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SUBJECT: SOI – Geophysical Assistance

July 29, 2010

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File Code: 330-7

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Purpose:
At the request of the Major Land Resource Area (MLRA) Soil Survey Office 12-6 in Tolland, Connecticut, ground-penetrating radar (GPR) and electromagnetic induction (EMI) technical field assistance was provided to the initial soil survey of Hudson County, New Jersey, at Liberty State Park in Jersey City. In open areas of the Park, electromagnetic induction (EMI) was used as a reconnaissance tool to characterize the fill materials and delineate zones with different types and amounts of artifacts. Ground-penetrating radar (GPR) was used to estimate the thickness of "clean" fill materials overlying older coal ash/slag or dredged materials.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
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Debbie Surabian, MLRA Soil Survey Office 12-6 Leader, USDA-NRCS, Tolland, CT

Activities:
All geophysical activities were completed on 28 to 30 June 2010.

Summary:

1. The initial soil survey of Hudson County, New Jersey is nearing completion. This study reports on the use of geophysical tools over relatively open, lawn areas of Liberty State Park in support of this soil survey. Much of this park is located on land-filled tidal flats. Historically, this area

served as a major waterfront-industrial district with extensive road, rail and ferry infrastructures and related industrial buildings. The land was later abandoned and used as a dump site. Liberty State Park was opened in 1976 as an urban recreational area. The New Jersey Division of Parks and Forestry has transformed an area that once consisted of blighted buildings, overgrown tracks and debris into a model urban state park. The park has been largely cleared of all visible remains of its former land uses.

2. The methodology used in this investigation was designed to rapidly cover a large area with a relatively dense number of measurements and to identify anomalous zones. The intent was not to conduct a high resolution survey that would identify individual structural or infrastructure features. Such a high-resolution survey would require grids of more closely spaced (1 to 6 m) traverse lines and greater attention to possible sources of background noise.

3. Electromagnetic induction was used to delineate different areas of near-surface anthropogenic materials. The EMI data identified several major contrasting zones that appear to correspond with historic records of land use and differences in composition of fill and dredged materials. GPR provided estimated of the thickness of relatively "clean" fill materials that overlie, contrasting older coal ash/slag and/or dredge materials.

4. Geophysical tools are not routinely used in urban soil surveys. Results from this study confirm the role of geophysical tools in locating anomalous areas, which correspond to differences in former land use, concentrations of subsurface artifacts (including buried infrastructures, foundations, and utility lines) and dredged or fill materials. Geophysical data can be used to judiciously and safely locate the placement of soil borings and pits, and to help delineate urban soil boundaries.

/s/ Jonathan W. Hempel

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Director

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Technical Report on Geophysical Investigations conducted in Liberty State Park on 28 to 30 June 2010.

James A. Doolittle

Equipment:
An EM38-MK2 meter (Geonics Limited, Mississauga, Ontario) was used in this study. [1] The EM38-MK2 meter weighs about 2.8 kg (6.2 lbs) and requires only one person to operate. The meter, which consists of one transmitter coil and two receiver coils, operates at a frequency of 14,500 Hz. The receiver coils are separated from the transmitter coil at distances of 100 and 50 cm. The 50-cm intercoil spacing provides nominal penetration depths of 0 to 75 cm in the vertical dipole orientation (VDO) and 0 to 38 cm in the horizontal dipole orientation (HDO). The 100-cm intercoil spacing provides nominal penetration depths of 0 to150 cm in the VDO and 0 to 75 cm in the HDO. Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2008). The EM38-MK2 meter provides simultaneous measurements of both quadrature-phase (imaginary component; the portion of the secondary magnetic field that is shifted 90-degrees relative to the primary magnetic field) and in-phase (real component; portion of the secondary magnetic field that is in-phase with the primary magnetic field) components within two depth ranges.

To help summarize results, SURFER for Windows (version 9.0), developed by Golden Software, Inc. (Golden, CO), was used to construct plots of the collected EMI data.[1] Grids of EMI data were created using kriging methods with an octant search.

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (hereafter referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH). [1] 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 200 MHz antenna was used in this study.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records shown in this report.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, migration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). In this report, all radar records are displayed as 3D-renditions.

A Pathfinder ProXT GPS receiver (Trimble, Sunnyvale, CA) with Hurricane antenna was used to georeferenced data collected with the EM38-MK2 meter and the SIR-3000 system.[1] During surveys, EMI and GPS data were automatically recorded in an Allegro CX field computer (Juniper Systems, Logan, Utah). [1] The RTmap38MK2 and the RTmap38 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EMI and GPS data.[2] Quadrature-phase data (EC_a) are expressed in milliSiemens/meter (mS/m). In-phase data are expressed in parts per thousand (ppt).

The SIR-3000 system provides a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan of the radar can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN is used to proportionally adjust the position of each radar

[1] Trade names are used for specific references and do not constitute endorsement.

scan according to the time stamp of the two nearest positions recorded with the GPS receiver. On the GPS receiver, position data were recorded at a time interval of one second.

Survey Procedures:
The EMI surveys were completed by towing the EM38-MK2-2 meter, which is mounted in a plastic sled, behind an ATV (Figure 1). This mobile survey was completed by driving the ATV at a uniform speed (3 to 4 m/sec) across the open lawn areas of Liberty Park. The EMI data discussed in this report were not temperature corrected to a standard temperature (25^{o} C).

Random GPR surveys were conducted over open lawn areas located in the southern portion of Liberty Park east of Freedom Way (see Figure 8). The SIR-3000 GPR system was carried in a harness with the 200 MHz antenna being dragged along the surface (Figure 2). As Liberty Park is a protected area, no ground-truth auger observations or calibration trials were conducted. On all displayed radar records, the depths scale approximates and is based on the depth to the base of relatively clean fill materials observed in a nearby soil pit (see Figure 5). This scale uses a dielectric permittivity of 18, which corresponds to values for moist, moderately-coarse textured soil materials.

Figure 1. The mobile platform used to conduct EMI surveys at Liberty Park (photograph courtesy of Debbie Surabian).

Figure 2. Conducting a GPR survey at Liberty Park with the SIR-3000 system and a 200 MHz antenna.

Study Sites:
Liberty State Park is located along the Upper New York Bay in Jersey City, New Jersey. Much of this 1,212 acres (490 hectares) park is located on land-filled tidal flats. The area was once a major waterfront-industrial district with extensive road, rail and ferry infrastructures, and related industrial buildings. As the associated industries and the rail and ferry commerce declined, the land was abandoned and became a dump site. Presently, the New Jersey Division of Parks and Forestry operates and maintains Liberty State Park. This agency has transformed an area that once consisted of blighted buildings, overgrown tracks and debris into a model urban state park. The park was opened in 1976 and presently contains about 300 acres (121 hectares) that is used for public recreation.

Figure 3. In this Google Image of a portion of Liberty State Park, the areas that were surveyed with EMI are enclosed by red-colored, segmented lines. Ellis Island is in the lower right corner of this image.

Figure 4. In this pit, due to numerous hand dug pits at this location to fix a broken pipe, some coal ash/slag from below is mixed into the clean fill place on the surface.

Figure 5. Presumably this profile is more typical of the southern lawn area: a thin capping of relatively clean fill materials over coal ash/slag and sandy loam dredged materials overlying gray finer-textured dredged materials.

Results:

EMI:

An EMI survey was completed over 130 acres (53 hectares) of open lawns within Liberty State Park. This survey resulted in over 26,400 measurements being recorded in both the in-phase and quadrature phases for two different soil-depth intervals. The results of the survey are plotted in Figure 6. Each plot was compiled from over 26, 400 EMI measurements. In Figure 6, the two left-hand plots show the quadrature response, which corresponds to soil conductivity measured in mS/m. The two right-hand plots show the in-phase response, which is more sensitive to the presence of highly conductive metallic materials and is expressed in parts per thousands (ppt). In Figure 6, the upper plots are for the 0 to 75 cm depth interval as measured with 50-cm intercoil spacing on the EM38MK2 meter. The lower plots are for the 0 to 150 cm depth interval as measured with 100-cm intercoil spacing on the EM38MK2 meter. Recorded EC_a values ranged from about -480 to 1280 mS/m. Recorded in-phase values ranged from 1280 to 1280 ppt. These values are not diagnostic in themselves, but do reflect the presence of metallic artifacts (values of ±1280 are the highest allowed with the meter). Comparing the plots of quadrature and in-phase data, responses are larger and more variable with increasing depths of observation.

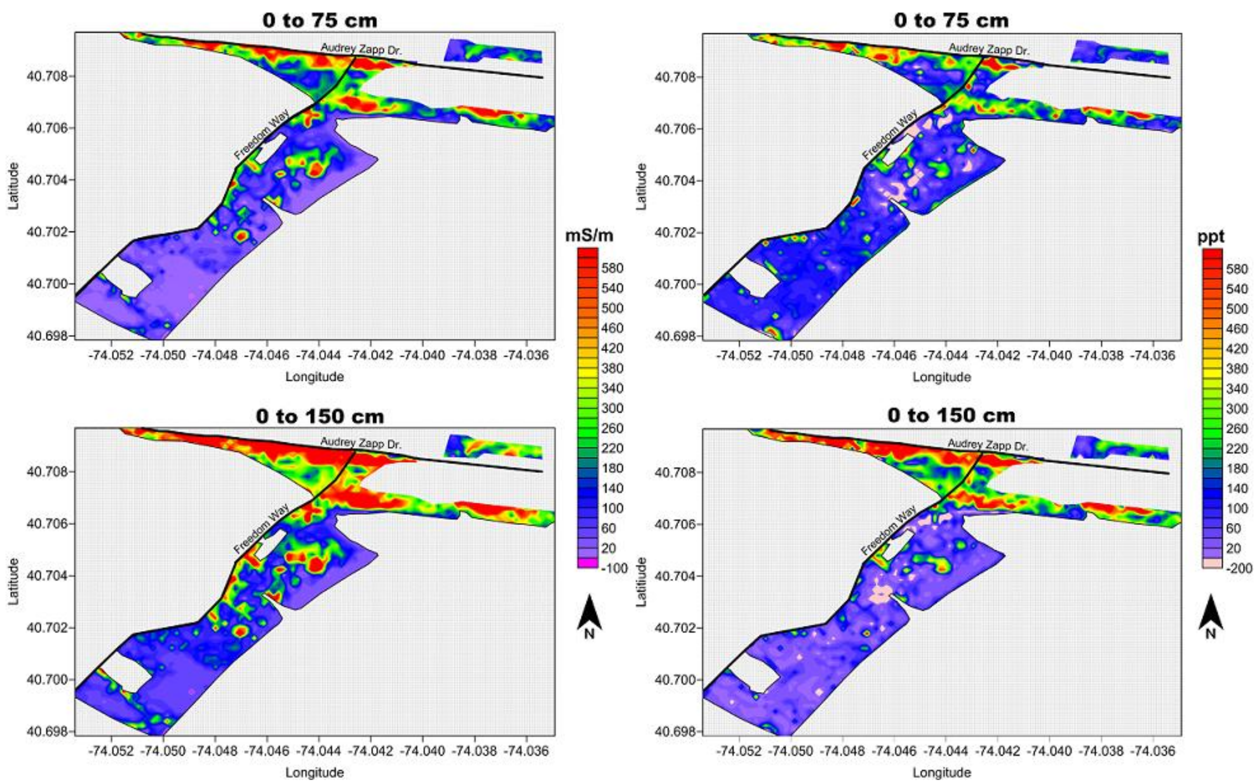

Figure 6. Date collected with the EM38MK2 meter with the shallower sensing 50-cm (upper plots) and deeper-sensing 100-cm (lower plots) intercoil spacings. Left-hand plots are for quadrature (soil conductivity) and right-hand plots are for in-phase (metal detection mode) responses.

The quadrature response reflects soil conductivity and the presence of metallic conductors. The in-phase response is more sensitive to metallic conductors and is often referred to as the "*metal-detection*" mode (McNeill, 1980). The magnitude of the in-phase response is proportional to the cube of the surface area of the metallic conductor and is inversely proportional to the conductors depth raised to the sixth power (Jordan and Costantini, 1995). In addition, the EMI response to buried metallic conductors is dependent on the orientation of the buried metals relative to the axis of the EMI meter. Spatial patterns that persist on both plots of quadrature and in-phase data are produced by metallic objects (Vickery and Hobbs, 1998).

In Figures 6 background conductivity and in-phase response levels are shown in shades of blue. Areas of highly conductive soil materials or buried metallic objects are shown principally is shades of yellow, green, and red. Figure 7, is a GIS rendition of the same conductivity data, but using different color ramps and scales.

In Figures 6 and 7, the northern portion of the survey area is known to be the location of former rail lines belonging to the now non-operational, Central Railroad of New Jersey (CRRNJ) and the Lehigh Valley Railroad. These lines ran essentially east to west and terminated in the northeast corner of the park. Here the historic CRRNJ Terminal serves as a tourist attraction and park office (building to the immediate west of the ferry slips in Figure 7). Conspicuously large in-phase and quadrature phase responses in this area of the park (Figures 6 and 7) are undoubtedly associated with buried rails and other debris associated with this former land use.

Figure 7. This GIS rendition of the quadrature response collected with the EM38MK2-2 meter operated in the VDO and recorded with the deeper-sensing (0 to 150 cm) 100-cm intercoil spacing was prepared by Debbie Surabian. Can you see areas of different land use and dredged materials?

The southern portion of the survey area contains more recent, and what is interpreted to be *cleaner* fill and dredged materials (see Figures 6 and 7). Here both in-phase and quadrature responses are generally lower. Isolated anomalous areas of higher or lower EMI responses reflect the presence of buried metallic artifacts scattered across this portion of the park. Though the EMI responses are lower in this portion of the park, these responses are still relatively high and are believed to reflect the composition of dredged materials and proximity to brackish water. In Figures 6 and 7, two inferred buried utility lines are apparent in the quadrature data (left-hand plots) collected in the extreme southern portion of the survey area. These two lines appear to merge with one another near Upper New York Bay. In Figure 7, linear patterns in the center section of the surveyed area are also suspected to represent buried utility lines running orthogonal with the shoreline. Relative EMI responses and spatial patterns evident in the plots shown in Figures 6 and 7 reflect differences in land use, dredged materials, and the concentration of buried metallic conductors. These patterns can be used to guide the partitioning of the survey area into different urban soil map units.

GPR:

Three radar traverses were completed in the southern portion of the open lawn area in the park. The identity, location, and direction of travel for each traverse line are shown in Figure 8. In Figure 8, colors have been used to indicate the estimated thickness of relatively clean fill materials (see Figure 5) based on soil depth classes. Based on the estimated (and not confirmed) dielectric permittivity and velocity of propagation used, the average thickness of relatively clean fill materials in the traversed areas is 96 cm with a range of 62 to 144 cm.

Figure 8. In this Google Earth image, the identity, location, and direction of travel of the three GPR traverse lines are shown. Colors are used to show relative thickness of clean fill based on soil depth classes.

Figure 9 is a plot showing the GPR traverse lines with data collected with the EM38MK2 meter in the deeper-sensing 100-cm (0 to 150 cm) intercoil spacing. Also shown in this figure are the locations of the soil pits shown in Figures 4 and 5. The area that was traversed with GPR is characterized in Figure 9 by relatively low and uniform EMI responses. Based on the results of geophysical surveys, this area is presumed to be covered by a thin cap of relatively "clean" fill materials overlying coal ash/slag and dredged materials and characterized by relatively low concentration of buried metallic conductors.

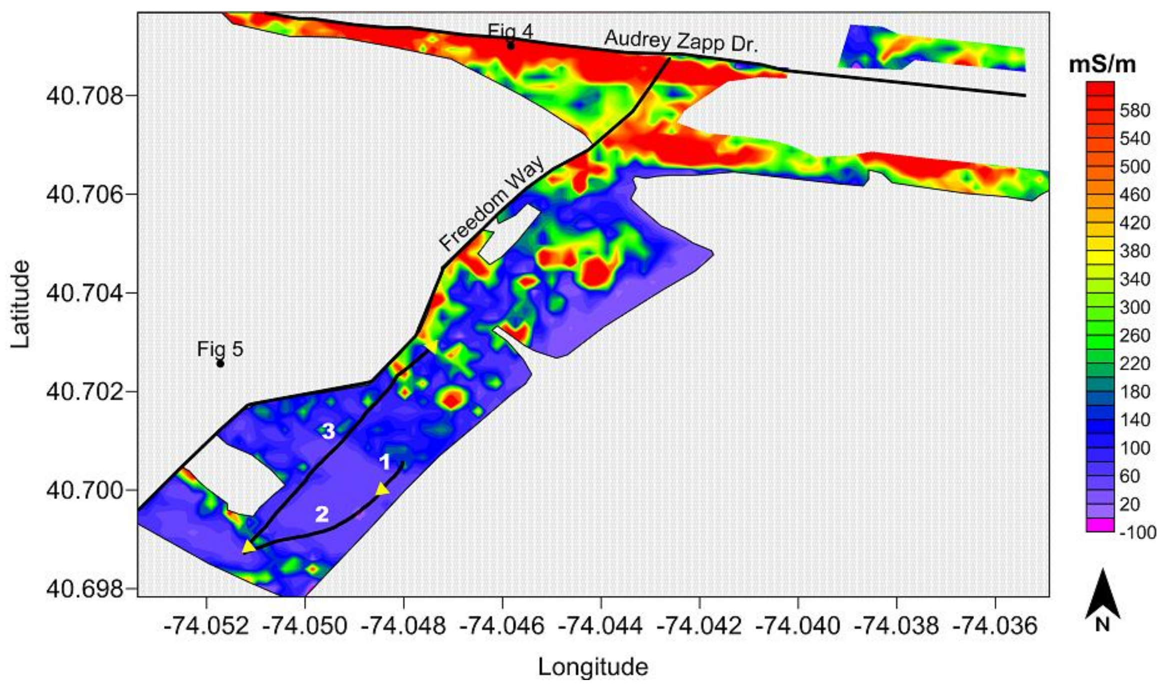

Figure 9. Plot of the date collected with the EM38MK2 meter operated in the VDO and with the deeper sensing, 100-cm (0 to 150 cm) intercoil spacing. Also shown are the locations of the three GPR traverse lines, their identities, lengths, and directions of travel. The locations of the soil pits shown in Figures 4 and 5 are also identified.

Figure 10 is a 3D rendition of the radar record for traverse line 1 (see Figures 8 and 9 for location). The direction of travel was from left (north) to right (south). The depth scale is expressed in meters. The Universal Transverse Mercator (UTM) grid is used in this and all 3D radar renditions shown in this report. Two *radar facies* are identifiable on this radar record. A *radar facies* is a mappable three-dimensional unit composed of GPR reflections whose internal reflection patterns and characteristics differ from adjoining units. The termination of these internal reflection patterns indicates the boundary of a radar facies. A thin, surficial radar facies is identifiable on this and the following radar records. This facies is relatively free of reflectors and represents the relatively thin (62 to 144 cm) "clean" fill materials that cover the park. The lower boundary of these deposits are indicated by relatively high amplitude (colored white, pink, blue, green and yellow) planar reflectors, which indicate contrasting textural layers of coal-ash, slag, and dredged materials. These underlying materials are stratified and contain greater abundances of fragmental materials (coal fragments, oyster shells, artifacts). These underlying, contrasting layers appear segmented and vary in inclination from horizontal to steeply incline.

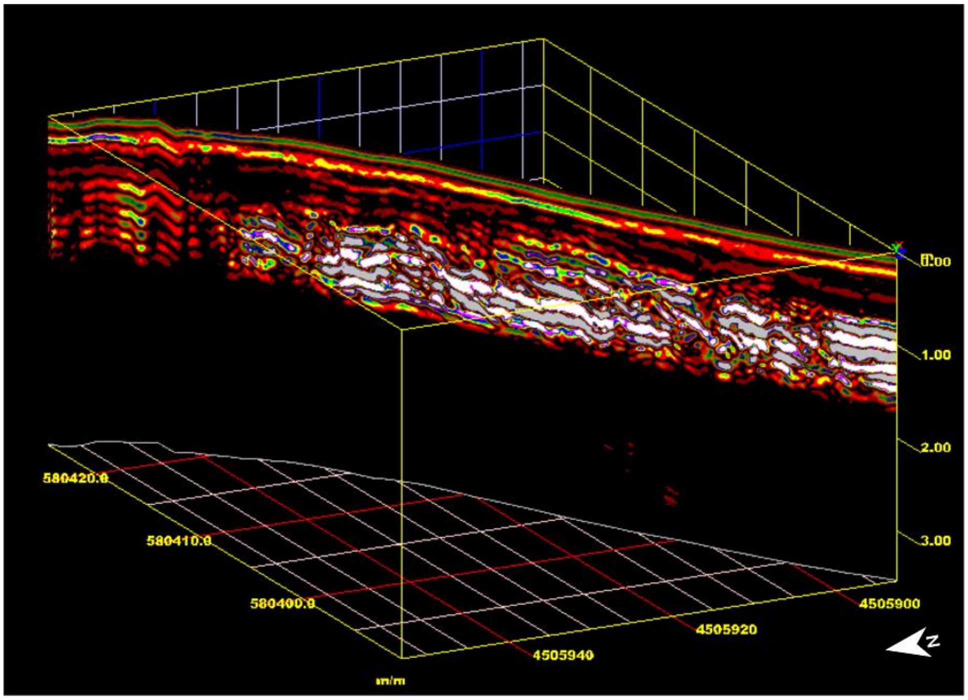

Figure 10. This 3D rendition of the radar record for traverse line 1 can be identified and located in Figure 8. The depth scale is expressed in meters. Coordinates are expressed in UTM.

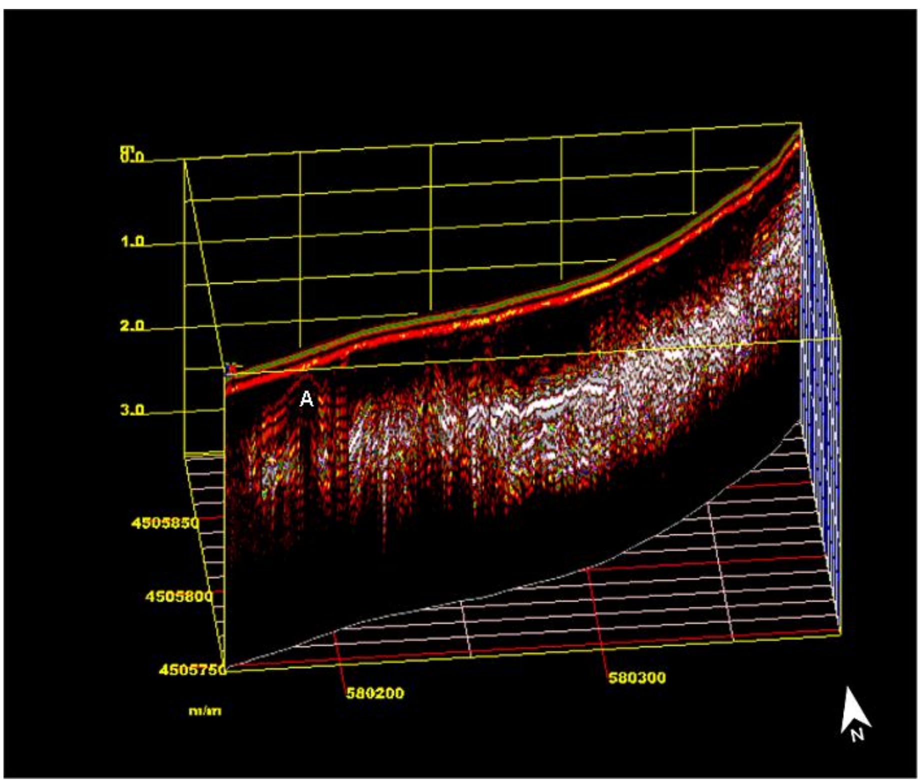

Figure 11. This 3D rendition of the radar record for traverse line 2 can be identified and located in Figure 8. The depth scale is expressed in meters. Coordinates are expressed in UTM.

Figure 11 is a compressed, 3D rendition of the radar record for traverse line 2 (see Figures 8 and 9 for location). The direction of travel was from right (north) to left (south). On the radar record shown in Figure 11, the same two radar facies identified in Figure 10 are evident. The lower facies is presumed to consists of multiple, contrasting textural layers of coal-ash, slag, and dredged materials and contain a greater abundance of fragmental (coal fragments, oyster shells, artifacts) and finer-textured soil materials. These characteristics of this facies would explain its more variable internal geometry and amplitudes.

Near the southern end of GPR traverse line 2, a large subsurface pipe was crossed. The point of a near-surface hyperbolic reflection (near "A" in Figure 11) marks the crossing of the antenna over this feature. Beneath the hyperbola, there are no further radar reflections as the signal has been largely scattered and attenuated by this artifact.

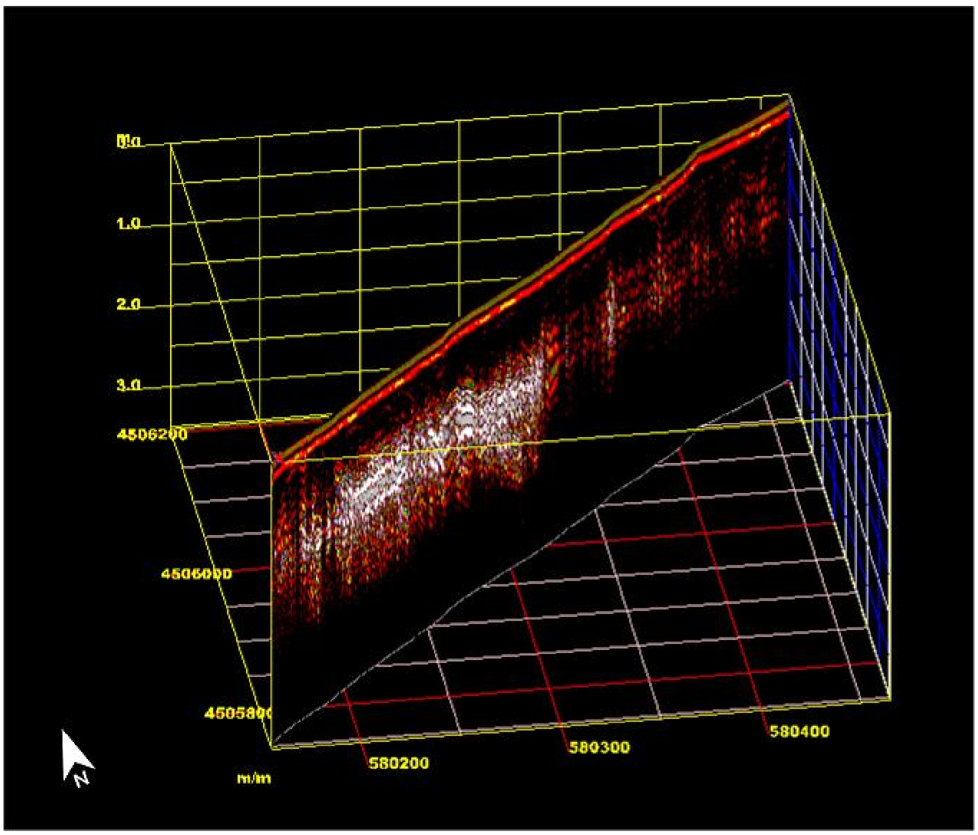

Figure 12. This 3D rendition of the radar record for traverse line 3 can be identified and located in Figure 8. The depth scale is expressed in meters. Coordinates are expressed in UTM.

Figure 12 is a compressed, 3D rendition of the radar record for traverse line 3 (see Figures 8 and 9 for location). The direction of travel was from left (southwest) to right (northeast). Once again, the same two radar facies are evident. However, the amplitude of the lower facies weakens from about midway to the northern terminus of this traverse line. As shown in Figure 9, apparent conductivities increase from values < 60 mS/m to values > 100 to 120 mS/m. This increase in EC_a is believed to have resulted in the weakening of the reflected signals recorded on the radar record.

References:

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