United States Department of Agriculture

NRCS

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Subject: Soils – Geophysical Investigations **Date:** 7 September 2010

To: Patricia S. Leavenworth
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USDA-Natural Resources Conservation Service
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Purpose:
The purpose of this visit was to work with Mark Krupinski and provide geophysical field assistance to the Wisconsin soil staff. Training was provided to Mark Krupinski on GPR interpretations and procedures used to process radar data through the RADAN for Windows software program. Comparative studies using both the 400 and 900 MHz antennas to detect soil and stratigraphic features were completed in areas of Vilas soils.

Participants:
Kristina Ashpole, Soil Scientist, USDA-USDA, Aurora, IL
Ryan Bevernitz, Soil Scientist, USDA-NRCS, Rhinelander, WI
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Mike England, Soil Scientist, USDA-NRCS, Onalaska, WI
Scott Eversoll, MLRA Project leader, USDA-NRCS, Rhinelander, WI
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Samantha Lawien, Student Trainee, USDA-NRCS, Rhinelander, WI
Chris Miller, MLRA Soil Survey Project Leader, USDA-NRCS, Juneau, WI
Kyle Reedy, Soil Conservation Technician, USDA-NRCS, Juneau, WI
Lindsay Reinhardt, Soil Scientist, USDA-USDA, Aurora, IL
Natalie Irizarry Rivera, Soil Scientist, USDA-NRCS, Juneau, WI
Jesse Turk, Soil Scientist, USDA-NRCS, Stevens Point, WI
Carl Wacker, State Soil Scientist, USDA-NRCS, Madison, WI

Activities:
All activities were completed on 23 to 25 August 2010.

Summary:

1. Jim Doolittle is very impressed by the ground-penetrating radar interpretative and data processing skills of Mark Krupinski. We are also pleased to learn that you have allowed Mark's skills and tools to be used in northeastern Minnesota to support ongoing soil survey operations, which are focused on estimations of the depth to bedrock and improved soil map unit interpretations.

2. Soils are manipulated and changed in most urban settings. Conventional soil survey methods are difficult to apply and are restricted in many urban settings. Geophysical tools are not routinely used in urban soil surveys. However, rapid, non-destructive methods for delineating difference in soils are highly desirable in urban settings. Results from this study confirm the role of

geophysical tools in urban setting for delineating dissimilar zones, which correspond to differences in former land use, concentrations of subsurface artifacts (including buried infrastructures, foundations, and utility lines) and manipulated soil and 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.

3. In areas of Vilas soils, both the 400 and 900 MHz antennas provided suitable penetration depths and resolution of subsurface interfaces. With each antenna, three different *radar facies* were identified on radar records: loamy sand solum, sandy BC or upper C horizon, and stratified outwash deposits that form the lower C horizons. While the 900 MHz antenna provided higher resolution and ample penetration depths in areas of Vilas soils, the clarity of the 400 MHz antenna was preferred for soil interpretations.

4. Though not ideally suited for use over electrically resistive Vilas soils, electromagnetic induction (EMI) did revealed spatial apparent conductivity patterns that are attributed to differences in soil moisture and clay contents, and use and management.

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

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:
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Technical Report on Geophysical Fieldwork completed in Wisconsin on 23 to 26 August 2010.

Jim Doolittle

Equipment:

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).[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. The 400, 500, and 900 MHz antennas were used in the studies discussed in this report.

The RADAN for Windows (version 6.6) software program (here after referred to as RADAN) developed by 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, range gain adjustments, and signal filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

An EM38 and EM38-MK2-2 meters (Geonics Limited; Mississauga, Ontario) were used in the investigations[1]. These meters require no ground contact and only one person to operate. These meters measure the apparent conductivity (EC_a) and magnetic susceptibility of the soil. Apparent conductivity is typically expressed in milliSiemens/meter (mS/m). Susceptibility is expressed in parts per thousand (ppt).

The EM38 meter operates at a frequency of 14,600 Hz and weighs about 1.4 kg (3.1 lbs). The meter has one transmitter and one receiver coil that are spaced 1-m apart. When placed on the soil surface, it has effective penetration depths of about 0.75 m and 1.5 m in the horizontal (HDO) and vertical (VDO) dipole orientations, respectively (Geonics Limited, 1998).

The EM38-MK2-2 meter operates at a frequency of 14,500 Hz and weighs about 5.4 kg (11.9 lbs). The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter coil by distances of 1.0 and 0.5 m. This configuration provides nominal penetration depths of about 1.5 and 0.75 m in VDO, and about 0.75 and 0.40 m in the HDO. In either dipole orientation, the EM38-MK2-2 meter provides measurements of both EC_a and susceptibility components for two depth ranges. Operating procedures for the EM38-MK2-2 meter are described by Geonics Limited (2007).

A Pathfinder ProXT GPS receiver with Hurricane antenna (Trimble, Sunnyvale, CA) was used to georeferenced EMI data collected with the EMI meters.[1] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used with the meters to record and store both GPS and EMI data[1]. The RTM38 and RTM38MK2 programs (Geomar Software, Inc., Mississauga, Ontario) were used with the EM38 and EM38-MK2-2 meters, respectively, to display and record both GPS and EC_a on the Allegro CX field computer.[1]

Walnut Way:

Walnut Way Conservation Corporation is a resident-led, community development organization serving the Milwaukee Central City neighborhood that is bounded by North Avenue, 12th Street, Fond du Lac Avenue, Walnut Street and 20th Street. The Mission of the Walnut Way Conservation Corporation is to "*sustain economically diverse and abundant communities through civic engagement, environmental stewardship, and ventures for prosperity*." The Walnut Way Conservation Corporation is a collaboration

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

of residents, academic institutions, businesses, public agencies, and neighborhood associations. Partners include Growing Power, Keep Greater Milwaukee Beautiful, City of Milwaukee Economic Development Corp, Dept of City Development, MATC's Horticultural Program, UW-Extension, UW-Milwaukee and WHEDA.

At the request of the Walnut Way Conservation Corporation, urban geophysical soil investigations were conducted in Milwaukee on the morning of 23 August 2010. The site is located on N 17th Street just north of its intersection with West Lloyd Street (43.0587 N Latitude, 87.9345 W. Longitude). Two former houses had been imploded and the area leveled for gardens. The survey area encompasses one standing house. The survey area is presently unmapped. The State GPR Soil Suitability Map of Wisconsin (ftp://ftp-fc.sc.egov.usda.gov/NSSC/maps/GPR/GPR_WI.pdf) presently portrays much of the southeastern portion of the state as having low potential to GPR because of the high clay contents of the soils

Survey Procedures:
Random surveys were conducted with the SIR-3000 GPR system with a 500 MHz across representative portions of the site (Fig. 1, left). All open areas of the site were surveyed with an EM38 meter (see Fig. 2, right). The EMI survey was completed by walking in a back-and-forth manner across all open areas with the EM38 meter held in the VDO (exploration depth of 0 to 150 cm) (see Fig.2, right). The soil materials had an average EC_a of about 41 mS/m with a rather wide (but not unexpected) range of about -200 to 263 mS/m. However, one-half of the measurements collected at this site were between about 37 and 58 mS/m.

Figure 1. Geophysical surveys at Walnut Way Project Area in Milwaukee. In the left-hand photo, Kyle Reedy and Carl Wacker conduct a GPR survey using the SIR-3000 GPR system with a 500 MHz antenna. In the right-hand photo, Natalie Irizarry Rivera completes an EMI survey with an EM38 meter.

Results:
The effectiveness of GPR was restricted by the high clay content of the soil materials. Figure 2 is a representative radar record that was recorded at the Walnut Way site. Effective signal penetration is restricted to depths of less than 70 cm and the profiled near-surface materials are plagued by signal multiples and reverberations (unwanted noise). To improve resolution of near-surface features a

relatively high frequency (500 MHz) antenna was used. Although the depth of penetration can generally be increased by using a lower frequency antenna, in these finer-textured soil materials, it is unlikely that the use of a lower frequency antenna would significantly increase the observation depth.

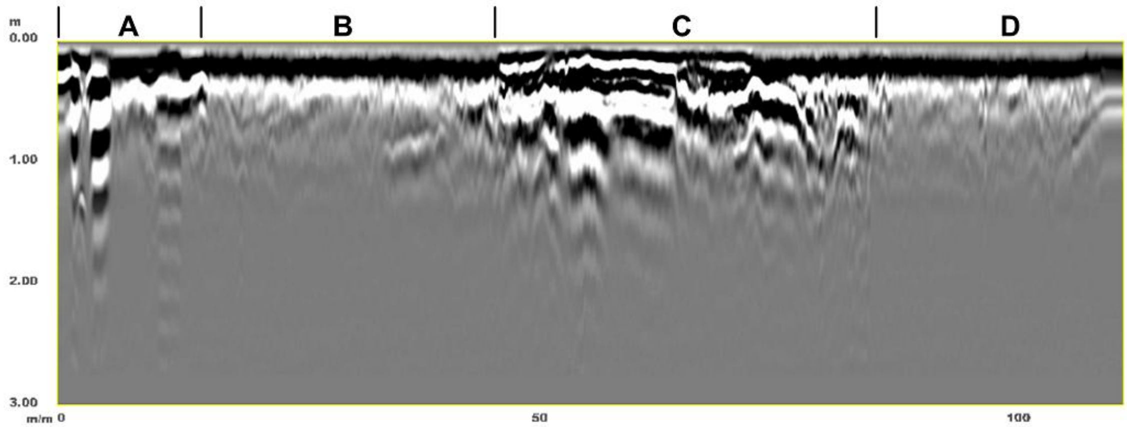

Figure 2. This representative radar record from the Walnut Way Site was collected using a 500 MHz antenna. Effective penetration depth is restricted to depths of less than 70 cm.

The radar record shown in Fig. 2 is from a traverse that began over and ended near a city street (N 17th Street) and formed a U-shaped pattern around a house that is in the middle of the proposed garden area. The radar record in Fig. 2 has been partitioned into four zones (see lettering above the surface pulse). Zone "A" represent the portion of the radar record that crossed the paved, city street. Within this zone, the two high-amplitude, reverberated signals represent metallic street covers. Zone "B" and "D" represent the area traversed on either side of the house. Zone "B" cross directly over the site of a formerly implode house. No evidence of this structure can be gleaned with confidence from the radar record and reflective patterns in both zones "B" and "D" are nondescript. Zone "C" represents the portion of the radar record that was conducted across the back of the lot. This portion of the traverse line is oriented parallel with the city street. Sequential layers of near-surface fill materials appear to have been profiled. Near-surface, discontinuous, parallel bands of reflected energy are characteristic of Zone "C". Ground-penetrating radar, though considered of marginal use in this urban setting, did partition the proposed garden area in units with presumably different soil materials and artifact contents.

Figure 3 is a plot of the EC_a data collected at this site. In Fig. 3, the location of the standing house has been filled in gray and is labeled "*Structure*". In general, soil materials have a largely uniform, moderately-high (40 to 60 mS/m) EC_a level across most of the eastern 2/3 of the site. These values suggest fine-textured soil materials. Anomalously higher and lower EC_a values occur in the western third of the site. These values and spatial patterns suggest possible buried metallic artifacts (blue-colored, negative EC_a values) and contaminated and potentially hazardous fill materials (red- and yellow-colored, positive EC_a values). The area with the anomalous high EC_a fill materials in Fig. 3 corresponds with Zone "C" on the radar record shown in Fig. 2.

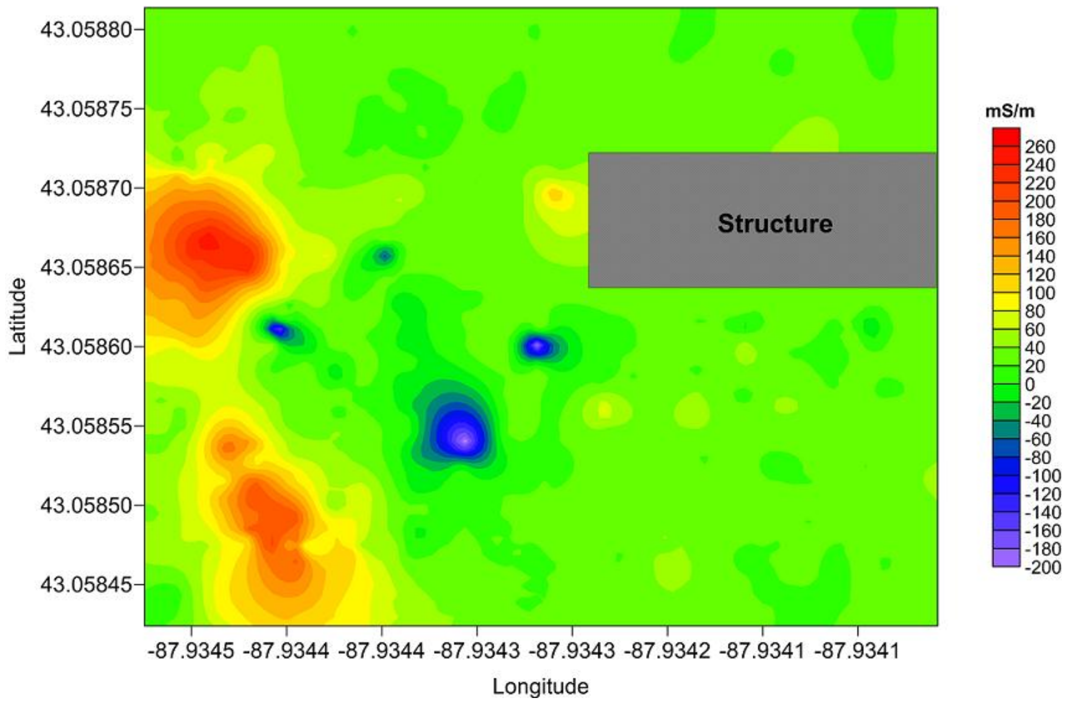

Figure 3. A plot of spatial apparent conductivity patterns measured in an urban area in Milwaukee.

Soils are constantly disturbed, manipulated, and altered in most urban settings. Conventional soil survey methods are difficult to apply and are restricted in many urban settings. Geophysical tools are not routinely used in urban soil surveys. However, rapid, non-destructive methods of soil investigation are highly desirable in urban areas. Results from this study confirm the role of geophysical tools in delineating some dissimilar zones, which correspond to differences in former land use, concentrations of subsurface artifacts (including buried infrastructures, foundations, and utility lines), and soil and 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.

Vilas map units:

Soil Scientists from the Rhinelander MLRA Project Office are using GPR to characterize outwash sediments, depth to lamellae, and map unit components in areas of Vilas soils in northern Wisconsin. The presence, depth, and thickness of lamellae affect moisture retention and soil interpretations. Student trainee Samantha Lawien is pursuing a Masters Degree at the University of Wisconsin at Stevens Point. NRCS is supporting her research on the origin and distributions of lamellae in Vilas soils.

The very deep, excessively drained Vilas soils form in sandy deposits on outwash plains. Vilas is a member of the sandy, isotic, frigid Entic Haplorthods taxonomic family. The thickness of the Vilas solum ranges from 18 to 45 inches. Typically, the solum is loamy sand. The substratum of Vilas soils is sand with less than 10 % gravel (by volume).

Five study sites were located in areas of Vilas soils in Lincoln and Oneida Counties. The Lincoln County sites (*Case* and *Callahan* sites) are located in hay lands. These areas have been mapped as Vilas-Sayner loamy sands on 1 to 6 % slopes (VsB). The very deep, excessively drained Sayner soil is a member of the sandy, mixed, frigid Entic Haplorthods taxonomic family. Sayner soils contain a greater volume of gravel (up to 35 %) than Vilas soils. Two of the Oneida County sites (*Tomahawk* and *Clean* sites) are located in wooded areas that are mapped as Vilas loamy sands on 0 to 6 % slopes (VsB). The *Sowinski Farm* site is located in a cultivated field of VsB. Multiple, random GPR traverses were completed across each site using both the 400 and 900 MHz antennas.

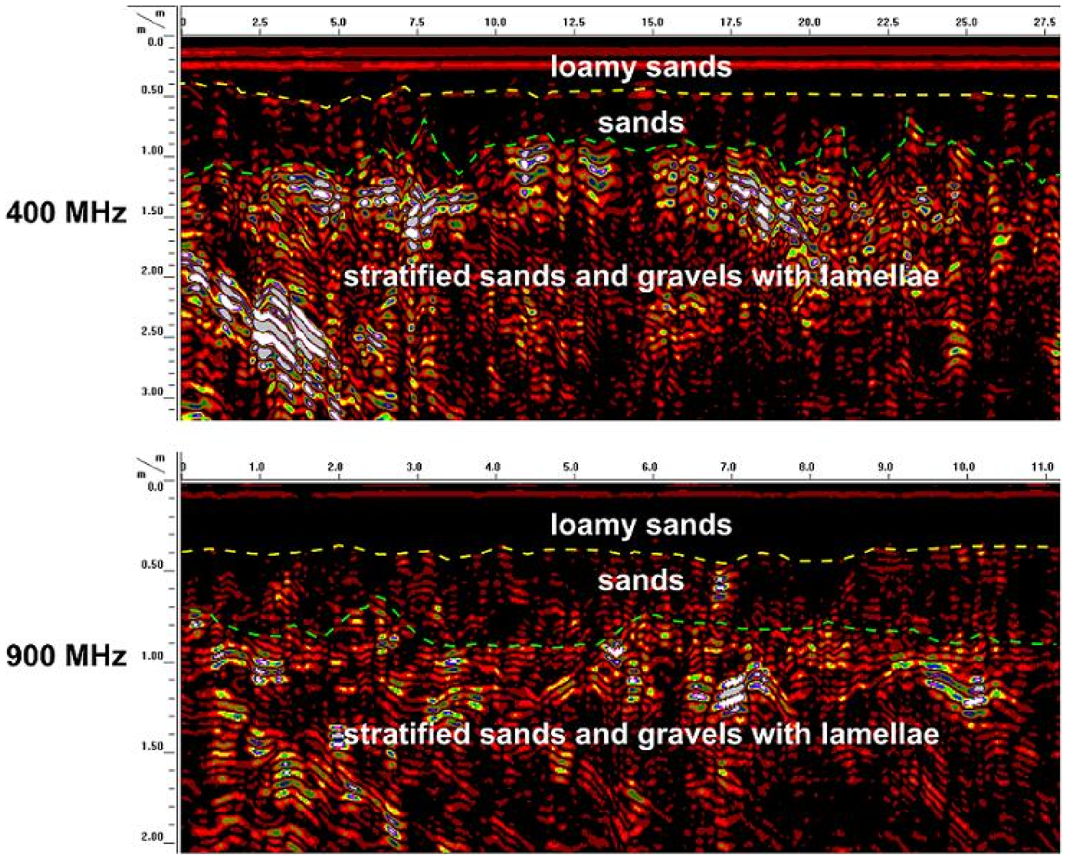

Figure 4. These radar records were obtained with the 400 (upper radar record) and 900 (lower radar record) MHz antennas in areas of Vilas soils. The locations of the two traverses were not identical. The horizontal and vertical scales are expressed in meters.

Figure 4 contains radar records obtained with both the 400 and 900 MHz antenna in an area of Vilas soils. Both antennas provide suitable penetration depths and resolution of subsurface interfaces. Three different *radar facies* can be identified in both of these radar records: a near-surface area that contains almost no soil reflections; an intermediate area composed of horizontal to slightly inclined, weakly-expressed reflectors; and a deeper area made up of visibly more numerous and higher-amplitude, inclined reflectors. The near-surface *radar facies* conforms to the solum, which is loamy sand. The intermediate *radar facies* conforms to the BC or C horizon composed of coarser sands. In general, reflections within the intermediate *radar facies* are of low signal amplitude suggesting materials of closely similar dielectric properties. The boundary between these two facies (solum and BC or upper C horizons) is often poorly expressed and segmented, but can be traced on radar records with a relatively high degree of confidence. The intermediate *radar facies* generally occurs at depths ranging from about 50 to 120 cm and has an irregular (topography) lower boundary. The deeper or lower *radar facies* represents stratified outwash deposits. Reflectors in this lower *radar facies* represent stratification formed in materials with different grain sizes, gravels and/or lamellae contents.

While the 900 MHz antenna provided higher resolution and ample penetration depths in areas of Vilas soils, the clarity of the 400 MHz antenna was preferred for soil interpretations. On many radar records, too much detail is as troubling to radar interpretations as too little.

Electromagnetic induction surveys were completed at the *Case* site in Lincoln County and the *Sowinski Farm* site in Oneida County. These surveys were performed to provide extra site data and for training purposes. While both are mapped as predominantly Vilas soils, they differed in use and management. The *Case* site is in pasture; the *Sowinski Farm* site is cultivated to clover. Difference in use and management appear to have affected the EC_a measurements at shallow soil depth.

Because of very low clay and moisture contents, the sandy excessively drained Vilas soil is electrically resistive and characterized by very low and invariable EC_a. At both sites, for the 0 to 150 cm soil column, one-half of the recorded EC_a measurements were between about 3 and 5 mS/m. The average EC_a for the 0 to 150 cm depth interval was 4.4 and 5.6 for the *Case* and *Sowinski Farm* sites, respectively. However, as evident in Fig. 5, the EC_a of surface (0 to 75 cm) layers were radically different between the two sites. At the *Case* site (this was in pasture) EC_a averaged about 7 mS/m with a range of about -12 to 12 mS/m. Negative values are attributed to errors in calibration and/or metallic artifacts scattered across the site. At the *Sowinski Farm* site (this was in cultivation) EC_a averaged about 16 mS/m with a range of about 11 to 21 mS/m. Higher values at the *Sowinski Farm* site are attributed to differences in management and the possible recent application of fertilizer.

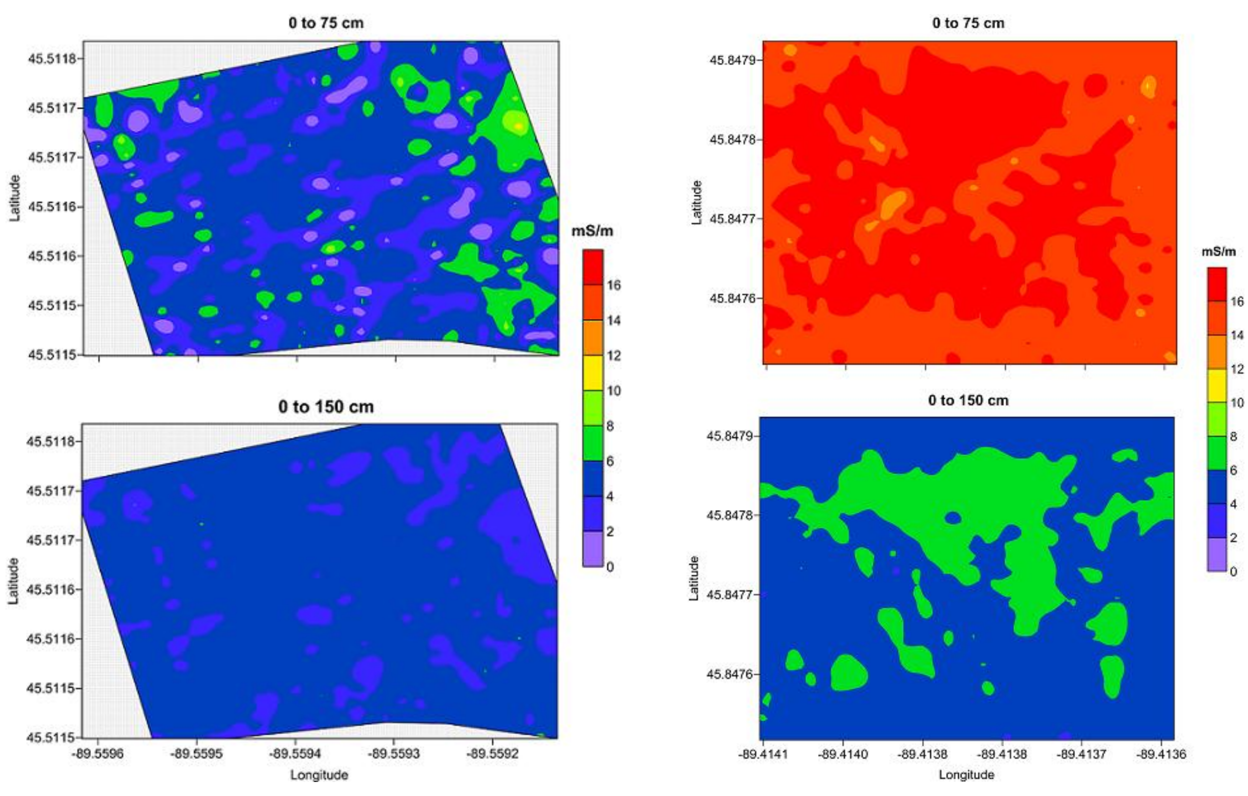

Figure 5. The plots of spatial apparent conductivity patterns were obtained with the EM38MK2-2 meter at the Case (Lincoln County) and the Sowinski Farm (Oneida County) sites.

References:

Daniels, D.J., 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.

Geonics Limited, 1998. EM38 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.

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