United States Department of Agriculture **Natural Resources Conservation Service** **11 Campus Boulevard, Suite 200 Newtown Square, PA 19073**

Subject: ENG -- Electromagnetic Induction (EMI) Assistance **Date:** 12 September 2002

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Purpose:
An electromagnetic induction (EMI) survey was conducted along the lower reaches of Lees Creek in Mayfield, Lackawanna County. The purpose of this survey was to use EMI to trace the presence and former channel of the lower reaches of Lees Creek. Immediately above the Business Route 6 culvert, the stream looses flow as water is diverted underground presumably through an abandoned mine tunnel. The restoration of this stream has been proposed. Under this proposal, stream waters lost to the abandoned mine would be redirected along its natural course and no longer resurface as acid mine drainage. In addition, adjoining lands would be cleaned of litter and debris and a system of nature trails would be developed.

Participants:
John Coleman, Conservation Engineering Specialist, PA Association of Conservation Districts, Bloomsburg, PA
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Joe Rutkoski, Engineer Technician, USDA-NRCS, Plymouth, PA
John Zaginaylo, Area Engineer, USDA-NRCS, Bloomsburg, PA
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Activities:
All field activities were completed on 10 September 2002.

Equipment:
A GEM300 multifrequency sensor was used in this study. Geophysical Survey Systems, Inc. manufactures the GEM300 sensor. [*] Won and others (1996) describe the use and operation of this sensor. This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation. With the GEM300 sensor, the penetration depth is considered “skin depth limited.” The skin-depth represents the theoretical maximum depth of penetration and is frequency and soil dependent. Multifrequency sounding with the GEM300 theoretically allows multiple depths to be profiled with one pass of the sensor.

The location of each observation points was measured with a Trimble Pathfinder PRO-XRS Sub-meter GPS receiver[*]. The coordinates of all observation points were differentially corrected using Trimble’s Pathfinder Office (version 2.70). [*] SURFER for Windows, version 8.0, developed by Golden Software, Inc.,[*] was used to construct two-dimensional

[*] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

simulations. Grids were created using kriging methods with an octant search.

Study Sites:

The study area is located along Lees Creek in Mayfield, PA. Lees Creek is a small stream that emanates on West Mountain in Lackawanna County and flows for about 3.0 miles to its confluence with the Lackawanna River. The stream drains a very small watershed (about 0.73-mi^2). An area adjoining the lower 1000-foot reach of this creek was surveyed with EMI. This area lies between PA Business Route 6 and the Lackawanna River. Lees Creek looses flow and the channel is poorly defined in portions of this reach. Here the channel crosses coal wastes, rail ballast, and cinders that are associated with the former Mayfield Rail Yard and the roundhouse of the now defunct New York, Ontario and Western Railway. This wooded, highly disturbed area of rough and broken ground is ill suited to an EMI survey. Buildings, utility lines and large amounts of buried and partially buried artifacts from the former railroad yard interfered with the electromagnetic fields of the GEM300 sensor, producing anomalous responses that either obscured or complicated spatial patterns.

Field Procedures:

Random traverses were conducted with the GEM300 sensor and a Trimble Pathfinder PRO-XRS sub meter GPS system. A noteworthy accomplishment of this survey was the ability of the Trimble Pathfinder PRO-XRS sub meter GPS system to track satellites and maintain a satisfactory position dilution of precision under a fairly dense canopy. A total of 79 observations were made during this survey. Figure 1 shows the locations of the observation points.

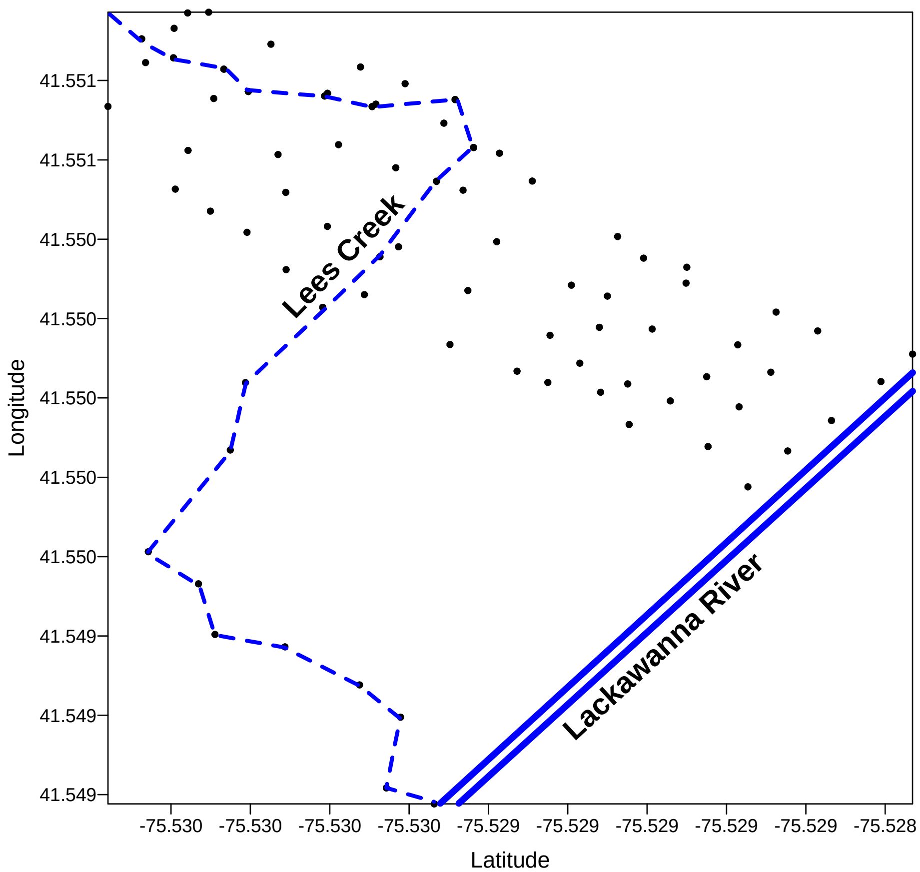

Figure 1. Location of EMI observation points relative to Lees Creek and the Lackawanna River.

At each of these observation points, measurements were taken with the GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity was measured with the GEM300 sensor at three operating frequencies: 6030, 9810, and 14790 Hz. These frequencies correspond to the frequencies of the EM34-3, EM31, and EM38 meters (manufactured by Geonics, Limited), respectively . Apparent conductivity measurements are expressed in mS/m.

Background:
Electromagnetic induction (EMI) is a noninvasive geophysical tool that can be used for detailed site assessments. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. This geophysical method can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are caused by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the type and concentration of ions in solution, the amount and type of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). The apparent conductivity of soils increases with increased soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic induction measures vertical and lateral variations in apparent electrical conductivity. Values of apparent conductivity are seldom diagnostic in themselves, but lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used.

Electromagnetic induction is not suitable for use in all investigations. Generally, the use of EMI has been most successful in areas where subsurface properties are reasonably homogeneous and one property (e.g. salt, clay, or water content) exerts an overriding influence over soil electrical conductivity. In these areas, variations in apparent conductivity can be directly related to changes in the dominant property (Cook et al., 1989). In this survey, it was hoped that EMI responses could be obtained from the underlying bedrock, and that air or water filled voids would contrast significantly with underlying bedrock and be detectable with EMI.

Depth of Observation:
The theoretical penetration depths of the GEM300 sensor are governed by the "skin-depth" effect (Won, 1980 and 1983). The skin-depth is the maximum depth of penetration for an EMI sensor operating at a particular frequency and sounding a medium with a known conductivity. Penetration depth or "skin-depth" is inversely proportional to the operating frequency of the sensor and the bulk conductivity of the profiled earthen material(s) (Won et al., 1996). Low frequency signals travel farther through conductive mediums than high frequency signal. Lowering the frequency will extend the depth of penetration. At a given frequency, the depth of penetration is greater in low conductivity than in high conductivity soils.

With the GEM300 sensor, the depth of penetration or the "skin depth" is estimated using the following formula (McNeill, 1996):

$$D = 500/(s*f)^{-2} \qquad [1]$$

Where s is the ground conductivity (mS/m) and f is the frequency (kHz). With the GEM300 sensor held at hip height in the vertical dipole orientation, the average apparent conductivities were 17.3, 14.9, and 17.6 mS/m at frequencies of 6030, 9810, and 14790 Hz, respectively. Based on equation [1], the selected frequencies, and these average conductivities, the estimated skin depths were about 49 m at 6030 Hz, 41 m at 9810 Hz, and 31 m at 14790 Hz. Within these theoretical skin depths, earthen materials from all depths contribute, in varying degrees, to the measured response. With increasing depth, the relative contribution from various depth layers passes through a maximum. While the induced magnetic fields may achieve these theoretical skin depths, the strengths of the response diminish with increasing depth and are often too weak to be sensed by the GEM300 sensor.

The *depth of observation* is defined as the depth that contributes the most to the total EMI response measured on the ground surface. Although contributions to the measured response come from all profiled depths, the contribution from the *depth of observation* is the largest (Roy and Apparao, 1971). As noted by Roy and Apparao (1971), for any system, the depth of observation is a good deal shallower than is generally assumed or reported.

Interpretations:
Table 1 summarizes the basic statistics for this EMI survey. The first column denotes the operating frequency (6030, 9810, or 14790 Hz) and the dipole orientation (V for vertical; H for horizontal). Values of apparent conductivity were extremely low across the site. However, sporadic anomalously high positive or negative measurements were recorded. These measurements reflect the presence of buildings, utility lines, and buried or partially buried metallic debris. All apparent conductivity measurements have been *zero adjusted* (for each frequency, with the exception of anomalously low negative values, the lowest recorded value (absolute) is added to each measurement). Quartiles are useful measures of the range of apparent conductivity within a survey area. One half of the observations are between the first and third quartiles. The few anomalously low negative values reflect the presence of buried metallic reflectors and were not removed from the data set.

Table 1 – Basic statistics for the survey conducted along the lower reaches of Lees Creek.
(All values are in mS/m.)

					Quartiles	
Freq/Orient	**Average**	**SD**	**Minimum**	**Maximum**	**First**	**Third**
6030 V	17.3	17.1	-15.8	72.5	5.7	23.6
6030 H	16.6	15.5	0.0	71.5	5.5	23.9
9810 V	14.9	16.6	-15.6	73.6	4.1	20.4
9810 H	16.2	13.0	0.0	52.0	6.7	20.9
14790 V	17.6	17.2	-14.5	79.2	6.9	23.6
14790 H	19.1	13.2	0.0	57.0	10.2	25.4

Figure 2 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor. The color interval is 2 mS/m. The approximate locations of Lees Creek and the Lackawanna River are shown in each plot. The left-hand plots represent data collected in the horizontal dipole orientation; the right-hand plots represent data collected in the vertical dipole orientation. The upper plots were obtained from data collected at a frequency of 6030 Hz. The middle plots were obtained from data collected at a frequency of 9810 Hz. The lower plots were obtained from data collected at a frequency of 14790 Hz.

All plots appearing in Figure 2 are similar. However, plots collected in different dipole orientations are more dissimilar than plots collected at different frequencies but in the same dipole orientation. Plots collected at different frequencies but in the same dipole orientation look remarkably similar. Strong positive (r = 0.891 to 0.990) correlations were obtained between data collected at different frequencies, but in the same dipole orientation. All correlations were significant at the .001 level. These findings suggest that regardless of frequency, the GEM300 sensor is responding to the same depth interval. Based on spatial patterns, as the depth *of observation* appears similar at all frequencies, multifrequency soundings at this site provide no benefits over signal frequency soundings. However, because of differences in the depth-weighting functions of the sensor, measurements made in different dipole orientations do show dissimilar spatial patterns that reflect differences in the sensors depth-weighting response and variations in the conductivity of earthen materials within that depth interval. The shallower-sensing, horizontal dipole orientation is more sensitive to earthen materials located near the soil surface. The deeper-sensing, vertical dipole orientation is more sensitive to earthen materials located at deeper depths.

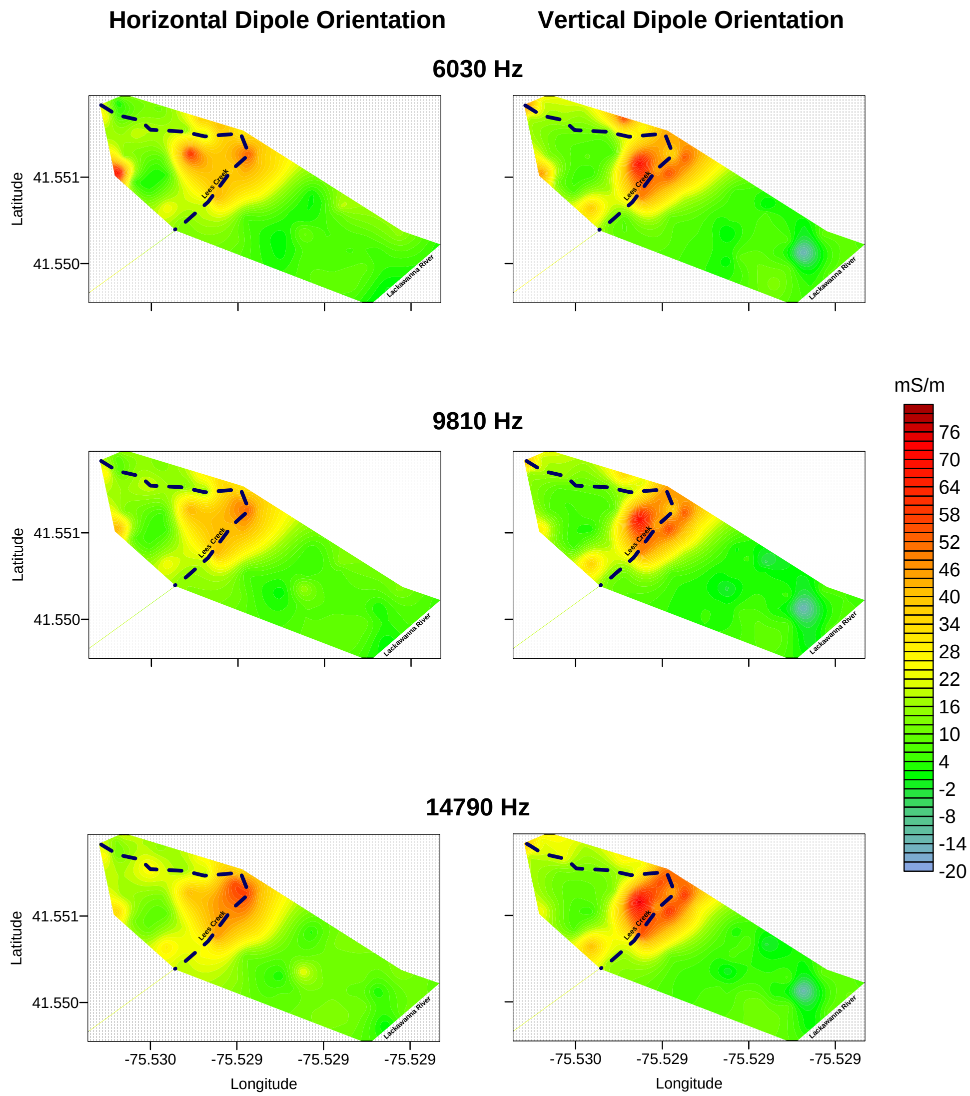

Figure 2. – Spatial patterns of apparent conductivity collected with the GEM300 sensor.

Figure 3 contains plots of EMI data collected with the GEM300 sensor operating at a frequency of 14790 Hz in both the horizontal (upper plot) and vertical dipole (lower plot) orientations. The color interval is 2 mS/m. The approximate locations of Lees Creek and the Lackawanna River are shown in each plot. Spatial patterns shown in Figure 3 appear to reflect layers of debris and fill associated with the former railroad yard site. Several *terraces*, each with a distinguishing EMI response and elevation, were observed within the survey area. These different levels of fill and debris essentially parallel the Lackawanna River (southwest to northeast orientation). A zone of conspicuously high apparent conductivity materials is evident in all plots in the central portion of the survey area. The higher conductivity may be associated with less gravelly, more finer-textured materials, or possible contaminants. However, as no borings were made these interpretations are highly speculative. In Figure 3, random point anomalies reflect the presence of interfering cultural debris.

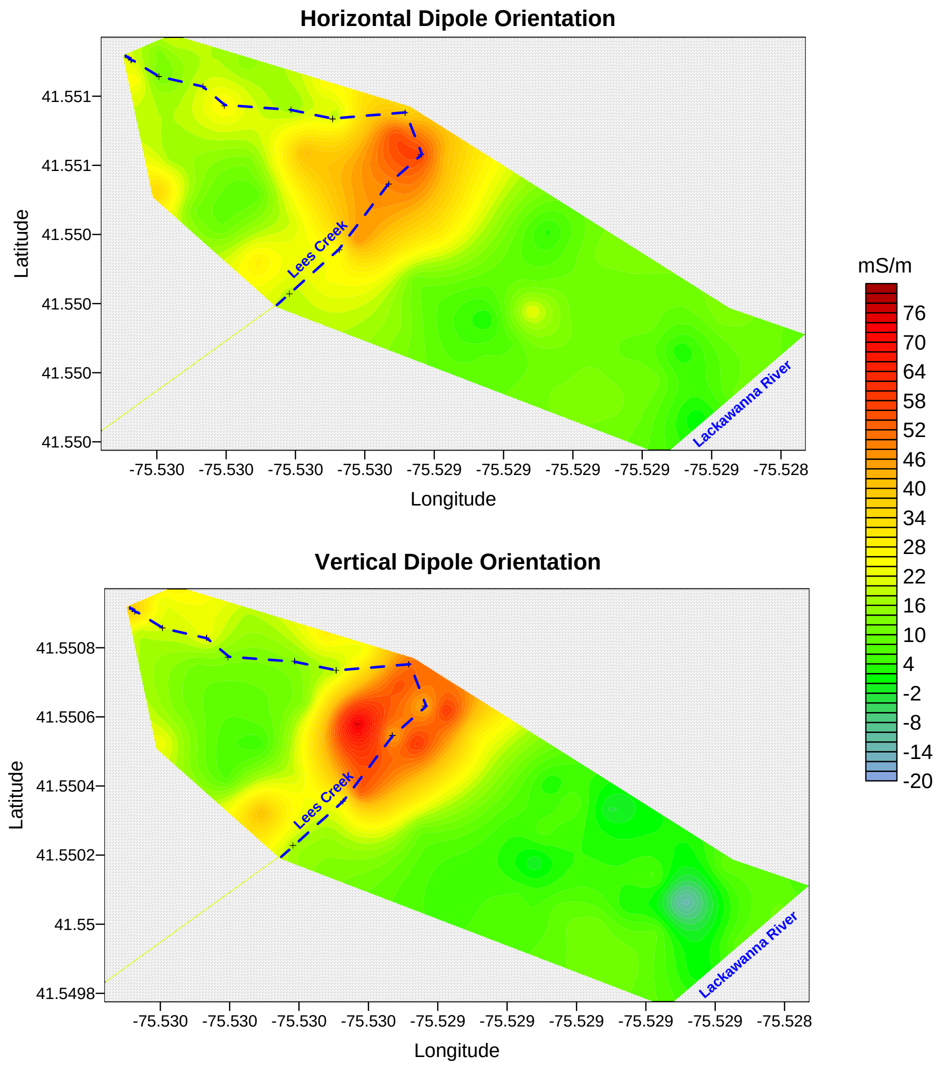

Figure 3. – Spatial patterns of apparent conductivity collected with the GEM300 sensor at an operating frequency of 14790 Hz.

No distinct pattern defines the present course of Lees Creek. The stream crosses the different debris terraces without leaving any unique and identifying EMI signature that can be used to trace its presence or former locations. What is noteworthy is that Lees Creek changes its flow direction from essentially east–west to northeast–southwest and takes a striking right angle bend within the area of highest apparent conductivity and presumably finer-textured debris materials. This may or may not be coincidental.

Results:

1. The EMI survey did not reveal any indications of the original or subterranean course of Lees Creek. Spatial pattern of apparent conductivity appear to principally reflect differences in surface fill and debris deposits. Lees Creek passes over different levels of fill and debris deposits without leaving any unique and identifying EMI signature that can be used to trace its current or former locations.

2. Had it not been for the availability of Joe Rutkoski and his GPS unit, this EMI survey of a densely wooded area of rough, broken ground would not have been possible. The successful amalgamation of EMI and GPS technologies to effectively and efficiently complete this survey was a highly gratifying and noteworthy accomplishment.

3. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil borings and pits). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

It was my pleasure to work in Pennsylvania and with members of your fine staff.

With kind regards,

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