United States Department of Agriculture

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SUBJECT: MGT – Trip Report - Geophysical Assistance

January 23, 2012

TO: Astor Boozer
State Conservationist, NRCS
Syracuse, New York

File Code: 330-20-7

Purpose:
An electromagnetic induction survey of a suspected leaky, earthen waste-storage pit in Lewis County was completed. In addition, training was provided to soil scientists on the setup and operation of a newly acquired Profiler EMP-400 meter.

Participants:
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Amy N. Langner, Resource Soil Scientist, NRCS, Lowville, NY
Olga M. Vargas, Resource Soil Scientist, NRCS, Greenwich, NY

Activities:
Field activities were completed during the period of October 11-13, 2011.

Summary:

1. Two EMI surveys were completed over accessible areas surrounding the suspected leaky, earthen waste-storage pit. Separate surveys were completed with the EM31 and Profiler EMP-400 meters. The effective depth of exploration for the EM31 and Profiler meters are about 6 and 1.8 m, respectively. Because of the limited profiling depths of these meters, it is possible for contaminants from the earthen waste-storage pit to move vertically along fracture planes in the underlying bedrock and then to move laterally along bedding planes at greater depths than profiled with these sensors.

2. Similar spatial apparent conductivity (EC_a) patterns were obtained with each sensor. In the accompanying plots of EMI data, higher EC_a values are associated with higher concentrations of soluble salts and moisture contents in the soil materials, and the presence of metallic artifacts (ramp, fence line, farm equipment) surrounding the waste-storage facility. Apparent conductivity decreases progressively away from the lagoon and beneath the higher-lying embankment. Along the outer foot slope of the northern embankment, a zone of slightly higher EC_a suggests the possibility of higher moisture and soluble salt contents resulting from seepage.

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 sampling). 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 the pleasure of Jim Doolittle and the National Soil Survey Center to provide this assistance to you and your staff.

/s/ Jonathan W. Hempel

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Technical Report on Electromagnetic Induction (EMI) Investigations conducted at the Hilltop Farm in Lewis County, New York, during the period of October 11 – 13, 2011.

James A. Doolittle

Background:
Electromagnetic induction (EMI) methods were used to identify areas of potential groundwater contamination emanating from an earthen animal waste-storage facility in Lewis County, New York. The earthen structure was built in 2009 under an Environmental Quality Incentives Program (EQIP) contract and designed to serve a 500 cow dairy. The base of the structure rests on limestone bedrock. In the spring of 2011, water sampled from a nearby spring was found to contain excessive levels of E-coli bacteria and nitrates. Since the effluence was observed in a seepage area below the waste-storage structure, leakage thru the structure's clay liner is suspected. The clay for the liner was mined from a property located about 3 miles away, tested and approved by the design engineer. However, the structure was not immediately used and cracking of the clay liner may have occurred. Plots of acquired EMI data will assist engineers assess the structural integrity and potential of seepage from this structure.

Animal waste-holding facilities provide economical means of handling large quantities of wastes from livestock operations. The perimeter areas of properly designed and constructed earthen waste-holding facilities are assumed to self-seal within two to twelve months of operation (Swell et al., 1975; Miller et al., 1985). However, in some facilities, all areas do not effectively seal, resulting in the discharge of contaminants. Brune and Doolittle (1990) describe these non-sealing events as being sporadic and unpredictable.

Electromagnetic induction (EMI) is a noninvasive geophysical tool that has been used to assess the structural integrity and detect contaminant plumes emanating from waste-storage facilities. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity (EC_a) of earthen materials. Apparent conductivity is the weighted, average conductivity for a column of earthen materials (Greenhouse and Slaine, 1983). Variations in EC_a are produced by differences in the electrical conductivity of earthen materials. Electrical conductivity is influenced by volumetric water content, type and concentration of ions in solution, temperature and phase of the soil water, and amount and type of clays in the soil matrix (McNeill, 1980a). The EC_a of earthen materials increases with increased soluble salt, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic induction measures vertical and lateral variations in EC_a. Values of EC_a are seldom diagnostic in themselves. However, lateral and vertical variations in EC_a 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. Computer simulated plots of EC_a data provide the basis for assessing site conditions and locating sampling or monitoring sites.

Electromagnetic induction has been used to infer the relative concentrations, extent, and movement of contaminants from waste-holding facilities (Eigenberg et al., 1998; Drommerhausen, et al., 1995; Ranjan and Karthigesu, 1995; Radcliffe et al., 1994; Brune and Doolittle, 1990). Typically soils affected by animal wastes have higher EC_a (owing to higher soluble salts concentrations and water contents) than soils that are unaffected by these contaminants. While EMI does not provide a direct measurement of specific ions or compounds, EC_a has been correlated with concentrations of chloride, ammonia, and nitrate-nitrogen in soils (Eigenberg et al., 1998; Ranjan and Karthigesu, 1995; Brune and Doolittle, 1990).

Equipment:
A Profiler EMP-400 sensor (Geophysical Survey Systems, Inc.; Salem, NH) and an EM31 meter (Geonics Limited; Mississauga, Ontario) were used in this study[1]. These meters need only one person to operate and require no ground contact. Lateral resolution is approximately equal to the intercoil spacing of the device.

Figure 1. Olga Vargas (Soil Scientist, Greenwich, NY) conducts an EMI survey of an agricultural-waste holding facility in Lewis County, New York, with a Profiler EMP400 EMI sensor.

A Profiler EMP-400 sensor (here after referred to as the Profiler) has a 1.22 m (4.0 ft) intercoil spacing and operated 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 collect data at three discrete frequencies. For each frequency, in-phase and the quadrature phase component data are recorded. The calibration of the Profiler is optimized for 15 kHz and, as a consequence, EC_a is most accurately measured at this frequency (Dan Delea, GSSI, personal communication). A rechargeable Li-ion battery pack powers the sensor. Surveys can be conducted with the sensor held in the shallower-sensing, horizontal dipole (HDO) or the deeper sensing, vertical dipole (VDO) orientations. The sensor's electronics are controlled via Bluetooth communications with a TDS RECON-400 Personal Data Assistant (PDA). To collect geo-referenced data, the PDA is configured with an integral 12-channel WAAS (Wide Area Augmentation System) GPS.

The EM31 meter has a 3.66 m (12.0 ft) intercoil spacing and operates at a frequency of 9,810 Hz. The EM31 meter weighs about 9 kg (19.9 lbs). When placed on the soil surface, the EM31 meter provides theoretical penetration depths of about 6 m (19 ft) in the vertical dipole orientation (McNeill, 1980b). McNeill (1980b) described the principles of operation for the EM31 meter.

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

The Geonics DAS70 Data Acquisition System was used with the EM31 meter to record and store both EC_a and GPS data.[2] The acquisition system consists of the EM31 meter, an Allegro field computer (Juniper Systems, Logan, Utah), and a Pathfinder ProXT GPS receiver with Hurricane antenna (Trimble, Sunnyvale, CA).[2] With the acquisition system, the EM31 meter is keypad operated and measurements can either be automatically or manually triggered.

To help summarize the results of the EMI surveys, the SURFER for Windows (version 9.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulations shown in this report.[2]

Depth of Exploration for the EM31 meter and the Profiler EMP-400 sensor:
As knowledge of the effective depth of exploration (d_e) is vital to interpretations, a brief discussion of this parameter is presented. McNeill (1980b) noted that a meter's d_e is geometry limited and dependent on coil separation, coil orientation, and frequency. Larger coil separations and lower frequencies are used to achieve greater depths of exploration. Won et al. (1996), however, observed that changing the transmitter frequency will change the d_e. Won (1980 and 1983) maintains that the exploration depths of multi-frequency EMI instrument (such as the Profiler) are governed by the *skin-depth effect*: lower frequency signals travel farther through conductive mediums than higher frequency signal.

The EM31 meter operates under conditions of low induction number (LIN), the depth-response functions of this meter is assumed to be independent of soil conductivity. Historically, LIN conditions are assumed to be satisfied in soils having low (<100 mS/m) EC_a (McNeill, 1980b). McNeill's LIN approximation, however, used restrictive physical and mathematical assumptions to derive a solution and, is therefore valid only in more restricted physical soil settings (Callegary et al., 2007). Greenhouse et al. (1998) noted that the electrical conductivity of soils plays a critical role in the d_e obtained with all EMI instruments. Slavich (1990) and de Jong et al. (1979) reported that the d_e varies depending on the bulk electrical conductivity of the profiled material(s). Results of numerical simulations conducted by Callegary et al. (2007) indicate that the spatial sensitivity and d_e of LIN instruments, such as the EM31 meter, varies significantly with changes in σ. Callegary et al. (2007) observed that only in very electrically resistive soils are the LIN approximations and its predictions of d_e correct.

With the Profiler, the depth of exploration is considered *skin depth limited* rather than *geometry limited* (Won, 1980 and 1983, Won et al., 1996). The *skin effect* is the tendency for electrical current density to be greatest at the surface and decreases exponentially with depth. *Skin depth* represents the maximum depth of exploration for the Profiler operating at a specific frequency and sounding a medium of known conductivity. Theoretically, the maximum d_e or *skin depth* is inversely proportional to frequency (Won et al., 1996). Low frequency signals have longer periods of oscillation, loose energy less rapidly, and supposedly achieve greater depths of exploration than high frequency signals. In addition, for a given frequency, the d_e is greater in low than in high conductivity soils.

Brosten et al. (2011) note how multifrequency EMI sensors continue to challenge practitioners. Brosten et al. (2011), using synthetic modeling methods, determined that with a GEM-2 multifrequency sensor (similar to the Profiler), in a medium with an estimated skin depth of 23.4 m (76.8 ft), the actual depth of exploration ranged from only 1.8 to 2.7 m (5.9 to 8.9 ft).

Based on the findings of Brosten et al. (2011), the Profiler is viewed as a *geometry limited* instrument like the EM31 meter. In the VDO, the effective depths of exploration for the EM31 and Profiler (when placed on the ground surface) are approximately 6 and 1.8 m (19.7 to 5.9 ft), respectively. However, as a result

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

of the aforementioned studies by Callegary et al., (2007) the manufacturer's specified effective depth of penetration is considered greater than the actual depth of observation.

Site Conditions:
A soil map of the site and the surrounding area are shown in Figure 2. The waste-storage facility (in Figure 2, see "A") is located in an area that was mapped as Galway loam, 2 to 8 % slopes (NcB). The moderately deep (50 to 100 cm) to limestone bedrock, well drained and moderately well drained Galway (coarse-loamy, mixed, superactive, mesic Typic Eutrudepts) soils formed in till. The till and underlying bedrock are characterized by low (<15 mS/m) apparent conductivity.

The steeply sloping, forested slopes located to the northeast and east of the waste-storage facility were avoided as the forest canopy was too impenetrable and limiting for appropriate GPS reception. In addition, slippery slope conditions and dense undergrowth with a great deal of fallen woody debris would limit the effective use of EMI. Rough, broken land, which bounded the south side of the structure, was also not surveyed. A drainage ditch parallels the outer border of the waste-holding facility and served as the eastern and southern limits of the survey area. The drainage ditch was cut into the underlying bedrock and partially refilled with excavated rock fragments.

Figure 2. This soil map of the area surrounding the surveyed earthen waste-holding facility (see A) is from the Web Soil Survey[3].

Field Procedures:
Separate surveys were conducted with each meter. Each meter was operated in vertical dipole orientation and continuous mode with measurements recorded at 1-sec intervals. The EM31 meter was held at hip-

[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 [October 13, 2011].

height (about 1 m; 40 inches) with its long axis parallel to the direction of traverse. The Profiler was held about 10 cm (4 inches) above the ground surface and orientated with its long axis parallel to the direction of traverse. Each survey was completed by walking with an EMI meter at a rather slow and uneven pace, in a random back and forth pattern across the accessible portions of survey area. Cultural features, such as farm implements and fence lines, were avoided where possible.

Apparent conductivity (EC_a) is measured in milliSiemens per meter (mS/m). The collected EC_a data were not corrected to a standard temperature of 75° F.

Results:
In general, EC_a was relatively low and invariable across most of the survey area. However, the presence of nutrients in the lagoon and metallic artifacts (concrete ramps with rebar at both ends of the lagoon) resulted in elevated levels of EC_a. With the Profiler, EC_a averaged 13.7 mS/m and ranged from -53.5 to 57.7 mS/m. However, one-half of the 3552 measurements recorded with the Profiler were between 9.2 and 15.1 mS/m. Anomalously high or low EC_a are attributed to metallic artifacts that were either approach to closely or passed over with the meter.

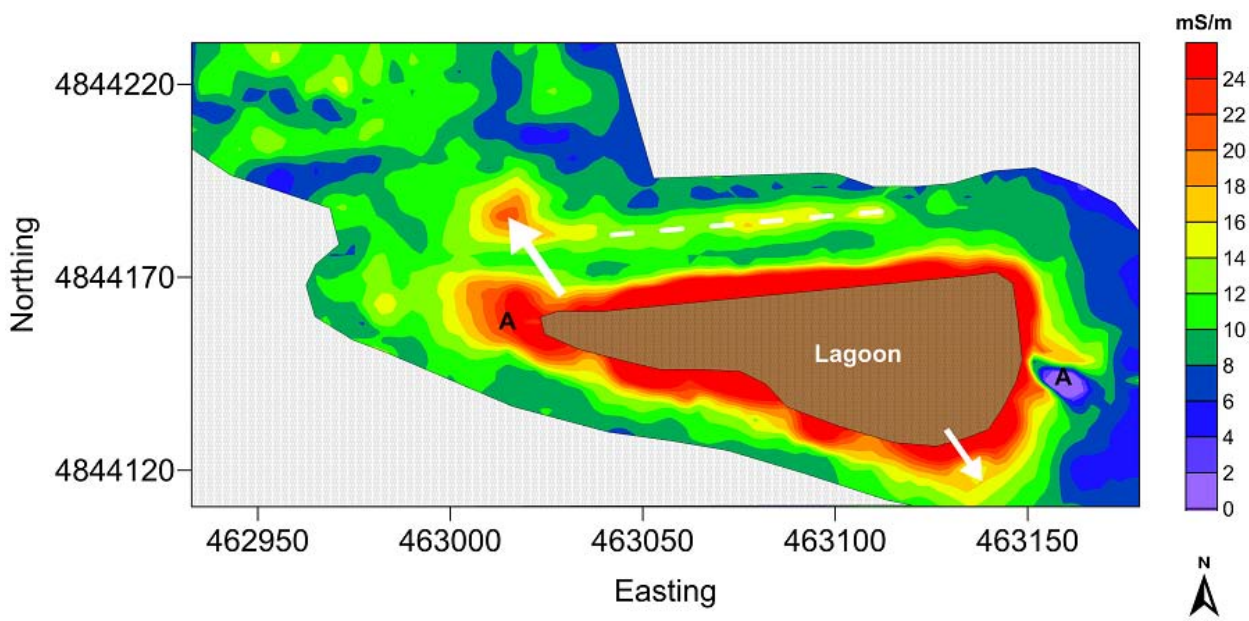

Figure 3. Plot of EC_a data collected with the Profiler operated in the VDO and held about 10 cm above the ground surface (effective depth of exploration is about 1.8 m).

Figure 3 is a plot of the EC_a data collected with the Profiler. In Figure 3, the approximate locations of the two concrete ramps have been labeled "A". Higher EC_a was consistently measured in areas immediately surrounding the water-filled portion of the lagoon. The higher EC_a is attributed to higher concentrations of soluble salts and moisture contents in the soil materials. Apparent conductivity decreased progressively away from the lagoon on the higher-lying embankment materials. In the plot shown in Figure 3, along the base of the northern embankment, a line of slightly higher (14 to 20 mS/m) EC_a is apparent (a dashed, white colored line indentifies the location of this anomaly). This pattern suggests the possibility of higher moisture and soluble salt contents resulting from seepage at the base of the embankment slope. In the northwest corner of the lagoon, an arrow suggests the possible flow of contaminants under or through the earthen embankment materials. A broad area of higher EC_a is evident near the arrow in the extreme southeastern corner of the structure. This pattern suggests the potential

flow of contaminants and moisture. In this plot, areas that are shallow to bedrock are presumed to have very low EC_a (<8 mS/m).

With the EM31 meter, EC_a averaged 11.0 mS/m and ranged from -0.8 to 39.8 mS/m. However, one-half of the 2737 measurements recorded with the EM31 meter were between 6.8 and 12.8 mS/m. Compared with the Profiler, the lower values recorded with the EM31 meter reflects the greater affect of the underlying bedrock column on the depth response of this deeper-sensing meter.

Figure 4 is a plot of the EC_a data collected with the EM31 meter. Spatial EC_a patterns evident in this plot are similar to the spatial EC_a patterns obtained with the Profiler (see Figure 3). Once again, EC_a is higher in the wetter and more contaminated soil materials adjacent to the water-filled portion of the lagoon. The two ramps (see "A") can be identified by their anomalous values. Apparent conductivity decreases away from the water-filled lagoon; a consequence of the increased height and thickness of embankment materials. Similar to the spatial EC_a patterns obtained with the Profiler, a linear zone of slightly higher EC_a is evident along the outer foot slope of the embankment materials. In Figure 4, arrows suggest possible directions of contaminant flow.

The area surrounding the earthen structure is known to be shallow to bedrock. The shallow depths to bedrock are reflected in the low EC_a (<8 mS/m) recorded at greater distances away from the lagoon and the earthen embankment materials. The center line of a drainageway, composed of refilled bedrock fragments, forms the eastern and southern border of the survey area. No indication of seepage is evident within this drain. However, the presence of rock fragments and air spaces will dampen the effects of any contaminants on EC_a.

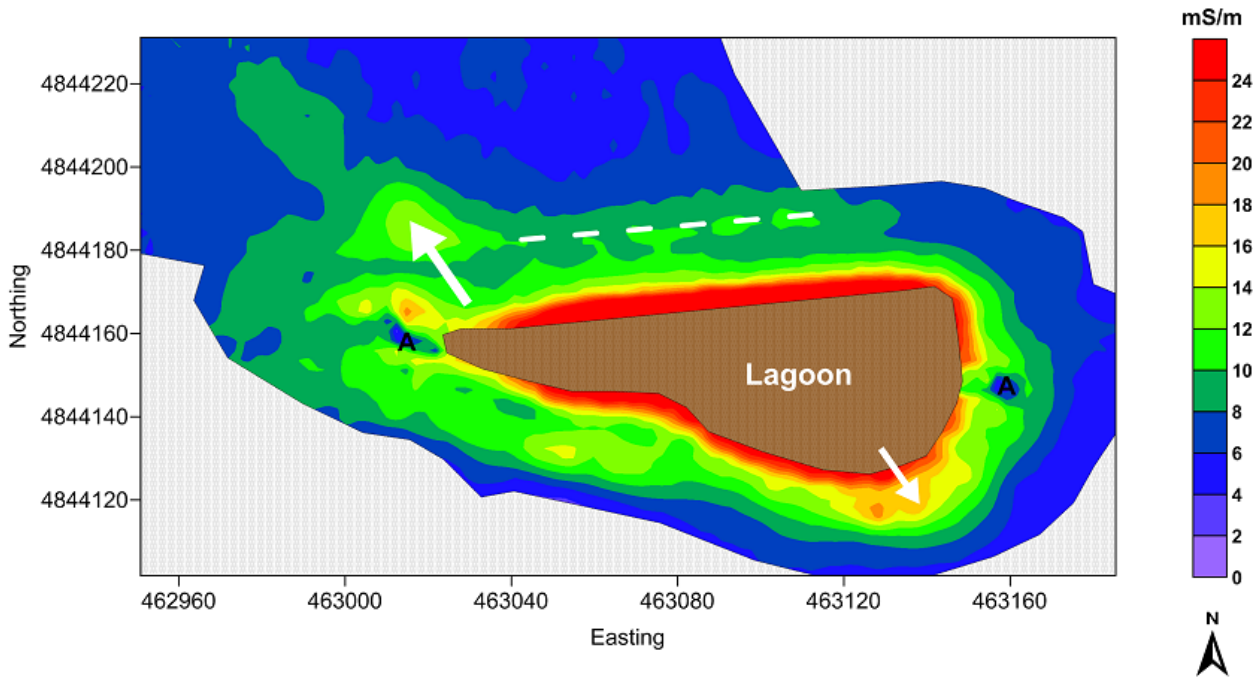

Figure 4. Plot of EC_a data collected with the EM31 meter operated in the VDO and held at hip-height (effective depth of exploration is about 5.0 m).

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