United States Department of Agriculture

NRCS

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Subject: Eng – Geophysical Investigations **Date:** 22 October 2010

To:

State Conservationist
USDA-Natural Resources Conservation Service
Federal Building, Room 152
100 Centennial Mall North
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Purpose:
Two dam structures in the Blackwood watershed have been breached because of the formation of cracks and zones of weakness resulting from differential settlement and desiccation. There are fourteen similar structures in the Blackwood watershed that have the potential to experience similar catastrophic events. The potential of using electromagnetic induction (EMI) to detect cracks and zones of weakness in similar earthen structures was evaluated. Structures 32-A and P-2 were surveyed with EMI methods. Training on the calibration of the EM31 and EM34-3 meters, and operating procedures were also provided to participants.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Ted Huscher, Geologist, USDA-NRCS, Lincoln, NE
Tom Cyre, Geologist, USDA-NRCS, Salina, KS
James Kearney, Geologist, USDA-NRCS, Lincoln, NE

Activities:
All activities were completed during the period of on 6 and 7 October 2010.

Summary:

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

While Tom Cyre, Jim Doolittle and I hauled the survey equipment along the steep slopes of P-2, Jim Kearney adroitly flagged holes in a zone near the east side (as well as other locations) on the dam. Jim thought there appears to be a possible trend here, possibly a crack zone. It shows up in the "3-D" EM-31 geophysical survey map on the "SOUTH FACE" and denoted with an arrow on DAM P@ 3D with arrow.TIF (attached). We did find a deeper (2.5') hole closer to the center line/principal spillway on the back side as well. This structure has a lot of burrows on it and an active prairie dog "village" on the back toe of the dam. (Andy Havlicek spotted/riled up a rattlesnake on the dam's back slope the day of our geophysical survey).
The EM-31 survey of Blackwood 32-A basically just showed areas with higher clay content (west alluvial foundation area). The (visible, sediment-filled) cracks did not show up as they are "too small" considering the mass. We did not survey the pool.

We ran both the EM-31 and EM-34 on P-2. The results from the EM-34 (which looks at 15 meters depth) appear to be inconclusive. Perhaps some wetter areas show up closer to the pool and nearer the exit channel. Some interesting "anomalies" showed up on the EM-31 survey (it looks at the 5 meter depth), but we will overlay an as-built diagram to determine whether the anomalies are the fill/charge pipes for the settlement blankets (which is what I suspect). Jim Kearney thinks the natural landscape surface (shallow foundation in the abutments) shows up pretty well on the EM-31 survey of P-2.
Thank you for your hard work helping us look for subsurface deficiencies at dam structures "Perry P-2" in southwest Nebraska with the EM31 and EM34. Your dedicated efforts at addressing the steep terrain and systematic explanation of results have helped us with determining the best way to approach non-intrusive investigation of this and a potential additional 14 other possible at risk structures (dams) within the greater watershed. Also, the EM31 geophysical survey you conducted on the Blackwood 32-A structure's foundation was helpful in us determining the usefulness of geophysics to look for small crack features. Your time and dedication to this project will help us go a long way in these efforts.

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

JONATHAN W. HEMPEL
Director
National Soil Survey Center

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Technical Report on Geophysical Fieldwork completed in Nebraska on October 2010.

Jim Doolittle

Background:

Two dam structures in the Blackwood Watershed of southwest Nebraska have been breached because of the formation of fissures and zones of weakness resulting from differential settlement and desiccation. The purpose of this investigation was to assess the potential of using non-invasive electromagnetic induction (EMI) methods to detect fissures or zones of potential weakness in these earthen structures.

Figure 1. Ted Huscher points to a fissure observed at Structure 32A.

Geophysical methods permit the visualization of trends or localized anomalous conditions missed from all but extremely close-spaced drilling programs (Butler and Llopis, 1990). Geophysical methods, such as direct current (DC) resistivity, transient electromagnetic (TEM) and self-potential (SP), have been used to map seepage paths, monitor temporal and spatial changes in seepage, and help direct remedial measures on earthen dams (Buselli and Lu, 2001). The response of these methods is strongly dependent on changes in moisture contents. The use of electromagnetic induction (EMI) for the investigation of earthen structures has not been as widely reported.

Butler and Llopis (1990) have categorized EMI as a primary geophysical tool for the detection of anomalous seepage zones in earthen dams. However, with EMI, the resolution of subsurface features decreases with increasing observation depths In addition, EMI is sensitive to above ground and buried metallic objects, and subject to interference from nearby electrical sources. The detection of fissures and zones of weakness in earthen structures with EMI depends on the size, depth and composition of these features.

Electromagnetic induction (EMI) is a noninvasive geophysical tool. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Electromagnetic induction provides in a relatively short time, a large number of observations. Maps prepared from properly 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 (EC_a) of earthen materials. Apparent conductivity is the weighted, average conductivity for a column of earthen materials (Greenhouse and Slaine, 1983). Apparent conductivity is a measure of the materials ability to conduct electrical current. The causes of variations in EC_a cannot be distinguished from measurements alone. In soils, EC_a is primarily controlled by and increases with increases in soluble salts, 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 earthen materials and physiochemical properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used.

The depth of observation and measured response are influenced by the EMI meter's coil orientation, coil separation, and frequency, as well as the conductivity of the profiled material(s). The EMI response is not uniform with depth; surface and shallow layers contribute more to the overall response than deeper layers. The orientation of the transmitter and receiver coil axis (with respect to the ground surface) affects the response from materials at different depths (McNeill, 1980). For example, in the shallower-sensing horizontal dipole orientation, meters are more sensitive to near surface materials. In the deeper-sensing vertical dipole orientation, meters are more sensitive to deeper materials. Slavich (1990) and de Jong et al. (1979) reported that the actual depth of observation would vary depending on the apparent conductivity (EC_a) of the profiled material(s). Greenhouse et al. (1998) noted that EMI instruments do not penetrate a fixed distance under all circumstances.

Equipment:
The EM31, and EM34-3 meters (Geonics Limited; Mississauga, Ontario) were used in the investigations [1]. These meters require no ground contact. With the exception of the EM34-3 meter, these meters require only one person to operate. These meters measure the apparent conductivity (EC_a) of soils and earthen materials. Apparent conductivity is typically expressed in milliSiemens/meter (mS/m).

The EM31 meter weighs about 12.4 kg (27.3 lbs), has a 3.66 m intercoil spacing, and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter has effective penetration depths of about 3.0 and 6.0 meters in the HDO and VDO, respectively (McNeill, 1980). McNeill (1980) describes the principles of operation for the EM31 meter.

McNeil (1980) and Geonics Limited (1990) describe the operation of the EM34-3 meter. The EM34-3 meter consists of a receiver and transmitter coil, three reference cables (10, 20, and 40 m), a receiver and transmitter console. The EM34-3 meter requires two people to operate. The frequency used by the EM34-3 meter is dependent on the intercoil spacing: 6400 Hz for the 10 m, 1600 Hz for the 20 m, and 400 MHz for the 40 m intercoil spacings. In this investigation, the EM34-3 measurements were made with all three intercoil spacings with coils placed vertically on the ground surface in the horizontal dipole

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

orientation (HDO) (Figure 1). The HDO configuration was used because, compared with the vertical dipole orientation (VDO) it is relatively insensitive to misalignment of the two coils (McNeil, 1980). In the HDO configuration, the theoretical depth of penetration is approximately 0.75 times the intercoil spacing.

A Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced EMI data collected with the EMI meters.[2] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used with the meters to record and store both GPS and EMI data[1]. The newly developed RTM31 (Geomar Software, Inc., Mississauga, Ontario) and the Dat34W programs (Geonics Limited, Mississauga, Ontario) were used with the EM31 and EM34-3 meters, respectively, to display and record both GPS and EC_a on the Allegro CX field computer.[2] The RTmap31 system provides immediate tracking and viewing capabilities that are displayed as a spatial color image of the collected EMI data. With these capabilities, operators can visually correlate spatial EC_a with observable features in the landscape as the survey progresses. In addition, surveys are carried out faster, and sites can be more uniformly covered (avoiding skipping areas) and unnecessary overlap of survey lines prevented.

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 two-dimensional simulations shown in this report.[2] Grids were created using kriging methods with an octant search.

Study Sites:

Structure 32-A

The site (40.3497 N. latitude, 100.9067 W longitude) is located off of County Road 372 along the Hayes and Hitchcock County line. It is about 8.7 miles north-northwest of Culbertson, Nebraska. The structure is presently being rebuilt and the survey was restricted to opened reworked areas. The structure is located in an area of Sulco-Ulysses silt loams on 9 to 30 % slopes, erode d (soil map unit 1833). These deep, well drained soils formed in calcareous silty loess on uplands. Depth to carbonates: 0 to 15 inches. The Sulco soil has a low clay content (8 to 17 %) and high silt (30 to 55 %) and very fine sand (30 to 60 %) contents. The Ulysses soil has slightly higher clay content. These soils are classified as a coarse-silty, mixed, superactive, calcareous, mesic Aridic Ustorthents (Sulco); and a fine-silty, mixed, superactive, mesic Aridic Haplustolls (Ulysses).

The site (40.2539 N. latitude, 100.7543 W longitude) is located in Red Willow County about 7.4 miles northwest of McCook, Nebraska. The structure is located in an area of Sulco-Ulysses silt loams on 9 to 30 % slopes, eroded (1833). This structure has steep faces, which had been mowed prior to our arrival. The surface was pockmarked with numerous animal burrows. The steep slope and uneven surfaces made survey work arduous and precarious.

Survey procedures:

The EM31 meter was used at both sites. The EM34-3 meter was only used at structure P-2. Multiple traverses were made across each site with the meter. These traverse line were parallel to the long axis of the structures. The EM31 meter was operated in the deeper-sens8uuuuuuuuuuuuuuuuuuuuuu0oing (0 to 6 m) vertical dipole orientation. Both inphase (apparent magnetic susceptibility) and quadrature phase (apparent conductivity) data were recorded. Apparent conductivity (EC_a) is expressed in milliSiemens/meter (mS/m); magnetic susceptibility in parts per thousand (ppt). The EM31 was operated in the continuous mode (measurements recorded at 1-sec intervals). Using the RTM31 program, both GPS and EC_a data were simultaneously recorded on the field computer. The meter was held at hip height

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and orientated with its long axis parallel to the direction of traverse. The EM31 surveys were completed by walking at a fairly uniform pace, in a random or back and forth pattern across each site.

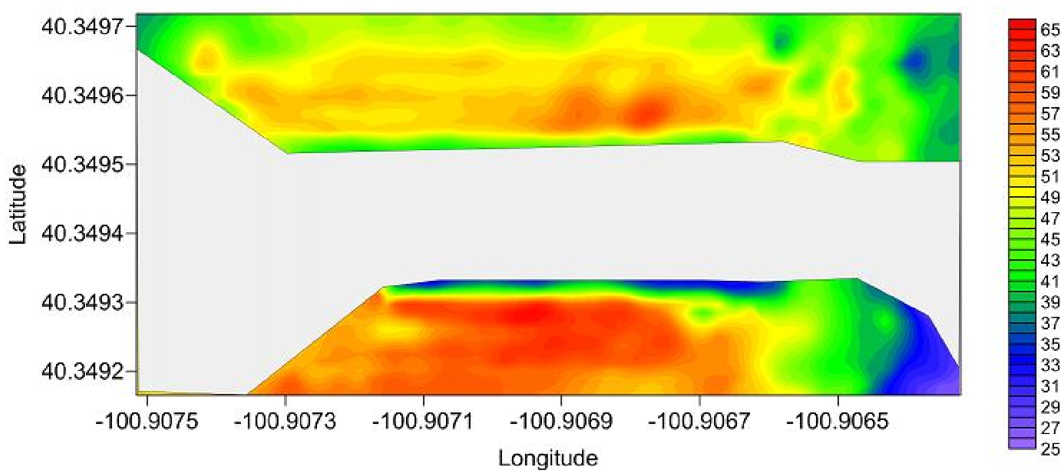
Figure 2. Ted Huscher conducts an EMI survey with the EM31 meter at Structure P2.

The EM34-3 meter was used at structure P-2. The EM34-3 meter was operated in the shallower-sensing horizontal dipole orientation with a 20 meter intercoil spacing. This provided a nominal penetration depth of about 15 m. Measurements were manually triggered along parallel lines spaced about 20 m apart. To record measurements, the coils of the EM34-3 meter were placed on the ground surface, orientated in the direction of traverse, and adjusted to the correct intercoil distance. The operation of this meter requires 2 people: one handling the transmitter coil and one operating the receiver coil (see Figure 1). With a 20-m intercoil spacing the area covered by this meter is comparatively large (see Figure 1) and resolution of subsurface features is coarse.

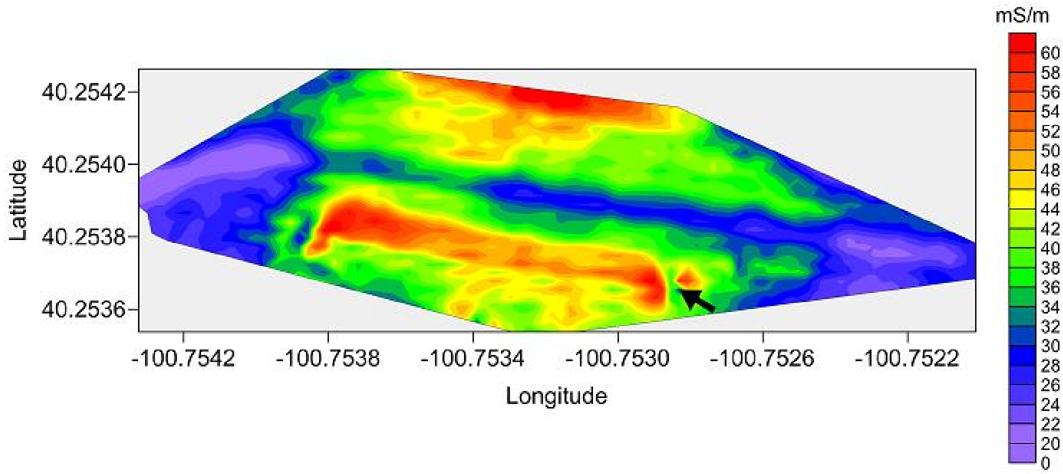
Figure 3. Ted Huscher and Tom Cyre conducts an EMI survey with the EM34-3 meter with a 20-m intercoil spacing) at Structure P2.

Results:

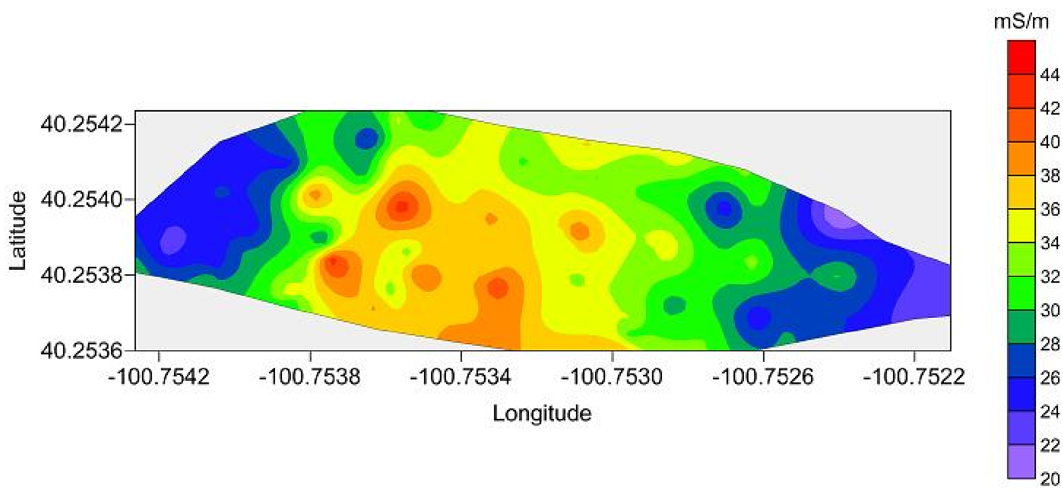
Structure 32A



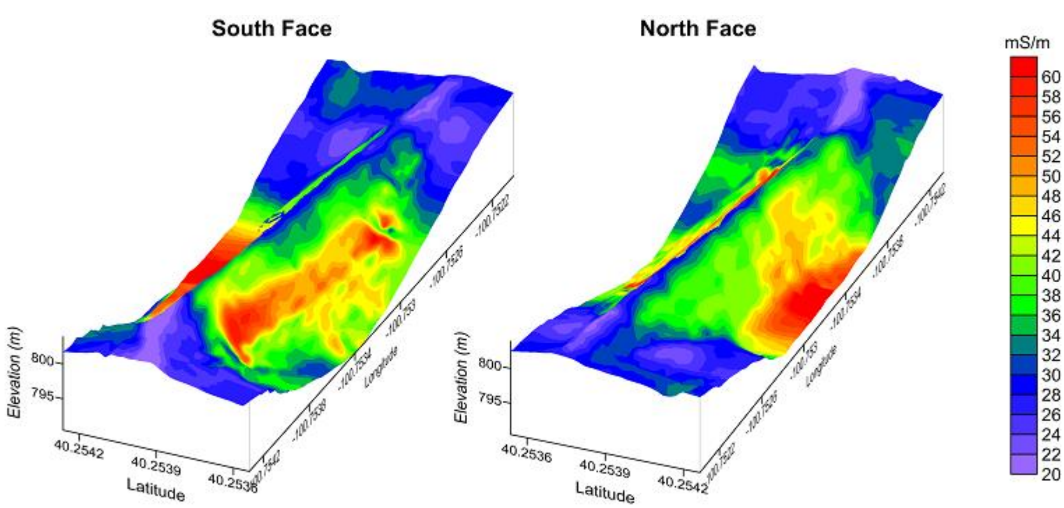
In this two-dimensional plot of the EC_a data collected at Structure 32A with the EM31 meter operated in the VDO, the effective depth of penetration is about 5 m. Gray areas represent a deep trench (center) or steeply sloping earth embankments.



In this two-dimensional plot of the EC_a data collected at Structure P2 with the EM31 meter operated in the VDO, the effective depth of penetration is about 5 m.



In this two-dimensional plot of the EC_a data collected at Structure P2 with the EM34-3 meter operated in the HDO, the effective depth of penetration is about 15 m.



In these three-dimensional simulations of the EC_a data collected at Structure P2 with the EM31 meter operated in the VDO, the viewpoints are facing east for the "South Face" and west for the "North Face".

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