meter operated in the VDO. The two upper plots show spatial EC_a (left-hand) and χ (right-hand) data measured with the shallower sensing (0 to 75 cm), 50-cm intercoil spacing. The lower plots show spatial EC_a (left-hand) and χ (right-hand) data measured with the deeper-sensing (0 to 150 cm), 100-cm intercoil spacing. Metallic debris scattered on the surface throughout the site obscures the identification of the cemetery with EMI. However, this debris was most concentrated in around the inset area in northwest corner of the site. Many of the anomalous values recorded in this portion of the site are associated with this debris.

While different values and patterns are evident in the plot shown in Figure 11, two areas that contain complex spatial patterns and anomalous values on all plots are identified. These two areas have been enclosed by circles in the plots shown in Figure 11. While no definite patterns suggesting the location of the cemetery are evident on the plots shown in Figure 11, the two areas enclosed by circles are the most promising based on EMI data alone. If needed, these areas are recommended for further archaeological investigation. In Figure 11, the plots of χ data (right-hand plots) show several sets of lines that cross the lower portions of this site. The features that cause these lineations are unknown at this time.

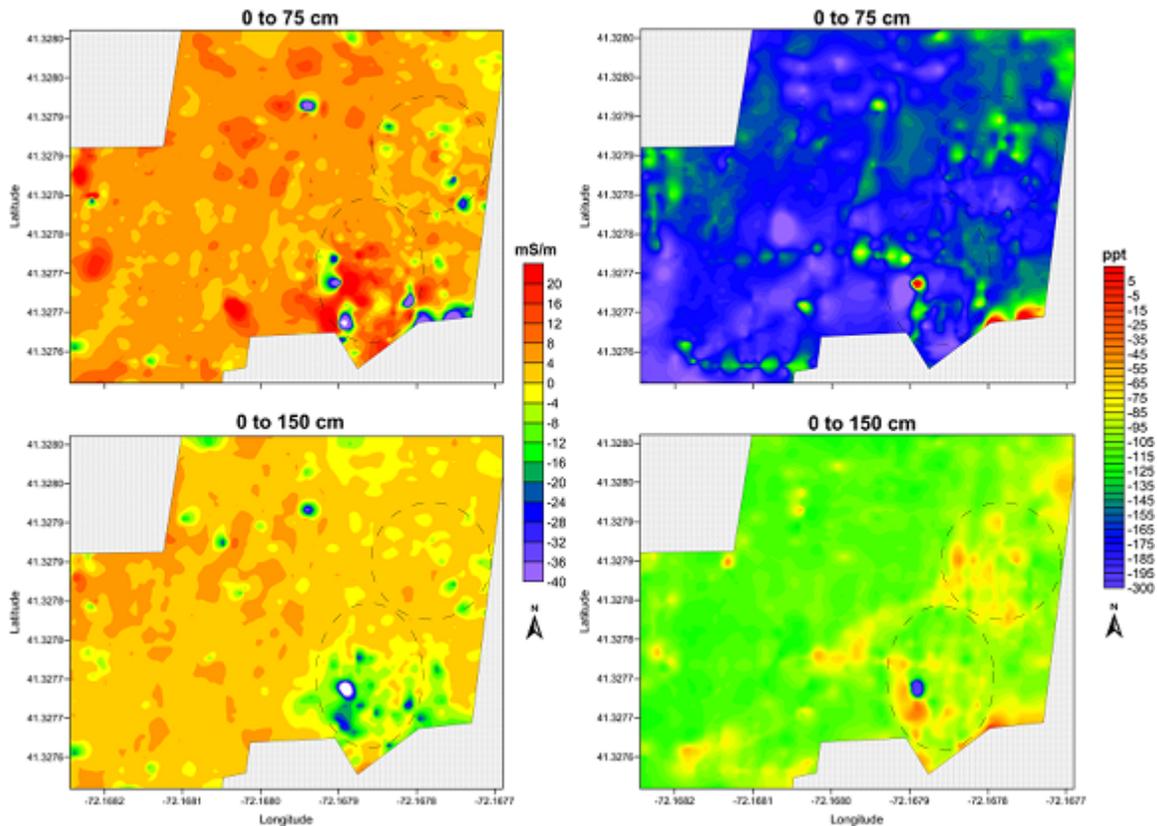


Figure 11. These plots of apparent conductivity (two left-hand plots) and apparent magnetic susceptibility (two right-hand plots) were generated from data collected with the EM38-MK2 meter operated in the VDO at the Waterford Cemetery Site. The effective depth exploration is shown above each plot.

Stonington Lighthouse:

The original Stonington Lighthouse was a 30-foot stone tower built on Stonington Point in 1823. Its beacon was visible over 12 miles out to sea. The original location of the lighthouse was vulnerable to excessive beach erosion, which forced the dismantling of the structure in 1840. Materials from the old lighthouse were used to build a new tower and keeper's dwelling on its present site (41.3285 North Latitude, 72.9054 West Longitude). The light remained active until 1889, when a beacon was installed on the outer end of a breakwater that protects the entrance to Stonington Harbor.

At the time of this geophysical investigation, the exact location of the original lighthouse was unknown to the investigators. Because of the size of the area of interest, only EMI was considered. This method is more expedient than GPR and would provide a more comprehensive coverage of the areas of interest in the allotted time. During the EMI survey, several participants entered the Stonington Lighthouse Museum and took a picture of a map, which showed the original lighthouse's location. Later, Jacob Isleib used GIS to overlay and georeference the historic map on modern imagery of the site. Figure 12 is the product that was produced by Jacob. As can be seen, the areas that were surveyed with EMI (polygons enclosed by black-colored lines) do not contain the site of the original lighthouse.



Figure 12. Image of a georeferenced map photographed in the Stonington Lighthouse museum (prepared by Jacob Isleib). Further inland, the location of the old lighthouse is marked at the bottom of the peninsula. Further inland, the present lighthouse and the areas surveyed with EMI are identified. This map suggests that the original site is under the parking lot area, which was not surveyed.

Two areas were surveyed with EMI: a portion of the lawn just north of a parking area and the lawn area east and north of the present Stonington Lighthouse. The “lawn area” consists of the southernmost survey area enclosed in by polygon in Figure 12. This area is within a delineation of Udorthents-Urban land complex (306). A large portion of this area, however, consists of beaches. The area surveyed around the present lighthouse is in a delineation of Hinckley gravelly sandy loam, 3 to 25 % slopes (38C). The very deep, excessively drained Hinckley soils (sandy-skeletal, mixed, mesic Typic Udorthents) formed in coarse-textured glaciofluvial materials. The low clay contents of these soil materials should result in comparatively low EC_a , however, the affects of salt spray on the EMI response is unknown.

Figure 13 contains plots of the EMI data collected at the “lawn areas” (left-hand plots) and the Stonington Lighthouse (right-hand plots). In each set of four plots, the upper two plots are of apparent conductivity the lower two plots are of apparent magnetic susceptibility. The effective depth exploration is shown either above (for the *lawn area*) or in the lower right-hand corner (for the *lighthouse* (LH)) of each plot.

The plots of EC_a for the lawn area (Figure 13; upper two plots in the left-hand set of plots) are unremarkable. Higher EC_a in the eastern portion of the site is associated with salt spray from Long Island Sound. Apparent magnetic susceptibility (Figure 13; lower two plots in the left-hand set of plots), though relatively uniform spatial across the site, shows a significant and unexpected increases with depth. The

reasons for this dramatic increase and change is unknown at this time, but may be worthy (from a soil point of view) of further study.

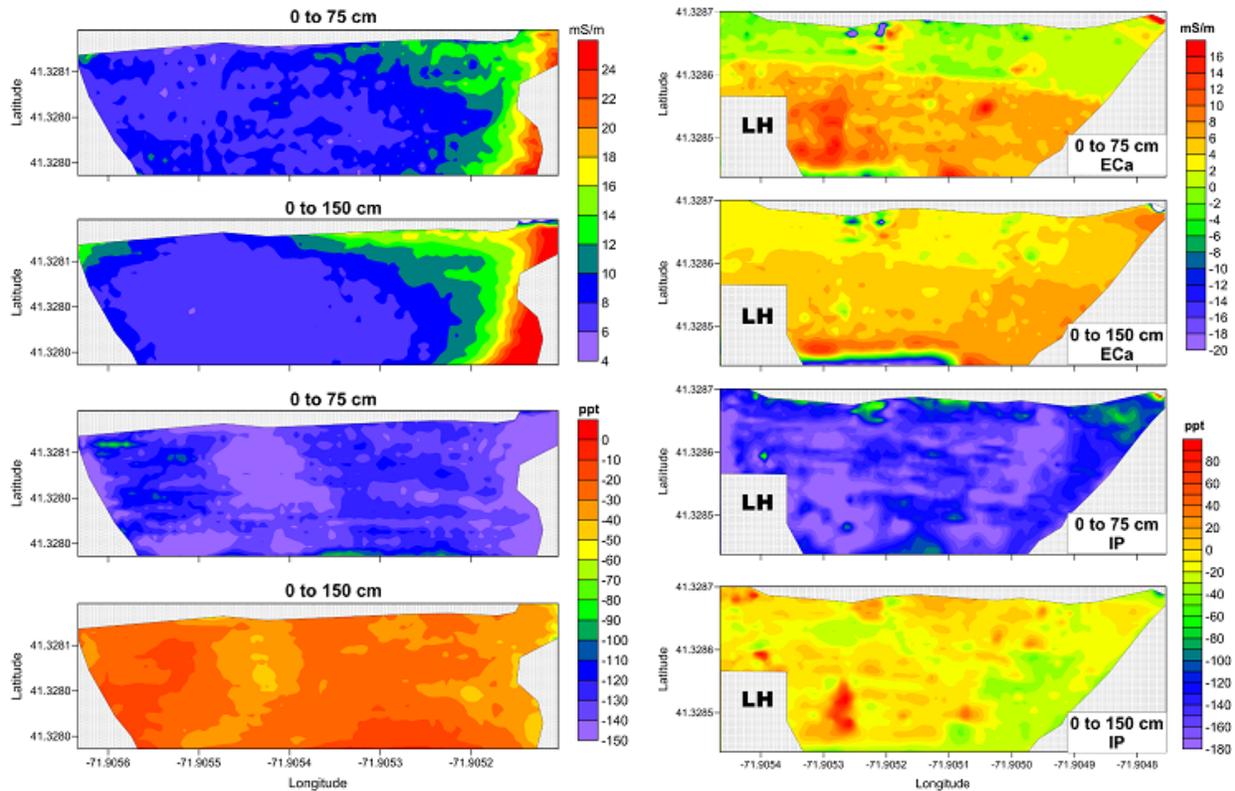


Figure 13. Plots of data collected at the “lawn areas” (left-hand plots) and the “lighthouse area” (right-hand plots) in Stonington, Connecticut. In each set, the upper two plots are of apparent conductivity, while the lower two plots are of apparent magnetic susceptibility. The effective depth of exploration is shown either above (lawn area) or in the lower right-hand corner (lighthouse (LH)) of each plot.

The plots of EC_a for the lighthouse area (Figure 13; upper two plots in the right-hand set of plots) show an east west line that separates lower EC_a readings to the north, from higher EC_a readings to the south. This difference is not caused by soil properties, but by a change in the meter’s operator. Difference in the carrying height of the meter or metallic items worn by one or both of the operators are presumably responsible for this noticeable change in EC_a . On the plots of EC_a data, the negative values just west (left) of center along the upper survey boundary were caused by metallic stakes, which had been driven into the ground at the corners of a parking pad, and by overhead power lines. The linear anomaly along the lower boundary of this survey area is attributed to buried utility line. The source of the anomalous EMI values to the immediate east (right) of the lighthouse (LH) is presently unknown. However, judging from their location, these anomalous values may be due to a buried septic system.

As was evident in the southern lawn survey area, χ , though spatially, relatively uniform across the lighthouse site, shows a large, comparable, and unanticipated increase in values with depth (Figure 13; compare the lower two plots in the right-hand set of plots). The reasons for this dramatic increase and change are unknown at this time, but are likely related to the differences in the concentration and size of ferromagnetic minerals in the sediments.

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