United States Department of Agriculture

SUBJECT: MGT – Trip Report – Geophysical Assistance 2 October 2014

TO: Gregory A. Kist
State Conservationist, NRCS
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File Code: 330-20-7

Purpose:
To provide ground-penetrating radar (GPR) interpretations of the depth-to-bedrock in areas of Amenia and Nellis soils in the Black River Valley of New York.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Amy Langner, Soil Scientist, USDA-NRCS, Lowville, NY
Gerald Smith, MLRA Office Leader, USDA-NRCS, Paul Smiths, NY
Olga Vargas, Resource Soil Scientists, USDA-NRCS, Greenwich, NY

Activities:
All geophysical surveys were completed on 9 to 10 September 2014.

Summary:

1. A total of 40 radar traverses were completed in areas mapped in the Web Soil Survey as very deep Amenia and Nellis soils in Lewis County. Twenty-three traverses were conducted in areas mapped as Amenia loam on 3 to 8 % slopes (AgB). Based on these GPR traverses, the soil-depth distribution in this map unit is 15 % shallow, 61 % moderately deep, 21 % deep and 2 % very deep. Five traverses were conducted in areas mapped as Amenia loam on 0 to 3 % slopes (AgA). Based on these GPR traverses, the soil-depth distribution in this map unit is 13 % shallow, 79 % moderately deep and 8 % deep. Twelve traverses were conducted in areas mapped as Nellis loam on 0 to 2 percent slopes (NeB). Based on these GPR traverses, the soil-depth distribution in this map unit is 14 % shallow, 69 % moderately deep and 18 % deep. Based on these GPR traverses, areas mapped as very deep Amenia and Nellis soils in Lewis County appear to be dominated by moderately deep Galway (coarse-loamy, mixed, superactive, mesic Typic Eutrudepts) soils.

2. Five GPR traverses were conducted in areas mapped in the Web Soil Survey as shallow Farmington soils. Three traverses were conducted in an area mapped as Farmington loam on 0 to 8 percent slopes (NbB). Based on these GPR traverses, the soil-depth distribution in this map unit is 28 % shallow, 71 % moderately deep and 1 % deep. Two GPR traverses were conducted in an area mapped as Rock outcrop-Farmington complex on 15 to 35 percent slopes (NfD). Based on these GPR traverses, the soil-depth distribution in this map unit is 8 % shallow, 54 % moderately deep, 38 % deep and 1 % very deep. Based on these GPR traverses, areas presently mapped as shallow Farmington soils appear to be dominated by moderately deep Galway soils.

3. A summary of all GPR traverse data is included as an addendum to the attached technical report. A spreadsheet containing all recorded GPR data has been forwarded to Gerald Smith.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work in New York and to be of assistance to you, and the Glaciated Soil Survey Region (SSR 12) and the Paul Smiths Soil Survey Office staffs.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

Attachment (Technical Report)

cc:
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Technical Report

James A. Doolittle

Background:
This study focused on areas mapped as different phases of Amenia and Nellis soils in the Black River Corridor of Lewis County in northern New York. When originally mapped in the late 1950s, both Amenia and Nellis soils were described as having depths to bedrock ranging from about 12 to greater than 40 inches (Pearson *et al*., 1960). However, different depth phases (shallow, moderately deep and deep) for these soils were also recognized and mapped. Limited investigations have revealed that the depth to bedrock is variable both within and among the different phases of Amenia and Nellis soils that were mapped in Lewis County. In addition, the concept of these soils has changed over the ensuing years, and both are presently recognized as being very deep to bedrock. The purpose of this study was to use ground-penetrating radar (GPR) of determine the depth-to-bedrock distribution and variability in areas of Amenia and Nellis soils, and to improve the soil legend and interpretations.

Survey Sites:
Five sites, largely composed of delineations of Amenia and Nellis soils, were selected in Lewis County. Table 1 lists the taxonomic classification of the soils named at the study sites visited during this investigation.

Table 1 – Taxonomic Classifications of Soils.

Soil Series	Taxonomic Classification
Amenia	Coarse-loamy, mixed, active, mesic Aquic Eutrudepts
Farmington	Loamy, mixed, active, mesic Lithic Eutrudepts
Galway	Coarse-loamy, mixed, superactive, mesic Typic Eutrudepts
Nellis	Coarse-loamy, mixed, superactive, mesic Typic Eutrudepts

Site 1 (43.8988 ° N latitude, 75.5872 ° W longitude) is located in a field that is just off of Old State Road in Denmark, New York. The entire field is in a delineation of Amenia loam, 3 to 8 % slopes (AgB). The very deep, moderately well drained Amenia soils formed in calcareous tills on uplands. In Amenia soils, the depth to carbonates ranges from about 10 to 34 inches. The depth to bedrock is greater than 60 inches.

Site 2 (43.8915 ° N latitude, 75.5816 ° W longitude) is located in two fields just south of Site 1 and off of State Highway 26 in Denmark, New York. This site consists of a slightly lower-lying field of Amenia loam, 0 to 3 percent slopes (AgA), and a slightly higher-lying field of mostly Nellis loam, 0 to 2 percent slopes (NeB). The very deep, well drained Nellis soils formed in calcareous till on uplands. In Nellis soils, the depth to carbonates ranges from about 15 to 38 inches. The depth to bedrock is greater than 60 inches.

Site 3 (43.7012 ° N latitude, 75.4307 ° W longitude) is located off of Meiss Road about 2.4 km west of Glenfield, New York. The site consists of an elongated, narrow field of Amenia loam, 0 to 3 percent slopes (AgA).

Site 4 (43.6960 ° N latitude, 75.4172 ° W longitude) is located off of Dovisk Road about 2.0 km southwest of Glenfield, New York. The site consists of a field of Amenia loam, 3 to 8 percent slopes (AgB).

Site 5 (43.8930 ° N latitude, 75.5353 ° W. longitude) is located in a wooded area about 2.0 km west-northwest of Castorland, New York. The site includes a delineation of Farmington loam, 0 to 8 percent slopes (NbB) and Rock outcrop-Farmington complex, 15 to 35 percent slopes (NfD). The shallow, well drained and somewhat excessively drained Farmington soils formed in till on glaciated uplands. Bedrock is at a depth of 10 to 20 inches.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000 system 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 system requires two people to operate (Figure 1). Operating procedures for the SIR-3000 are described by Geophysical Survey Systems, Inc. (2004). Jol (2009) and Daniels (2004) discuss the use of GPR.

A relatively high frequency, 400 MHz antenna was used in this study. This antenna provided suitable investigation depth and resolution of subsurface features in the profiled soils. The RADAN for Windows (version 7.0) software program (developed by GSSI) was used to process the radar records and to improve the recognition of radar reflection pattern.[1]

Figure 1. A SIR-3000 GPR system with a 400 MHz antenna was used to investigate areas of Amenia and Nellis soils in Lewis County.

The SIR-3000 system has a setup for the use of a GPS receiver with a serial data recorder. With this setup, each scan on radar records can be georeferenced (position/time matched). During data processing, a subprogram within RADAN is used to proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver. A Pathfinder ProXT GPS receiver (Trimble, Sunnyvale, CA) was used to georeferenced the GPR data (see yellow backpack in Figure 1).[1] Position data were recorded at a rate of one reading per second.

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

The electromagnetic induction (EMI) meters are the EM38-MK2, which is manufactured by Geonics Limited (Mississauga, Ontario), and the Profiler EMP-400 sensor (here after referred to as the Profiler), which is manufactured by Geophysical Survey Systems, Inc. (Salem, NH). [1] Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2007). The EM38-MK2 meter operates at a frequency of 14.5 KHz and weighs approximately 5.4 kg (11.9 lbs.). 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 two nominal exploration depths of 150 and 75 cm when the meter is held upright in the vertical dipole orientation (VDO), as it was in this study. Inphase, quadrature, and apparent conductivity (EC_a) data are simultaneously recorded for each exploration depth.

The Profiler has a 1.22 m intercoil spacing and operates at frequencies ranging from 1 to 16 KHz. It weighs about 4.5 kg (9.9 lbs.). The Profiler is a multifrequency EMI meter that can simultaneously record data in as many as three different frequencies. For each frequency, inphase, quadrature and EC_a data are recorded. However, calibration of the Profiler is optimized for 15 KHz and, therefore, EC_a will be most accurately measured at this frequency. Operating procedures for the Profiler are described by Geophysical Survey Systems, Inc. (2008).

The Profiler was held in the deeper sensing VDO (Figure 2). Data were recorded at both 15000 and 5000 KHz. The sensor's electronics are controlled via Bluetooth communications with a Trimble TDS RECON-400 Personal Data Assistant (PDA). The MagMap 2000 software (developed by Geometric, Inc., San Jose, CA) was used to process the survey data. [2]

Figure 2. Olga Vargas conducts and EMI survey with the Profiler in an area of Amenia soils.

Both EMI sensors need only one person to operate and require no ground contact (Figure 2). Lateral resolution is approximately equal to the intercoil spacing of the instruments. To help summarize the results of the EMI survey, SURFER for Windows (version 10.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulations shown in this report.[2] Plots of EMI data shown in this report were created using kriging methods with an octant search.

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

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., bedrock, soil horizon, stratigraphic layer) and back. To convert the two-way 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):

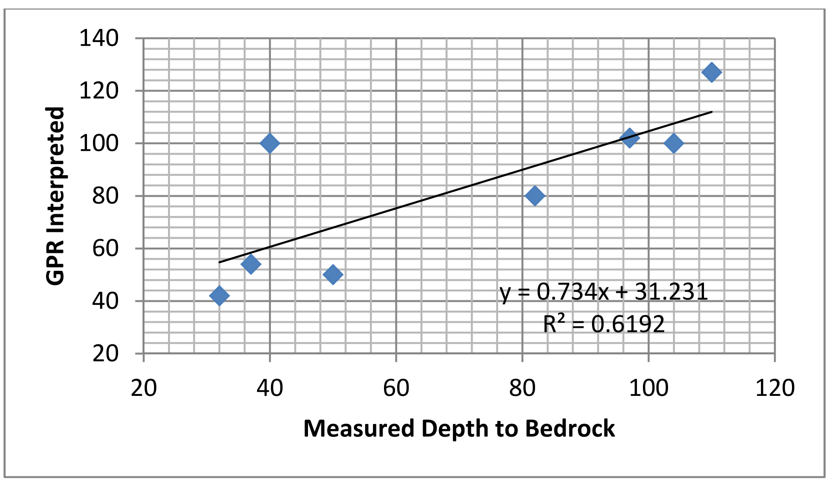
$$v = 2D/T \qquad [1]$$

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):

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

In equation [2], C is the speed of light in a vacuum in a vacuum (0.3 m/ns). Typically, the velocity of pulse propagation 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*.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (metallic plate), the average velocity of propagations and the relative dielectric permittivity through the upper part of the Amenia soil profile was estimated using equations [1] and [2]. The estimated E_r was 5.97. The estimated *v* was 0.1228 m/ns.



Graph 1 – Relationship between observed (with soil auger) and radar interpreted depths to bedrock.

During the course of the GPR surveys, 8 soil cores were extracted to determine the depth to bedrock and to confirm the radar interpretations. The measured depths (with soil auger) to bedrock ranged from 32 to 110 cm. The average difference between the auger measured and GPR interpreted depths to bedrock was 14.38 cm with a range of 0 to 60 cm. However, the correlation (r^2) between GPR and auger measurements was only 0.62 (see Graph 1). The relatively high range and lower than anticipated correlation were attributed to auger refusal caused by rock fragments rather than the bedrock surface, irregular or pitted bedrock surfaces, and errors in radar interpretation and/or calibration.

GPR Procedures:
Multiple GPR traverses were completed across each site. Each radar traverse was stored as a separate file. Surveys were conducted by moving the antenna over the ground surface at a slow walking pace.

Several of the radar traverses were not properly georeferenced due to range errors caused by major reported solar flare that occurred during the period of this study.

Each radar record was processed in RADAN 7.0. Following processing, the depth to bedrock was semi-automatically *picked* on each radar record using the Interactive 3D Module of RADAN. These measurements were grouped according to soil-depth classes (shallow: < 50.8 cm; moderately deep: 50.8 to 101.6 cm; deep: 101.6 to 152.4 cm; and very deep: > 152.4 cm), and the frequency distribution of the "picks" was determined for each GPR traverse.

Figure 3 contains a representative radar record from an area of Amenia loam, 3 to 8 % slopes (AgB). On this radar record all scales are expressed in meters. A white-colored segmented line has been used to identify the soil/bedrock interface, which ranges from about 35 to 120 cm below the soil surface. In most cases, the radar image of the soil/bedrock interface were clear and interpretable.

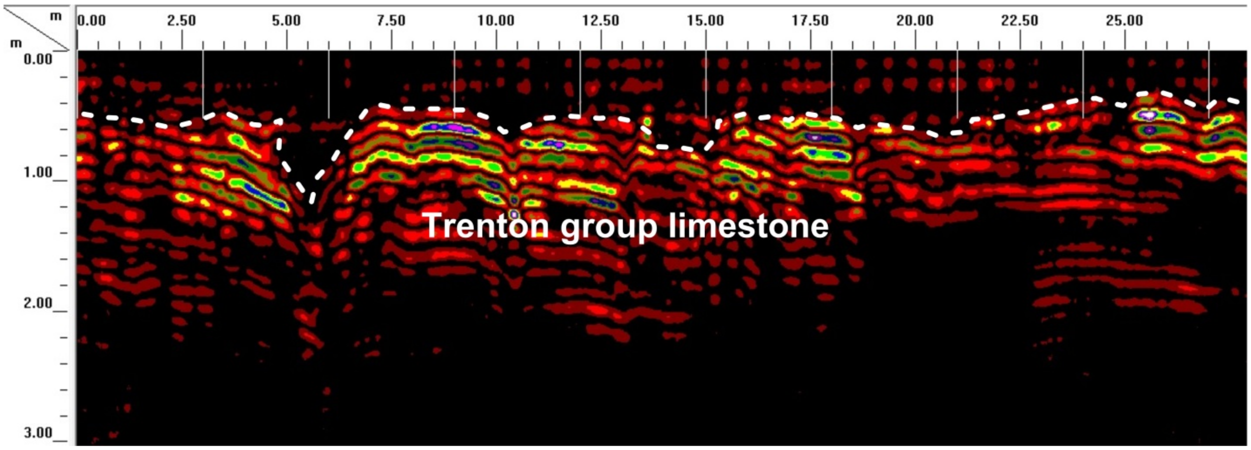


Figure 3. A representative radar record from an area of Amenia loam, 3 to 8 % slopes (AgB).

Results:

<u>Site 1:</u>

Thirteen radar traverses were completed across Site 1 providing a total of 49,589 soil-depth measurements. Based on these measurements, the average depth to bedrock is 66 cm with a range of 0 to 146 cm. Based on the averages from 13 traverses that were conducted in this area of Amenia loam, 3 to 8 % slopes (AgB), the depth to bedrock is largely moderately deep (72 %) and shallow (24 %) with some deep (4 %) inclusions.

Figure 4 is a *Goggle Earth* image of Site 1 showing the distribution of soils based on soil-depth classes. In this image, the locations of the GPR traverse lines are shown. Colors have been used to identify the different soil-depth classes. The dominance of moderately deep and shallow soils is evident in this delineation of Amenia loam on 3 to 8 percent slopes.

Figure 4. This Google Earth image of site 1 shows the dominance of moderately deep and shallow soils in a delineation of very deep Amenia loam, on 3 to 8 percent slopes.

Site 2:

Site 2 contained two soil delineations: a delineation of Amenia loam, 0 to 3 percent slopes (AgA) and a delineation of Nellis loam, 0 to 2 percent slopes (NeB). Five radar traverses were completed in the AgB delineation, and four in the NeB delineation. Based on 18,029 soil-depth measurements, the average depth to bedrock within the AgB delineation is 73 cm with a range of 21 to 159 cm. Based on the averages from the five radar traverses conducted in the AgB delineation, the depth to bedrock is mostly moderately deep (80 %) with minor inclusions of shallow (12 %) and deep (8%) soils.

Figure 5. This Google Earth image of site 2 shows the dominance of moderately deep and shallow soils in delineations of very deep of Amenia loam, on 3 to 8 percent slopes (mostly in the field to right or east) and Nellis loam, 0 to 2 percent slopes (mostly to west or left).

Based on 14,397 soil-depth measurements, the average depth to bedrock within the NeB delineation is 66 cm with a range of 0 to 146 cm. Based on the averages from four radar traverses conducted in the NeB delineation, the depth to bedrock is largely moderately deep (74 %) and shallow (19 %) with some deep (7%) inclusions.

Figure 5 is a Goggle Earth image of Site 2 showing the distribution of soils based on soil-depth classes. In this image, the locations of the GPR traverse lines are shown. Colors have been used to identify the different soil-depth classes. The dominance of moderately deep soils in both fields is evident. However, a reason for splitting the two fields into separated soil delineations (based on differences in soil depth) is lacking on this image.

Site 3:

Eight radar traverses were completed across Site 3 providing a total of 33,224 soil-depth measurements. These traverses were conducted entirely in a delineation of Amenia loam, 0 to 3 percent slopes (AgA). Based on these measurements, the average depth to bedrock is 87 cm with a range of 0 to 184 cm. Based on the averages from the 8 radar traverses, the depth to bedrock is largely moderately deep (66 %) and deep (23 %) with some shallow (11 %) inclusions.

Figure 6 is a Goggle Earth image of Site 3 showing the distribution of soils based on soil-depth classes. In this image, the locations of several GPR traverse lines are shown. The reception of GPS signals was impaired during this GPR survey. This resulted in the failure to geo-reference some radar scans and several radar traverses. In Figure 6, colors have been used to identify the different soil-depth classes. The dominance of moderately deep soils is evident in this delineation of Amenia loam, 0 to 3 percent slopes.

Figure 6. This Google Earth image of site 3 shows the dominance of moderately deep soils in a delineation of very deep Amenia loam, on 3 to 8 percent slopes.

Site 4:

Ten radar traverses were completed across Site 4 providing a total of 29,221 soil-depth measurements. All of these traverses are located in a delineation of Amenia loam, 3 to 8 percent slopes (AgB). Based on these measurements, the average depth to bedrock is 103 cm with a range of 14 to 287 cm. Based on the averages from the 10 radar traverses, soils within this delineation are largely moderately deep (50 %) and deep (39 %) with inclusions of shallow (5 %) and very deep (6 %) to bedrock soils.

Figure 7 is a Goggle Earth image of Site 4 showing the distribution of soils based on soil-depth classes. In this image, the locations of only four GPR traverse lines are shown. The reception of GPS signals was extremely impaired during the GPR survey of this site. This resulted in the failure to properly geo-reference most radar scans and six radar traverses. In Figure 7, colors have been used to identify the different soil-depth classes. The dominance of moderately deep and deep soils is evident in this delineation of Amenia loam on 3 to 8 percent slopes.

Figure 7. This Google Earth image of site 4 shows the dominance of moderately deep and deep soils in a delineation of very deep Amenia loam, on 3 to 8 percent slopes.

<u>Site 5:</u>
Five radar traverses were completed across Site 5 providing a total of 39,318 soil-depth measurements. Three of these traverses are located in a delineation of Farmington loam, 0 to 8 percent slopes (NbB) and two traverses in a unit of Rock outcrop-Farmington complex, 15 to 35 percent slopes (NfD). Based on 18,515 soil-depth measurements, the average depth to bedrock within the NbB delineation is 62 cm with a range of 20 to 161 cm. Based on the averages from 5 radar traverses, the depth to bedrock is mostly moderately deep (71 %) and shallow (21 %), with a very slight inclusion of deep (1%) soils.

Based on 20,803 soil-depth measurements, the average depth to bedrock within the NfD delineation is 91 cm with a range of 0 to 161 cm. Based on the averages from two radar traverses conducted within the NfD delineation, the depth to bedrock is largely moderately deep (54 %) and deep (38 %) with some shallow (8%) inclusions.

Figure 8 is a Goggle Earth image of Site 5 showing the distribution of soils based on soil-depth classes. In this image, the locations of only three GPR traverse lines are shown. The reception of GPS signals was seriously impaired throughout the GPR survey of this site. This resulted in the failure to accurately geo-reference the radar scans and two radar traverses. In Figure 8, colors have been used to identify the different soil-depth classes. The dominance of moderately deep and deep soils is evident in the area of Farmington loam, 0 to 8 percent slopes (two western traverse) and deep soils in the delineation of Rock outcrop-Farmington complex, 15 to 35 percent slopes (easternmost transect on right in Figure 8). .

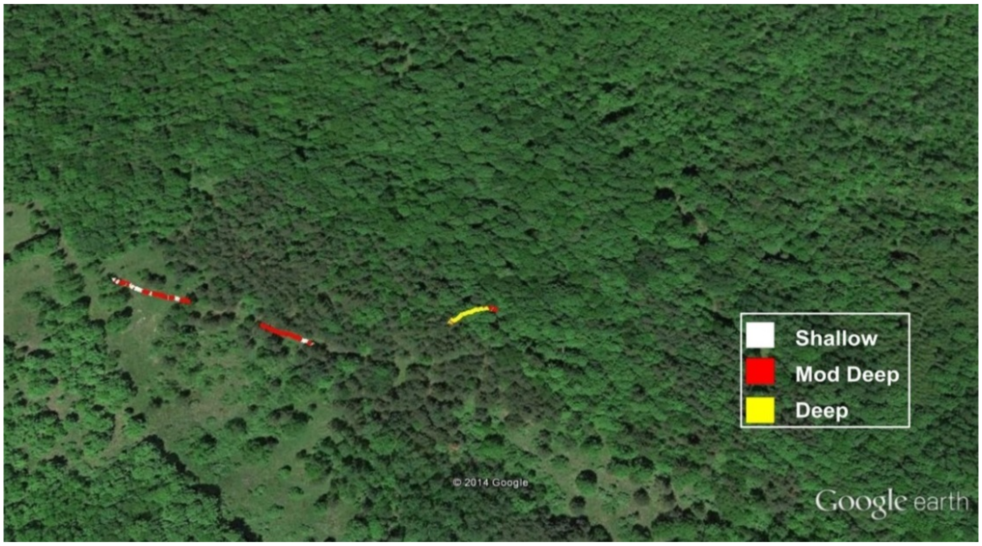


Figure 8. This Google Earth image of site 5 showing the distribution of moderately deep and deep soils in delineations of Farmington loam, 0 to 8 percent slopes (NbB) and Rock outcrop-Farmington complex, 15 to 35 percent slopes (NfD).

Electromagnetic Induction:
Electromagnetic induction surveys were completed at several sites. These surveys provided additional site information and were useful for training and sensor maintenance purposes.

Site 2:
A detailed EMI survey was conducted with an EM38-MK2 meter across the portion of Site 2 that is mapped as Amenia loam, 3 to 8 % slopes (AgB). The measured EC_a in this area of Amenia soil is relatively low and invariable reflecting the low clay, soluble salt and moisture contents of this soil and its relatively shallow depth to electrically resistive bedrock. Based on 2657 EC_a measurements, for a theoretical observation depth of 0 to 75 cm, EC_a averaged 10.0 mS/m and ranged from 3.0 to 20.6 mS/m across this site. One-half of these recorded measurements were between 8.9 and 10.7 mS/m. Based on 2657 EC_a measurements, for a theoretical observation depth of 0 to 150 cm, EC_a averaged 9.4 mS/m and ranged from -8.2 to 24.4 mS/m across this site. One-half of these recorded measurements were between about 7.5 and 9.4 mS/m. Comparing the two theoretical depths of observation, EC_a decreased, but became more variable with increasing soil depth

Figure 9 contains two plots of the EC_a data collected at Site 2 with the EM38-MK2 meter: one for the upper 0 to 75 cm (left-hand plot), and one for the upper 0 to 150 cm (right-hand plot) of Amenia soil. In both plots, two buried drainage lines, both trending in a roughly east to west direction, are shown by linear pattern of higher EC_a. The longer, more southerly line was known to the farmer. However, the shorter, more poorly expressed and northerly line was unknown and likely represents an older drainage line.

In Figure 9, background EC_a levels (away from the buried drainage lines) are lower and decrease with depth. The reduction in EC_a with increasing soil depth is attributed to the deeper measurements (plot on right) being more greatly influenced by the underlying, more electrically resistive bedrock. In both of the plots shown in Figure 9, EC_a increases along the western (left-hand) boundary of the survey area. This is believed to reflect the possible discharge of seepage water from higher lying slope positions and/or greater depths to bedrock.

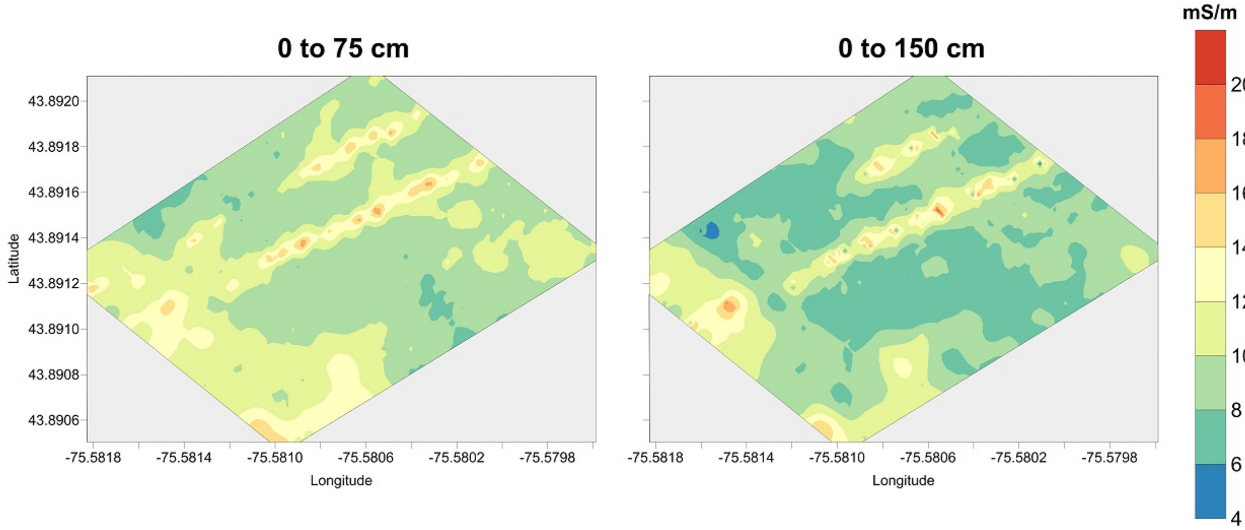


Figure 9. These plots of EC_a are from an area of Amenia loam on 3 to 8 % slopes within Site 2.

<u>Site 3:</u>
A detailed survey was conducted with the Profiler across this area of Amenia loam, 0 to 3 percent slopes. The measured EC_a is relatively low and invariable reflecting the comparatively low clay, soluble salt and moisture contents of this soil and its relatively shallow depth to electrically resistive bedrock. Based on 3500 EC_a measurements (at 15000 KHz), for a presumed observation depth of 0 to 183 cm, EC_a averaged only 3.7 mS/m, but ranged from -43.0 to 63.8 mS/m across this site. However, one-half of these recorded measurements were between 1.77 and 4.01 mS/m. The low EC_a manifested across this site reflects the low conductivity of the soil and the relatively shallow depths to bedrock. The high range in EC_a suggests the presence of metallic artifacts that are either on the surface or buried at shallow depths within the surveyed area. These features would produce anomalously high and low EMI responses.

Figure 10 contains plots of EMI data that were measured at Site 3 with the Profiler. The upper and lower plots show data recorded at 15000 and 5000 KHz, respectively. The left- and right-hand plots show inphase and the apparent conductivity data, respectively. The collection of EMI data at two different frequencies results in similar EC_a spatial pattern and values. However, different values, but similar spatial patterns are evident in the plots of the inphase data collected at the two different frequencies.

In general, EC_a data are relatively invariable across this site. Higher values were recorded in the northern and southern ends of the field. These areas of higher EC_a form linear patterns that suggest buried utility or drainage lines. Conversations with the landowner may help to reveal the source(s) for these anomalous values and spatial patterns.

As evident in Figure 10, the inphase response is noticeably higher at 5000 KHz (left, lower plot) than at 15000 KHz (left, upper plot). However, on closer inspection, the spatial patterns recorded at the different frequencies are comparatively similar in the plots shown in Figure 10. The correlation (r^2) between the two sets of inphase measurements was 0.86. The correlation between the two sets of EC_a data (recorded at 5000 and 15000 KHz) was lower; r = 0.76. These plots and the relatively high correlation of data sets suggest no interpretational advantages in collecting and processing multiple frequency data sets.

Unless highly conductive materials are present, the inphase component is considered proportional to and has been used as a proxy to infer the magnetic susceptibility of soils. Inphase data are expressed in parts per thousand of the primary magnetic field generated by the EMI transmitter. Without further examination and sampling, the inphase response is not well enough understood to make further comments concerning it.

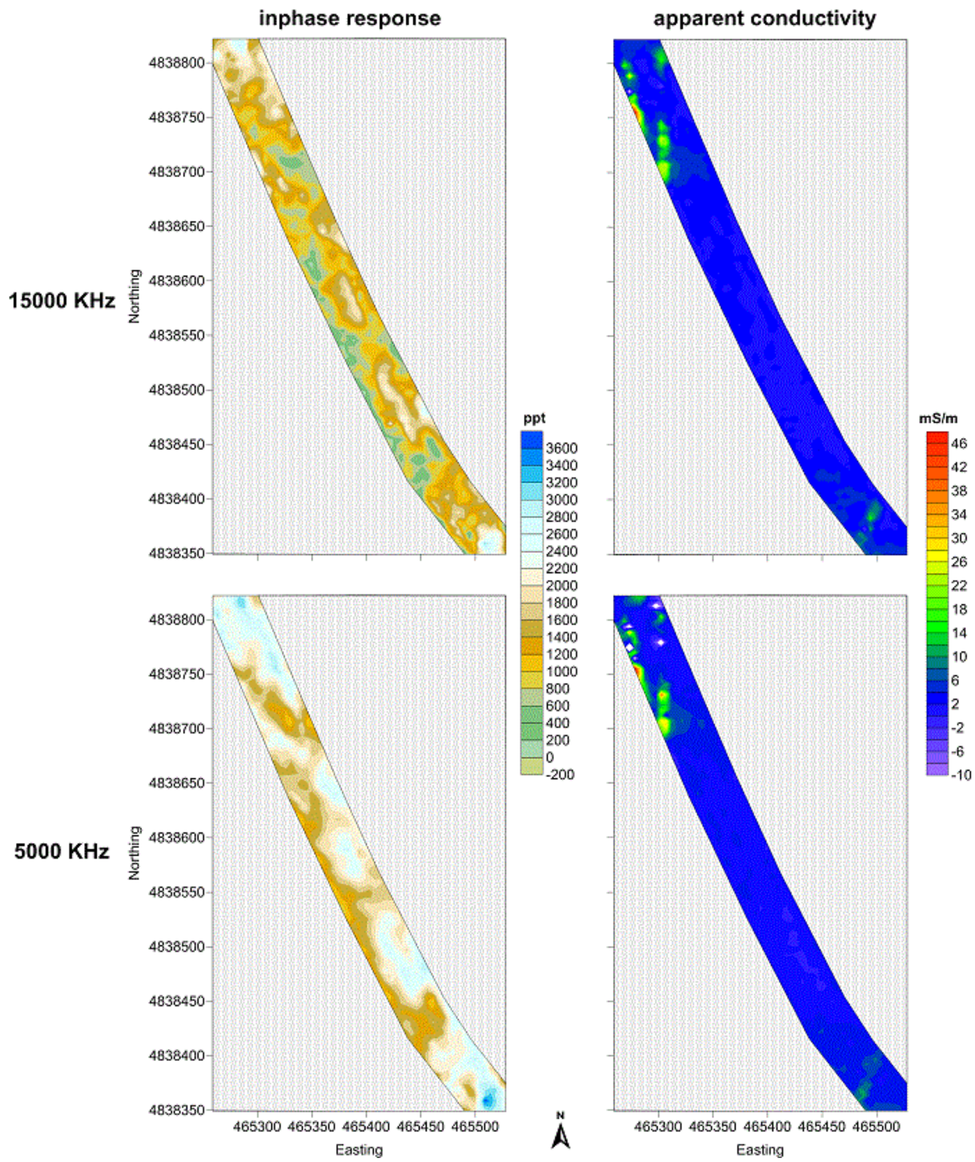


Figure 10. These plots of EMI data were collected with the Profiler at Site 3. The upper and lower plots show data collected at 15000 and 5000 KHz, respectively. The left- and right-hand plots show inphase and apparent conductivity data, respectively.

Site 4

A detailed survey was conducted with the Profiler across this area of Amenia loam, 3 to 8 percent slopes (AgB). Once again, the measured EC_a is considered relatively low and invariable reflecting the relatively low clay, soluble salt and moisture contents of this soil and the relatively shallow depth to electrically resistive bedrock. Based on 1717 EC_a measurements (measured at 15000 KHz), for a nominal investigation depth of f 0 to 183 cm, EC_a averaged 12.3 mS/m, and ranged from 5.7 to 37.4 mS/m across this site. One-half of the recorded measurements were between 9.8 and 14.2 mS/m. The low EC_a reflects the low conductivity of the soil and the relatively shallow depths to bedrock. However, compared with the results from Site 3, the slightly higher EC_a values at Site 4 may reflect slightly deeper depths to bedrock, higher soil moisture contents, or the effects of management. A more detailed investigation of these sites would be necessary to resolve the source(s) of these differences.

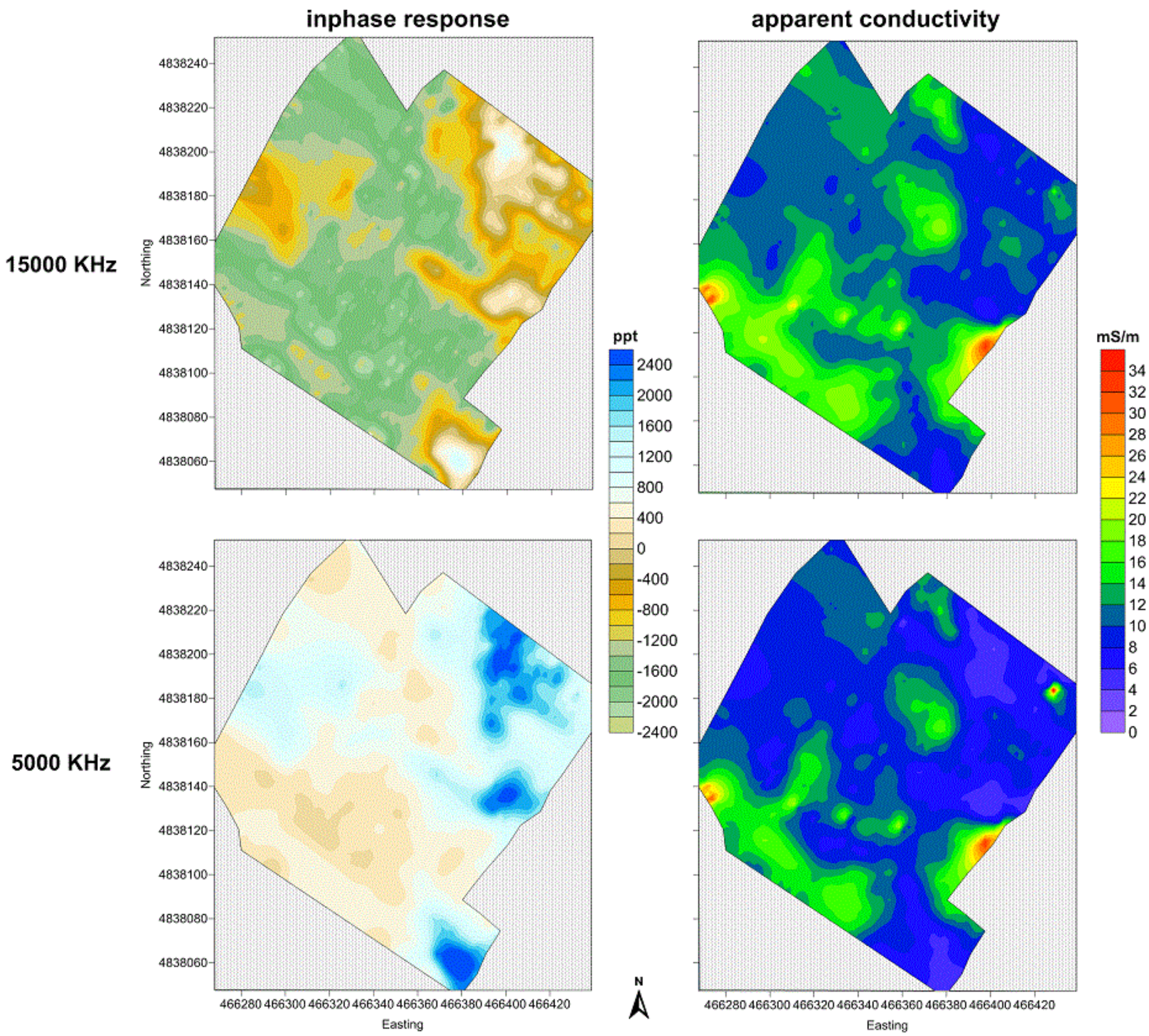


Figure 11. These plots of EMI data were collected with the Profiler at Site 4. The upper and lower plots show data collected at 15000 and 5000 KHz, respectively. The left- and right-hand plots show inphase and apparent conductivity data, respectively.

Figure 11 contains plots of EMI data that were measured at Site 4 with the Profiler. In Figure 11, the upper and lower plots show data recorded at 15000 and 5000 KHz, respectively. The left- and right-hand plots show inphase response and the apparent conductivity, respectively.

The collection of EMI data at two different frequencies results in similar EC_a spatial pattern, values, and interpretations. Multifrequency sounding with the Profiler theoretically should result in multiple depths being profiled with one pass of the sensor. As spatial patterns are similar, it is doubtful that the use of multiple frequencies provides multiple observation depths or any additional information about this site. In addition, the use of multiple frequencies requires additional time and expenses to process and display the data.

As represented in Figure 11, EC_a data appears spatially variable across this site. Although half of the recorded measurements (at 15000 KHz) were between 9.8 and 14.2 mS/m; sizable, dispersed areas of the higher EC_a (> 15 mS/m) were recorded in this field. It is presumed that these areas represent included soils that have slightly greater water and clay contents and/or deeper depths to bedrock.

Once again, the inphase response is noticeably higher at 5000 KHz than at 15000 KHZ, but spatial patterns remain remarkably similar in Figure 11. The correlation (r) between the two sets of inphase and conductivity measurements (made at 5000 and 15000 KHz) were 0.94. In this example, multifrequency profiling with the Profiler provides no additional information that justifies the added time required to process and display the data.

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Frequency Distribution of Observations falling into Different Soil-depth Classes along GPR Traverses

Radar File	Site	Map Unit	Shallow	Moderately Deep	Deep	Very Deep
2	Site 1	AgB	0.05	0.83	0.12	0.00
3	Site 1	AgB	0.17	0.76	0.07	0.00
4	Site 1	AgB	0.15	0.79	0.06	0.00
5	Site 1	AgB	0.24	0.74	0.02	0.00
6	Site 1	AgB	0.18	0.80	0.02	0.00
7	Site 1	AgB	0.05	0.94	0.01	0.00
8	Site 1	AgB	0.22	0.75	0.03	0.00
9	Site 1	AgB	0.15	0.80	0.05	0.00
10	Site 1	AgB	0.18	0.80	0.02	0.00
11	Site 1	AgB	0.40	0.57	0.02	0.00
12	Site 1	AgB	0.11	0.84	0.05	0.00
13	Site 1	AgB	0.61	0.39	0.00	0.00
14	Site 1	AgB	0.60	0.40	0.00	0.00
15	Site 2	AgA	0.20	0.71	0.09	0.00
16	Site 2	AgA	0.16	0.82	0.02	0.00
17	Site 2	AgA	0.09	0.78	0.13	0.00
18	Site 2	AgA	0.10	0.77	0.13	0.00
19	Site 2	AgA	0.08	0.87	0.05	0.00
20	Site 2	NeB	0.03	0.86	0.11	0.00
21	Site 2	NeB	0.33	0.67	0.00	0.00
22	Site 2	NeB	0.36	0.64	0.00	0.00
23	Site 2	NeB	0.04	0.79	0.17	0.00
24	Site 3	NeB	0.04	0.38	0.57	0.01
25	Site 3	NeB	0.03	0.59	0.38	0.00
26	Site 3	NeB	0.26	0.57	0.17	0.00
27	Site 3	NeB	0.12	0.83	0.05	0.00
28	Site 3	NeB	0.10	0.79	0.11	0.00
29	Site 3	NeB	0.13	0.82	0.05	0.00
30	Site 3	NeB	0.02	0.66	0.32	0.00
31	Site 3	NeB	0.20	0.63	0.17	0.00
32	Site 4	AgB	0.00	0.31	0.65	0.04
33	Site 4	AgB	0.00	0.58	0.33	0.09
34	Site 4	AgB	0.14	0.68	0.18	0.00
35	Site 4	AgB	0.00	0.21	0.58	0.21
36	Site 4	AgB	0.00	0.41	0.50	0.09
37	Site 4	AgB	0.09	0.84	0.07	0.00
38	Site 4	AgB	0.07	0.63	0.30	0.00
39	Site 4	AgB	0.07	0.35	0.55	0.03
40	Site 4	AgB	0.00	0.23	0.77	0.00
41	Site 4	AgB	0.03	0.47	0.50	0.00
42	Site 5	NbB	0.35	0.65	0.00	0.00
43	Site 5	NbB	0.26	0.72	0.02	0.00
44	Site 5	NbB	0.24	0.76	0.00	0.00
45	Site 5	NfD	0.15	0.51	0.34	0.00
46	Site 5	NfD	0.00	0.57	0.42	0.01