United States Department of Agriculture

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SUBJECT: SOI – Geophysical Assistance

November 28, 2011

TO: Denise C. Coleman
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File Code: 330-7

Purpose:
This investigation used electromagnetic induction (EMI) to infer spatial and temporal variations in soil moisture in an expanded area around two Odyssey well sites located in Crawford and Mercer Counties, Pennsylvania. Each well is equipped with an *Odyssey* soil moisture probe, which measures soil moisture content to a data logger. This information is periodically downloaded to a computer for documentation. This state-wide NRCS project is designed to collect data on seasonal soil moisture contents, duration of saturation, and depths to water table in Pennsylvania soils. This project collects data on soil moisture contents, fluctuations, and movement across soil-landscapes. The objective of this project is to improve the *soil moisture status data* in NASIS. In addition ground-penetrating radar (GPR) was used to assess the expression and continuity of fragipans in Ravenna and Venango soils.

Participants:
Alex Dado, MLRA Soil Survey Office Leader, USDA-NRCS, Mercer, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Michael Swaldek, Soil Scientist, USDA-NRCS, Mercer, PA

Activities:
Field activities were completed during the period of 2 to 4 November 2011.

Summary:

1. Electromagnetic induction data were collected at a site in Mercer and Crawford Counties. This data will be used to evaluate temporal and spatial variations in soil moisture contents and movement across soil-landscapes in Pennsylvania. The present surveys were conducted in the fall, when soil moisture contents were supposed to be at their lowest levels. However, Pennsylvania has experienced one of its wettest years on record, and soil moisture contents were at very high levels at both sites.

2. Temporal differences in the expression of fragipans on ground-penetrating radar (GPR) records are not well documented. During this study, two soils with fragipans were profiled (Ravenna and Venango). Water was observed perched above the fragipan of the two soils. The radar records collected over these soils will be compared with radar records collected when these sites are returned to under drier soil moisture conditions (fall 2012).

3. The presence of perch water is known to favor the detection of fragipan with GPR. Fragipans are often difficult to recognize on raw, unprocessed radar records. Signal processing and careful selection of color and transform settings are vital for the correct identification of fragipans. The use of higher frequency antenna (400 MHz versus 200 MHz antenna) results in higher resolution and greater detail, which adds unwanted additional complexity and obscures the *picking* of the fragipan on radar records.

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

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL

Director

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cc: See attached list

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Technical Report on the Use of Geophysical Methods for the Evaluation of Soil Water and Moisture Status at Odyssey Well Sites in Mercer and Crawford Counties, Pennsylvania, 2 to 4 November 2011.

James A. Doolittle

Background:
There is a recognized need for additional and improved data on seasonal soil moisture contents, duration of saturation, and depths to *high* water table in Pennsylvania soils. Data on *soil water status* are used for soil interpretations, conservation practices, risk management, and identifying hydric soils. In addition, hydrological models require accurate information on temporal and spatial variations in soil moisture and flow patterns. To accommodate these needs, a study, entitled *Evaluating Soil Water and Moisture Status,* has been implemented to improve the *soil water status* data in NASIS. This study is designed to collect data on soil moisture contents, fluctuations, and movement in different soils and across different landscapes in Pennsylvania. This project will revise and update the *soil moisture status* data in NASIS using graphs from data loggers on water table depths, analysis of Pennsylvania's Soil Climate Analysis Network (SCAN) data, and information collected with geophysical methods.

Equipment:
An EM38-MK2 meter (Geonics Limited; Mississauga, Ontario) was used in this study. [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 about 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 1.5 and 0.75 m when the meter is held in the vertical dipole orientation (VDO), and 0.75 and 0.40 m when the meter is held in the horizontal dipole orientation (HDO). In either dipole orientation, the EM38-MK2 meter provides simultaneous measurements of apparent conductivity (EC_a) over two depth intervals. Apparent conductivity is expressed in milliSiemens/meter (mS/m).

The Geonics DAS70 Data Acquisition System was used with the EM38-MK2 meter to record and store both EC_a and GPS data.[1] The acquisition system consists of the EM38-MK2 meter, an Allegro CX field computer (Juniper Systems, Logan, Utah), and a Pathfinder ProXT GPS receiver with Hurricane antenna (Trimble, Sunnyvale, CA). [1] With the acquisition system, the EM38-MK2 meter is keypad operated and measurements can either be automatically or manually triggered. The RTM38MK2 program (Geomar Software, Inc., Mississauga, Ontario) was used with the EM38-MK2 meter to display and record both GPS and EC_a data on the Allegro CX field computer. [1]

To help summarize the results of the EMI surveys, SURFER for Windows (version 10.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulations shown in this report. [1]

Field Sites:
<u>Mercer County:</u>
Because of vandalism, the Odyssey well site in Mercer County has been relocated to a cultivated field (near 80.2642 N. latitude, and 41.2484 W. longitude) about 0.6 miles west of the MLRA Office in Mercer. The well is located in a delineation of Ravenna silt loam on 0 to 3 percent slopes (RaA). The survey area includes an area of Frenchtown silt loam, on 0 to 3 percent slopes (FeA). The very deep, somewhat poorly drained Ravenna and poorly drained Frenchtown soils formed in till on till plains. The depth to the top of the fragipan ranges from 14 to 30 inches for Ravenna soils and 18 to 38 inches for

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

Frenchtown soils. Many pedons of Ravenna soils have a thin mantle of loess or other silty material. The taxonomic classifications of these soils are listed in Table 1.

Crawford County:
The Odyssey well site (near 80.1604 N. latitude and 41.8315 W. longitude) is located in pasture about 7.6 kilometers northeast of Venango, Pennsylvania. The site is located in a delineation of Venango silt loam on 0 to 3 percent slopes (VnA). The very deep, somewhat poorly drained Venango soils formed in low-lime till on till plains. The depth to the fragipan ranges from about 14 to 28 inches. Compared with Ravenna soils, Venango lacks a 2Bt horizon and a horizon above the fragipan that has clay films. The taxonomic classification of Venango soil is listed in Table 1.

Table 1. Taxonomic Classification of Soils

Series	Taxonomic Classification
Frenchtown	Fine-loamy, mixed, active, mesic Typic Fragiaqualfs
Ravenna	Fine-loamy, mixed, active, mesic Aeric Fragiaqualfs
Venango	Fine-loamy, mixed, active, mesic Aeric Fragiaqualfs

Field Methods:
Pedestrian surveys were completed with the EM38-MK2 meter across each site. The EM38-MK2 meter was operated in the deeper-sensing, vertical dipole orientation (VDO). The instrument was operated in the continuous mode with measurements recorded at a rate of 1/sec. The long axes of the meter was orientated parallel to the direction of traverse, and held, where possible, about 5 cm above the ground surface. Apparent conductivity data were recorded for both the 50 and 100 cm intercoil spacings. All EC_a data discussed in this report were temperature corrected to a standard temperature of 75^o F.

Results:
Mercer County:
At the time of the EMI survey, soils were moist in the surface layers, wet above the fragipan, and moist below suggesting episaturation conditions. Pennsylvania has experienced its wettest years on record, and soil moisture contents are at unusually high levels. Soil moisture conditions were not very different from those experienced at the abandoned Canfield site in April 2011.

Table 2. Apparent Conductivity Data from Mercer County Site- Ravenna and Frenchtown Soils

	EM38-MK2 50 cm	EM38-MK2 100 cm
Number	1377	1377
Minimum	-38.36	-2.60
25%-tile	10.20	10.91
75%-tile	14.60	14.00
Maximum	24.03	21.15
Average	12.57	12.54
Std. Dev.	3.51	2.60

Table 2 provides basic statistics for the EC_a data that were collected at this site. The bulk averaged EC_a remains constant with soil depth (average was about 12.6 mS/m for both intercoil spacings). For measurements obtained in the shallower-sensing, 50-cm intercoil spacing, EC_a ranged from about -38.4 to 24 mS/m. Negative values are attributed to the presence of metallic artifact(s) scattered across this site. One-half of the measurements for the 50-cm intercoil spacing were between about 10.2 and 14.6 mS/m. For the deeper-sensing 100-cm intercoil spacing, EC_a ranged from about -2.6 to 21.2 mS/m. One-half of these measurements were between about 10.9 and 14.0 mS/m. The consistent values and ranges suggest fairly homogeneous soil conditions and properties for the two penetration depth ranges.

Figure 1 contains plots of the EC_a data that were collected with the EM38-MK2 meter at the Mercer site. The same color scales and ramps have been used in both of the plots shown in Figure 1. Plots show data collected with the EM38-MK2 meter for the shallower-sensing, 50-cm intercoil spacing (left-hand plot) and the deeper sensing, 100-cm intercoil spacing (right-hand plot). Soil boundary lines have been digitized from Web Soil Survey data[2]. In general, areas mapped as Frenchtown soils have a higher EC_a than areas mapped as Ravenna soils. However, spatial EC_a patterns do not conform to soil boundaries. Alex Dado noted that the area mapped as Frenchtown soil was not poorly drained and would fit better into the concept of Ravenna soils.

The general trend across this site is for EC_a to decrease towards northwest. This trend may reflect soils with lower clay and/or moisture contents, deeper depths to argillic horizon, less perched water above the fragipan, and/or less dense fragipans. Additional core observations will be needed to confirm these interpretations.

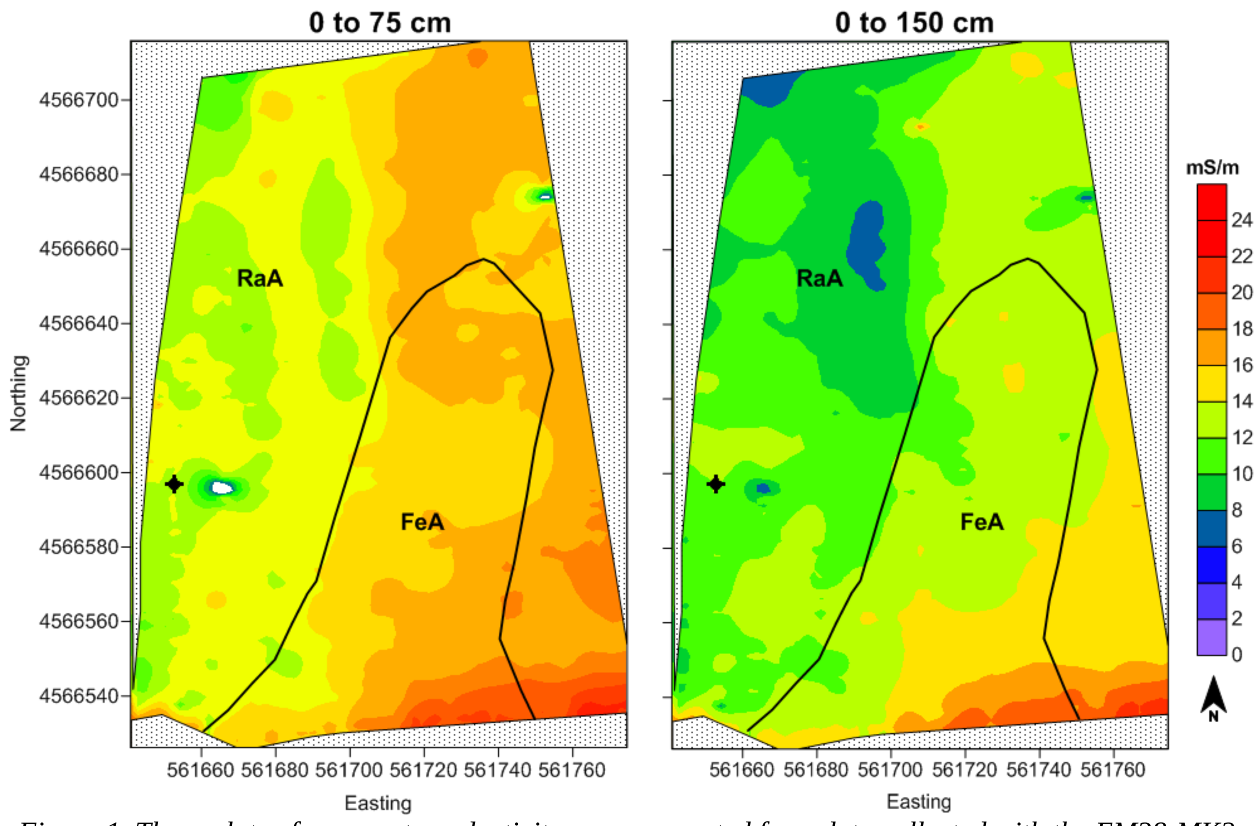

Figure 1. These plots of apparent conductivity were generated from data collected with the EM38-MK2 meter in delineations of Ravenna (RaA) and Frenchtown (FeA) soils. The depth of effective exploration is shown above each plot. A spot symbol identifies the approximate location of the Odyssey well site.

[2] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [11/7/2011].

In Figure 1, EC_a is conspicuously higher along the lower boundary of each plot. The southern boundary of the study site is a farm road. The higher conductivity may be the result of a buried utility line. A suspected artifact is expressed by the small area of anomalously low EC_a immediately east of the Odyssey well site.

Crawford County:

Table 3 provides basic statistics for the EC_a data that were collected at the Venango site in Crawford County. Apparent conductivity increased with increasing depth (comparison of measurements obtained in the deeper-sensing, 100-cm intercoil spacing with measurements obtained in the shallower-sensing, 50-cm intercoil spacing). Higher values recorded with the deeper-sensing, 100-cm intercoil spacing can be associated with higher clay and/or water contents at and below the fragipan and possibly the absence of a silt mantle.

Table 3. Apparent Conductivity Data from Crawford County Site- Venango Soils

	EM38-MK2 50 cm	EM38-MK2 100 cm
Number	586	586
Minimum	-8.16	-12.06
25%-tile	4.57	14.11
75%-tile	7.22	16.25
Maximum	51.47	96.57
Average	6.38	16.06
Std. Dev.	4.05	6.79

In this area of Venango soil, the average EC_a is low and increases with depth. For measurements obtained in the shallower-sensing, 50-cm intercoil spacing, EC_a ranged from about -8.2 to 51.5 mS/m. Negative values are attributed to the presence of metallic artifact(s) buried or scattered across this site. One-half of 50-cm intercoil spacing measurements were between about 4.6 and 7.2 mS/m. For the deeper-sensing, 100-cm intercoil spacing, EC_a ranged from about -12.1 to 96.6 mS/m. One-half of these measurements were between about 14.1 and 16.2 mS/m. The contrast between these two penetration depths (0 to 75 cm and 0 to 150 cm) suggests horizons with contrasting soil properties.

In comparison to Venango soils, Ravenna soils can have a thin mantle of loess or other silty materials. The silt mantle and the presence of an argillic horizon above the fragipan of Ravenna soils may explain its higher EC_a than the Venango soils at shallow soil depths (12.6 versus 6.4 mS/m). For these two soils, the more similar average EC_a (12.5 versus 16.1 mS/m) at deeper soil depths (0 to 150 cm) may reflect similarity physiochemical properties in the underlying till materials. If this relationship is consistently measured at other sites, this vertical difference in EC_a may help to differentiate these soils, or soils with and without a loess mantle and a shallower argillic horizon.

Figure 2 shows the spatial distribution of EC_a across the Venango soil site as measured with the EM38-MK2 meter operating in the shallower-sensing, 50-cm (left-hand plot) and deeper-sensing, 100-cm (right-hand plot) intercoil spacings. Soil boundary lines have been digitized from Web Soil Survey data[3]. The black circle represents the location of the Odyssey well.

[3] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [11/7/2011].

A comparison of the two plots shown in Figure 2 reveals that EC_a increases with increasing soil depth. The Venango soil has a Btx horizon that has greater clay content than surface layers, which, along with differences in consistency and the presence of a perched water, may explain, in part, this observed depth relationship.

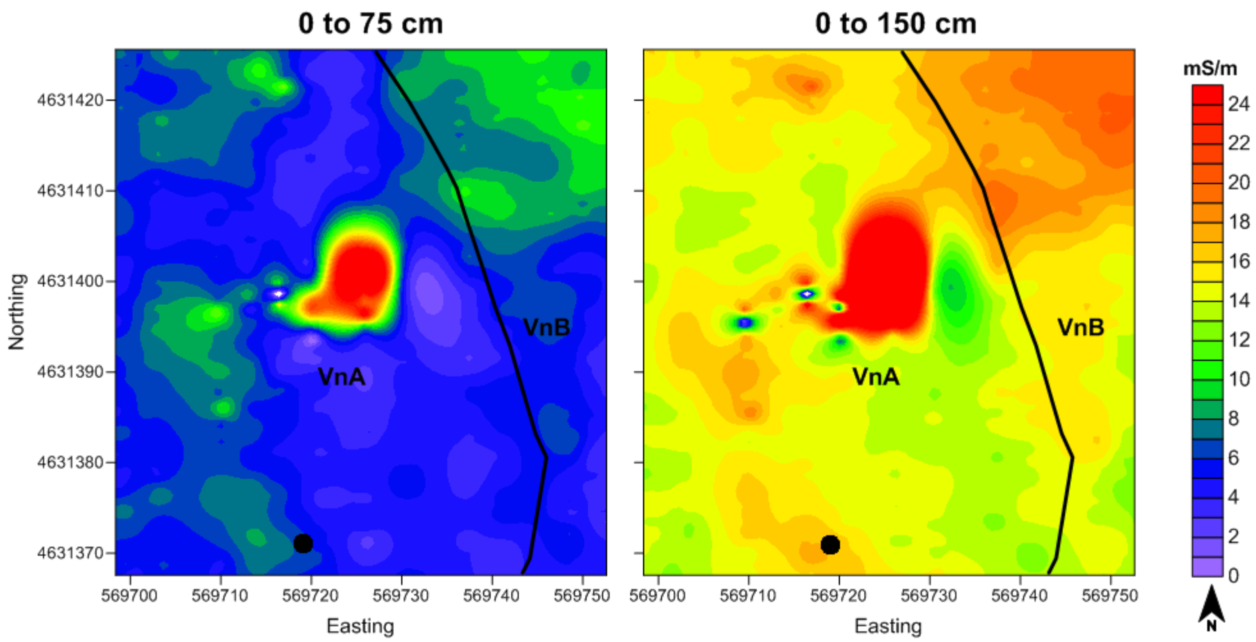

Figure 2. These plots of EC_a were generated from data collected with the EM38-MK2 meter at the Venango soil site in Crawford County. The depth of effective exploration is shown above each plot. The black dot in each plot identifies the approximate location of an Odyssey well.

In each plot shown in Figure 2, a large, anomalous feature is evident in the north-central portion of the surveyed area. This feature was neither investigated nor identified, and was not visually apparent in the field. Because of its limited areal extent and strong contrast with other portions of the survey area, this pattern brings to mind the possibility of buried cultural debris. In each plot, EC_a patterns, though different in magnitude (lower in 0 to 75 cm plot) are spatially similar. These patterns may reflect variations in the depth or expression of the fragipan, and/or the perching of water above this interface. Further core observations are needed to confirm the factors responsible for these patterns.

Figure 3 contains plots of EC_a collected with the EM38-MK2 meter operated in the VDO at the Venango site in the spring (left-hand plot) and fall (right-hand plot) of 2011. In both plot the nominal depth of exploration is 150 cm. The black dot in each plot identifies the approximate location of an Odyssey well. Different areas were surveyed in each survey. In the plot of EC_a data collected in the fall of 2011, the rectangle formed by segmented lines represents the area that was surveyed in the spring of 2011. In both plots, the letter "A" identifies a subsurface anomaly that is believed to represent buried cultural debris. The anomalous pattern near "B" in the spring 2011 data is believed to represent an equipment bag that had been placed on the ground surface during the survey.

A comparison of the two plots shown in Figure 3, reveals higher EC_a in the fall than in the spring data. As discussed earlier, this has been the wettest years on record in Pennsylvania. At the time of the fall 2011 survey, soils were exceedingly moist. The higher EC_a in the fall data may reflect wetter soil conditions. The soil temperature was warmer in the fall than in the spring 2011 survey. Although, all

EC_a data were corrected to a standard temperature, variations in the microclimate across this site and possible errors in the conversion equation cannot be ruled out at this time.

Using the fall 2011 plot in Figure 3, if EC_a is related to greater soil water contents, shallower depths and/or greater expression of the fragipan, then the areas that have an EC_a greater than 14 may be suspect of having these properties. Conversely, areas with lower EC_a are suspect of having lower soil moisture contents, greater depths and/or poorer expression of the fragipan. As the soils slope to the east and northeast, the area of higher EC_a in the northeast corner of the fall 2011 data plot may indicate a flow pattern. For the next survey of this site, a more expanded survey area will be used.

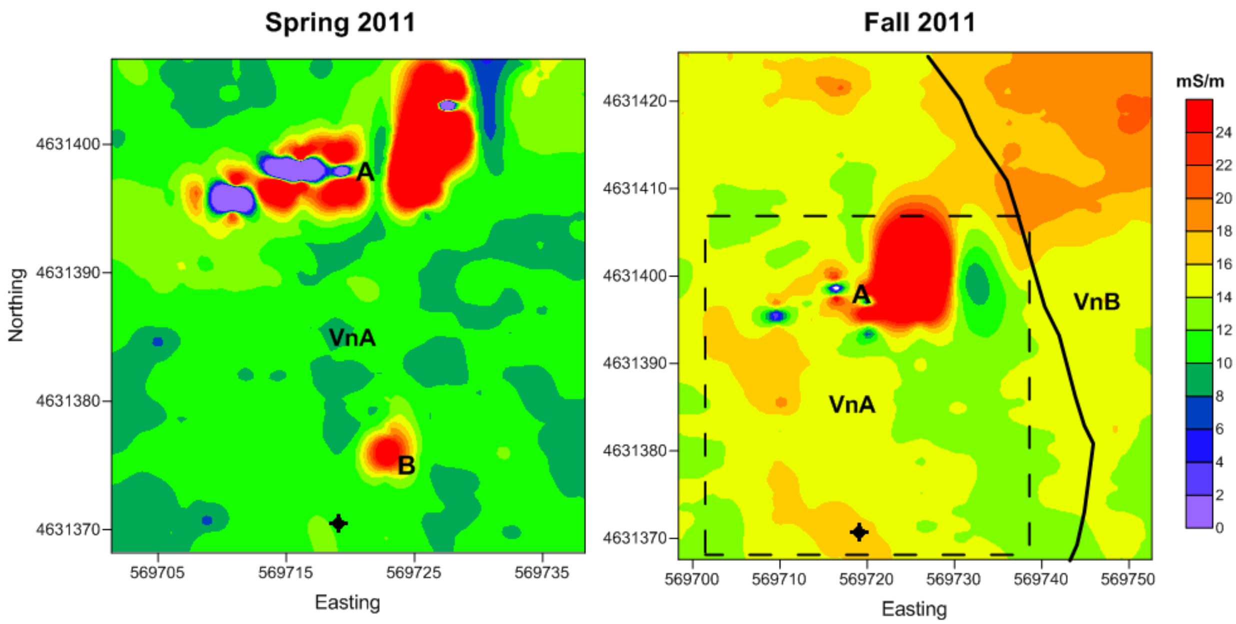

Figure 3. These plots of EC_a were generated from data collected with the EM38-MK2 meter at the Venango soil site in the spring (left-hand plot) and fall of 2011 (right-hand plot). In each plot the nominal depth of exploration is 150 cm. The black dot in each plot identifies the approximate location of an Odyssey well. In the plot of EC_a data collected in the fall of 2011, the rectangle formed by segmented lines represents the area that was surveyed in the spring of 2011.

Technical Report on Ground-Penetrating Radar (GPR) Investigations of Fragipans in Mercer and Crawford Counties, Pennsylvania, 2 to 4 November 2011.

The somewhat poorly drained Ravenna and Venango soils dominate landscapes in the till derived soils of eastern MLRA 139. Both soils are classified as fine-loamy, mixed, active, mesic Aeric Fragiaqualfs. The presence, spatial continuity and expression of fragipans are difficult to characterize with conventional soil survey tools. As fragipans form a depth restrictive layer to water and tree roots, they play an important role in near-surface hydrological processes. For nearly thirty years, ground-penetrating radar (GPR) has been used to chart the depth, lateral extent, and continuity of fragipans (Doolittle et al., 2000; Lyons et al., 1988; Olson and Doolittle, 1985). Results have had varied degrees of success, with the effectiveness of GPR being highly site and parent material specific. Temporal differences in the expression of fragipans on radar records are not well documented. The plan of this study is to profile soils with fragipans at different times of the year (under both wet (spring) and Dry (fall) conditions) and evaluate the performance of GPR.

GPR System:
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).[4] 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 this study.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records.[4] Processing included: header editing, positioning the initial pulse to time zero, color table and transformation selection, signal stacking, migration, horizontal high pass filtration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

For the collected radar data, the *Interactive 3D Module* of RADAN was used to semi-automatically picked the depths to the fragipan. The picked data were outputted to a worksheet (in an X, Y, and Z format; including longitude, latitude, and depth to fragipan data). .

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) 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):

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

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):

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

Where C is the velocity of propagation in a vacuum (0.298 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 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.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (buried metal plate), the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profiles were estimated using equations [1] and [2]. At the Mercer County sites (Ravenna soils), the estimated E_r and v were 14.4 and 0.0785 m/ns, respectively. At the Crawford County site (Venango soils), the estimated E_r and v were 25.2 and 0.0594 m/ns, respectively. At the time of these studies, soils were very moist and water was observed to be perched above the fragipan.

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

Detecting Fragipans with GPR:
The amount of energy reflected back to an antenna is a function of the dielectric gradient that exists across a soil interface or boundary. The greater and/or more abrupt the contrast in the dielectric properties of adjoining soil materials, the greater the amount of energy reflected back to the antenna, and the more intense and conspicuous the amplitude of the reflected signal appearing on radar records. Soil horizons, layers, and features that have similar relative permittivity are poor reflectors of electromagnetic energy and are difficult to identify on radar records.

The E_r of soil materials is dependent upon moisture content. As a consequence, the amount of energy reflected back to the radar's antenna is greatly influenced by the abruptness and difference in moisture contents that exist between soil horizons, layers or features. The perching of water above a relatively denser and drier fragipan is expected to increase the difference in relative dielectric permittivity across the upper boundary of the fragipan making this interface easier to detect and trace on radar records. In this investigation, this hypothesis was to be tested when these conditions were less than ideal; during a dry fall month. Unfortunately, this was the wettest year on record in Pennsylvania, and soil moisture was at a level comparable or higher than experienced during the spring of this year.

Results:
Figures 4, and 5 are representative radar records that were collected over areas of the somewhat poorly drained Ravenna and Venango soils (fine-loamy, mixed, active, mesic Aeric Fragiaqualfs), respectively. Signal processing and careful selection of signal color and transform settings are imperative to correctly identify fragipan. Fragipans were difficult to recognize on raw, unprocessed radar records. In this study a 400 MHz antenna was used rather than the 200 MHz antenna (which was used in the spring survey) to provide higher resolution of subsurface features.

On each radar record, the upper boundary of the fragipan has been identified with a red-colored, segmented line. Even with the relatively narrow wavelength of the 400 MHz antenna, it is generally difficult to resolve features occurring near the soil surface. Vertical resolution is dependent on the wavelength. Theoretically, vertical resolution (Rv) is about ¼ of the wavelength (λ). However, most accept vertical resolution as about ½ of the wavelength. If two events are separated in time by less than this length, they will be indistinguishable and interpreted as one event. The wavelength is determined by dividing the propagation velocity (*v*) by the antenna frequency (*f*).

$$\lambda = v/f \qquad [3]$$

At the Ravenna and Venango soil sites, the estimated *v* was 0.0785 and 0.0594 m/ns, respectively. With a 400 MHz antenna, according to equation [3], λ is about 20 an 15 cm at the Ravenna and Venango sites. Theoretically, the vertical resolution should be about 10 and 7.5 cm in areas of Ravenna and Venango soils.

Figure 4 is a representative portion of the radar traverse of the Ravenna soil. On the radar record shown in Figure 4, horizontal high pass filtration has been used to remove reflections and multiples from the strong surface pulse (which, as a consequence, is not seen). The horizontal (distance) and vertical (depth) scales are expressed in meters. In Figure 4, a segmented, yellow-colored line marks the interpreted upper boundary of the argillic horizon (2Bt horizon). A segmented, red-colored line marks the interpreted upper boundary of the fragipan (2Btx horizon). The fragipan, as indicated by its higher signal amplitude, provides a more contrasting interface than the argillic horizon. Multiple, closely-spaced, seemingly segmented, planar reflections suggest that the 400 MHz antenna is detecting several different closely-spaced layers with contrasting soil properties. While this is good, the complex patterns seen in Figure 4, adds greater uncertainty to the "picking" of individual horizons. With the 200 MHz antenna that was used in the spring, reflections from fragipans formed a more continuous and easily recognizable interface on radar records.

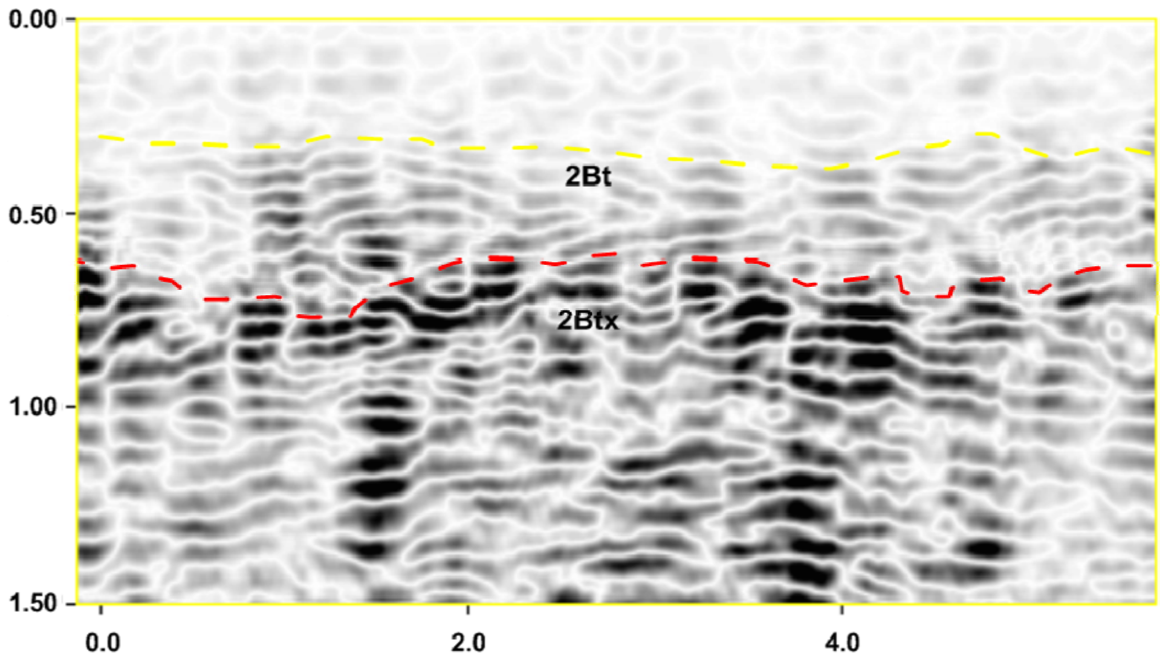

Figure 4. Representative radar record of an area of Ravenna soil with the upper boundary of the argillic horizon identified by a segmented, yellow-colored line, and the fragipan identified with a segmented, red-colored line.

Figure 5 is a representative portion of the radar traverse of the Venango soil. On the radar record shown in Figure 5, horizontal high pass filtration has been used to remove reflections and multiples from the strong surface pulse (which, as a consequence, is not seen). The horizontal (distance) and vertical (depth) scales are expressed in meters.

On the radar record collected over the Venango soils (Figure 5), the fragipan appears to have a more irregular topography and is laterally discontinuous with noticeable variations in signal amplitudes. On this radar record, the fragipan is difficult to properly identify because of the complexity of the image. Signal amplitudes increase (become darker in this representation) where an interface boundary is more abrupt and contrasting. These properties vary equally along the 2Bt/2Bx boundary of Ravenna and the Bw/Btx boundary of Venango soils. However, the more irregular boundary and the greater number of segmented, high amplitude reflections makes the identification of the fragipan more difficult on the radar record of Venango soils.

Soil moisture conditions under which these investigations were conducted appear favorable for the detection of fragipan with GPR. The presence of perch water generally favors the detection of fragipans. However, the use of a higher frequency antenna (400 MHz versus 200 MHz antenna) results in higher resolution and greater detail, which adds additional complexity and obscures the *picking* of the fragipan on radar records. It is hoped that these and additional sites can be surveyed with GPR during drier fall conditions to confirm and complete interpretations.

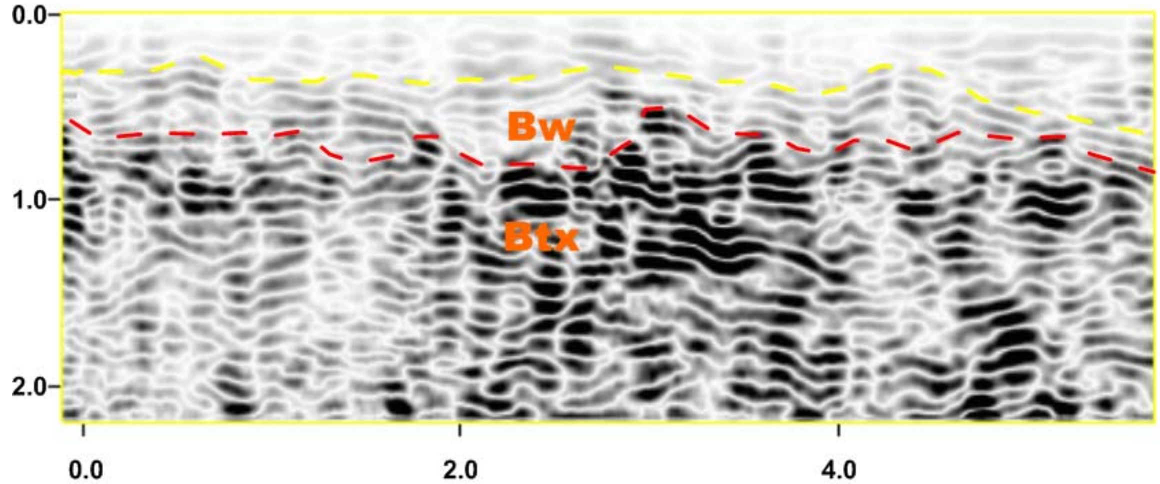

Figure 5. Representative radar record of an area of Venango soil with the upper boundary of the cambic horizon identified by a segmented, yellow-colored line, and the fragipan identified with a segmented, red-colored line.

References:

Cassidy, N.J. 2009. Electrical and magnetic properties of rocks, soils, and fluids. In *Ground Penetrating Radar: Theory and Applications*, ed. H. M. Jol, 41-72 pp. Elsevier Science, Amsterdam, The Netherlands.

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

Doolittle, J., G. Hoffmann, P. McDaniel, N. Peterson, B. Gardner and E. Rowan. 2000. Ground-penetrating radar interpretations of a fragipan in Northern Idaho: *Soil Survey Horizons* 41(3): 73-82.

Geonics Limited, 2007. EM38-MK2 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario.

Jol, H., 2009. Ground Penetrating Radar: Theory and Applications. Elsevier Science, Amsterdam, The Netherlands.

Lyons, J.C., C.A. Mitchell and T.M. Zobeck. 1988. Impulse radar for identification of features in soils: *Journal of Aerospace Engineering* 1:18-27.

Olson, C.G. and J.A. Doolittle. 1985. Geophysical techniques for reconnaissance investigations of soils and surficial deposits in mountainous terrain: *Soil Science. Society of America Journal* 49: 1490-1498.