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

Subject: -- Geophysical Assistance -- **Date:** 23 April 2002

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Purpose:
The purpose of this investigation was to evaluate the feasibility of using ground-penetrating radar (GPR) and electromagnetic induction (EMI) for soil and geologic applications in western Mississippi.

Participants:
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Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
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Activities:
All field activities were completed during the period of 8 to 12 April 2002.

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974) and Doolittle (1987) have discussed the use and operation of GPR. The SIR System-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. The 70, 120, and 200 MHz antennas were used in this study. Compared with higher frequency antennas, lower frequency antennas are less rapidly attenuated by earthen materials and provide greater penetration depths in most materials. Higher frequency antennas provide more limited depths of penetration, but higher resolution of subsurface features. All radar profiles shown in this report were processed through Radan for Windows NT (version 3.0) software.[1] Processing was limited to signal stacking, distance normalization, range gain adjustments, and color transforms and table customizing.

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

A GEM300 multifrequency sensor, developed by Geophysical Survey Systems, Inc., was also used in this study.[1] The GEM300 sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation (1.3 m). Won and others (1996) have described the use and operation of this sensor. With the GEM300 sensor, the depth of penetration is considered *skin depth limited*. The *skin-depth* represents the maximum depth of penetration and is frequency and soil dependent: lower frequency signals travel farther through conductive mediums than higher frequency signal. The theoretical penetration depth of the GEM300 sensor is dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequency. Multifrequency sounding with the GEM300 theoretically allows multiple depths to be profiled with one pass of the sensor.

The positions of observation points were obtained with a Rockwell Precision Lightweight GPS Receiver (PLGR).[2] The receiver was operated in the continuous and the mixed satellite modes. The Latitude/Longitude coordinate system was used. Horizontal datum was the North American 1983. Horizontal units were expressed in meters.

For EMI surveys conducted without the use of GPS, distances were measured or paced in the field. The locations of observations collected with the GEM300 sensor were processed through the MAGMAP96 software program. [2]

To help summarize the results of this study, the SURFER for Windows program (version 7), developed by Golden Software, Inc.,[2] was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search.

Results:

1. In Mississippi, because of restricted penetration depths, medium and fine textured soils with 2:1 expanding lattice clay minerals and superactive or active cation-exchange activity classes are considered inappropriate for most soil and geologic applications with GPR.

2. A GPR survey conducted in an area of coarse-textured splay deposits provided a comprehensive, technology-based approach to soil mapping and land assessment. Ground-penetrating radar can be used to rapidly estimate and map the thickness of splay deposits across large areas. This information can be used to assess splay deposits and to provide the data needed to support interpretations across larger areas.

3. A 70 MHz antenna was used effectively to conduct a bathymetric survey of a fresh water lake that has experienced rapid rates of sedimentation. GPR provided interpretable images of the lake bottom to depths of 6.46 m (maximum lake depth observed in survey). However, because the radar did not satisfactorily or consistently penetrate the sub-bottom materials nor resolve the underlying layers, its use for lake sedimentation surveys should be restricted to lakes and reservoirs in which data on the original bottom depth is know and available. On these lakes and reservoirs, comparisons can be made between these data sets and radar data sets, and the amount and rates of sedimentation can be computed

4. Electromagnetic induction methods can be used to create detailed maps showing the spatial distribution of apparent conductivity across units of management. These methods measure vertical and lateral variations in values of apparent conductivity. Interpretations are based on the identification of spatial patterns within data sets. EMI appears to have immediate and beneficial applications for soil scientists involved with soil mapping in area of the Mississippi flood plain that have been leveled for improved drainage and rice production. The study in Tunica County demonstrates that EMI can be used effectively to map and assess the composition of soils within leveled lands, and to design soil map units.

5. An EMI investigation of a field on a demonstration farm at the Greenville Airport revealed conspicuously high levels of apparent conductivity. Ground water contamination, possibly related to the former use of the site as a military base, is believed to be responsible for the observed high apparent conductivity values.

6. Geophysical interpretations are considered preliminary estimates of site conditions. The results of all

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geophysical investigations are interpretive and do not substitute for direct soil borings. The use of geophysical methods can reduce the number of soil observations, direct their placement, and supplement their interpretations. Interpretations should be verified by ground-truth observations.

It was my pleasure to work again in Mississippi and with members of your fine staff. Frank Adams is to be commended for his excellent scheduling and management of this investigation. Copies of the data files collected during this study have been returned to Frank Adam under a separate cover letter.

With kind regards,

James A. Doolittle
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Ground-Penetrating Radar:

Calibration of GPR:

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, bedrock) 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 the following equation (Morey, 1974):

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

The velocity of propagation is principally affected by the dielectric permittivity (E) of the profiled material(s) according to the equation (Morey, 1974):

$$E = (C/V)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric permittivity of a material.

Propagation velocities and depth scales were determined by comparing measured with interpreted depths to known reflectors appearing on the radar profiles. Based on the measured depths and the two-way travel times to these interfaces, and equation [1], the velocity of propagation was estimated at each site. In an area of disturbed and saturated Collins soil in Tallahatchie County, the velocity of propagation was estimated to be 0.0594 m/ns; the dielectric permittivity 25.2. In an area of moist, coarse-textured alluvial soils in Bolivar County, the velocity of propagation was estimated to be 0.0651 m/ns; the dielectric permittivity 20.9. For the lake sedimentation survey, the velocity of propagation was 0.033 m/ns; the dielectric permittivity was 81.

Results:

<u>Site Y-17-74</u>.

The drained dam site is located in Tallahatchie County near the town of Charleston. The site had been mapped as Collins silt loam, and Memphis silt loam, 12 to 17 percent slopes (Scott et al., 1970). Soils within the site had been disturbed. The deep, moderately well drained Collins soil formed in silty alluvium on flood plains of streams. Collins is a member of the coarse-silty, mixed, active, acid, thermic Aquic Udifluvent family. The very deep, well drained Memphis soil formed in loess deposits that are more than 48 inches thick on terraces and uplands. Memphis is a member of the fine-silty, mixed, active, thermic Typic Hapludalf family.

Radar traverse were conducted with a 120 MHz antenna. Radar profiles were exceedingly depth restricted and of poor interpretative quality. Collins and Memphis soils belong to the *active* cation-exchange activity class. Activity classes are useful for not only inferring the minerals present and the cation exchange capacity of soils, but also their suitability to GPR. The activity class is determined by the ratio of CEC to percent silicate clays (by weight) (Soil Survey Staff, 1999). Four activity classes are defined: subactive, semiactive, active, and superactive (Soil Survey Staff, 1999). In general, the penetration depth and performance of GPR have been unacceptable in areas of superactive and active soils. Collins and Memphis soils are *active* and have high amounts of 2:1 expanding lattice clays. These clays are highly absorptive to radar energy. In Mississippi, because of restricted penetration depths, soils with similar clay minerals, superactive or active cation-exchange activity classes, and/or higher clay contents must be considered inappropriate for most soil and geologic applications with GPR.

In areas of the Collins soil, depths of penetration were restricted to the upper part of a highly reduced silt loam subsurface layer and to depths of less than 0.5 to 1.0 m. The control section for Collins soil contains 5 to 18 percent clay. Figure 1 is a representative radar profile from an area of disturbed Collins soil. In Figure 1 the depth scale is in meters (see left-hand margin). The short white vertical lines that appear across the top of the radar profile represent referenced locations spaced at 5 m intervals. Although, reflections are superimposed and multiples (reverberated signals) are present in the upper part of this profile, two interfaces have been identified with dark lines. The upper most interface is believed to represent a highly gleyed subsurface layer. In this area of Collins soil, a gravelly layer was observed at a depth of about 1 meter. This interface is not evident in Figure 1.

Parallel bands of background noise plague the radar profile below a depth of about 1 m. Because of low signal to noise ratios no meaningful soil information is derivable below a depth of about 1 m.

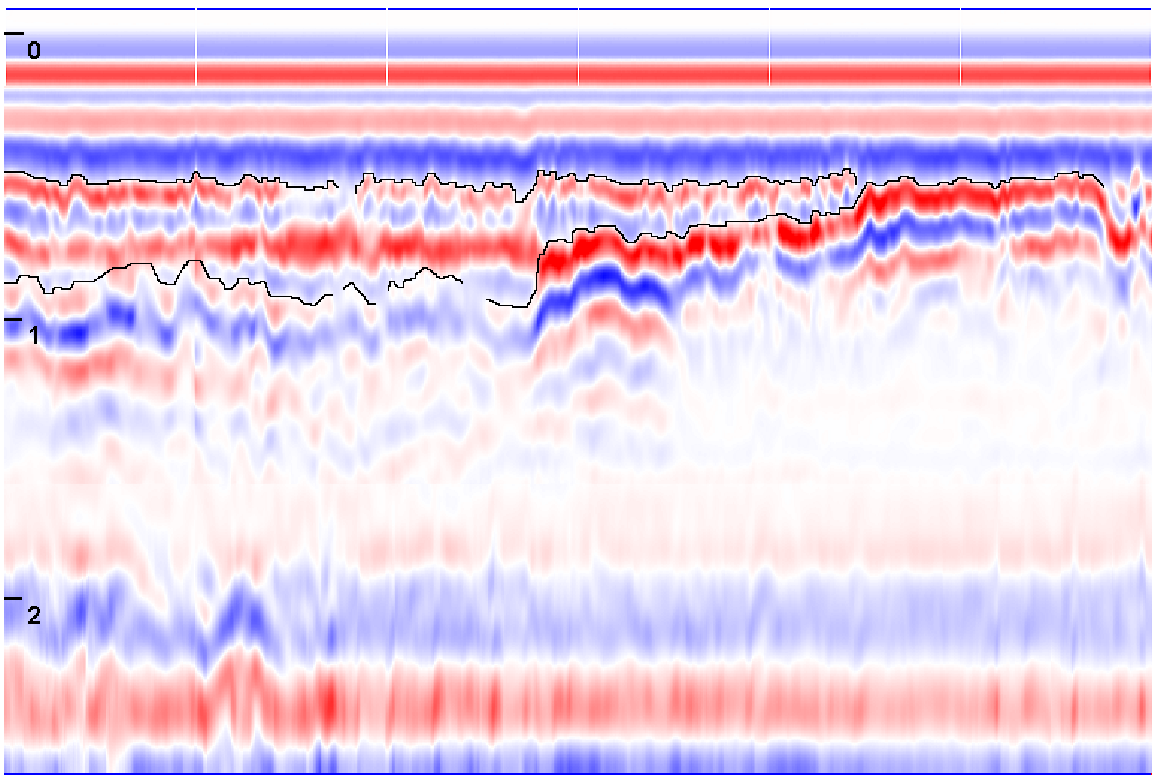

Figure 1. Representative radar profile from an area of Collins silt loam in Tallahatchie County.

<u>1927 Crevasse, Bolivar County.</u>

The site is located near the historic 1927 Bolivar County break in the levee to the Mississippi River. Where the floodwaters broke through the levee, the bottomland was deeply scoured and coarse-textured alluvial materials covered surrounding soils. Small alluvial fans or extended deposits of these materials are known as flood plain splays. The study site is located within an area that is overlain by splay deposits. The study site is to be flooded as part of a Wetland Reserve Program project. Low levee are to be constructed around the site to impound water. Ground penetrating radar was used to estimate the depth to finer textured soil materials and the thickness of surficial sand deposits.

Ground-penetrating radar provided interpretable images of the interface that separates the predominantly coarse-textured splay deposits from the underlying, buried, medium-textured soil materials. In general, with the 120 MHz antenna, the depth of observation was restricted to this interface. In addition, because of strong surface reflections and the limited resolution of the 120 MHz antenna, interfaces occurring within the upper 50 cm of the soil profile were difficult to resolve.

The profile shown in Figure 2 was collected over a low, dune-like, splay deposit composed of sandy alluvium. The soil is Crevasse. The very deep, excessively drained Crevasse soil forms on splays deposits. Crevasse soil is a member of the mixed, thermic Typic Udipsamment family.

In Figure 2, the depth scale is expressed in meters (see left-hand margin). The short white vertical lines that appear across the top of the radar profile represent referenced locations spaced at 5 m intervals. In this radar profile, based on an estimated propagation velocity of 0.0651 m/ns and a scanning time of 110 ns, the maximum depth of penetration is about 3.6 m.

In Figure 2, the lower-most, continuous interface (A) represents the boundary separating the coarse-textured splay deposits from the underlying, medium-textured soil materials. This interface consists of two or three, dark, sub-parallel bands. Exceptionally high rates of attenuation in the medium-textured materials limited signal penetration principally to this interface. In Figure 2, this interface ranges in depth from about 1.9 to 2.5 m. In the right-hand portion of Figure 2,7 a higher-lying portion of the dune-like feature was crossed with GPR. As the GPR crossed this higher-lying area, the interface separating the coarse-textured splay deposits from the underlying, medium-textured, buried soil appears to plunge to greater depths. While this interface does occur at deeper depths beneath this higher-lying area, its topography is more level than expressed in Figure 2, which has not corrected for difference in surface elevations. Several slightly inclined, parallel reflectors (B) are evident in the upper part of this profile. As these reflectors do not appear to restrict the radar 's observation depth, they are assumed to have low clay contents and to represent layers of coarser-textured soil materials that differ in grain size. Highly inclined and stratified layers of coarser-textured materials (C) are evident beneath the higher-lying portion of this dune-like feature.

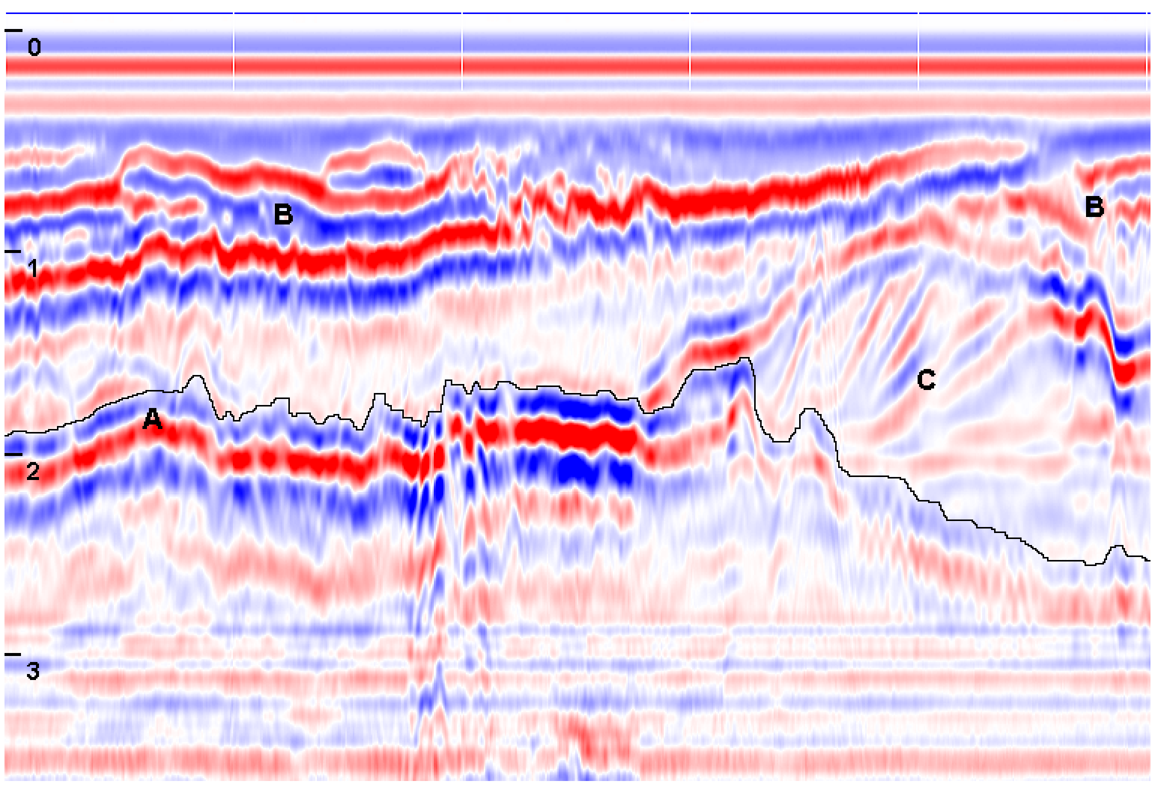

Figure 2. Representative radar profile from an area of Crevasse-like soils in Bolivar County.

Based on radar interpretations at 200 observation points, the thickness of the splay deposits ranged from 0.30 to about 2.5 m. Within this site, the average thickness was about 73 cm. One-half of the observations had splay deposits between 50 and 90 cm.

<u>Second Creek, Dam #12 – Adams County</u>.
Second Creek dam site is located in Adam County near the town of Kingston. The size of the lake is about 40 acres. Lake sedimentation rates are considered high especially in the upper reaches of the lake. The feasibility of using GPR for lake sedimentation surveys in Mississippi was assessed at this site.

For this investigation, a 70 MHz antenna was used. The 70 MHz antenna is the lowest frequency antenna that is available to NRCS. The SIR-2000 radar system was mounted in a boat and the 70 MHz antenna was towed alongside in an inflatable raft. The boat and raft made random traverses across the lake. The locations of observation points were recorded simultaneously with both GPS and GPR at intervals of 15 seconds.

Based on preliminary soundings, a scanning time of 430 ns was used for this investigation. With this scanning time and propagation velocity of 0.033 m/ns through water, the maximum depth of observation was about 7.1 m.

The radar survey was completed in about an hour. As the purpose of this investigation was to assess the potential of GPR for lake sedimentation surveys in southwestern Mississippi, no attempt was made to complete a comprehensive survey of the reservoir at this time. Traverses were conducted principally across the lower and upper ends of the lake. In addition, traverses were conducted along the long axis of the lake. The coordinates of each of these points were recorded with GPS.

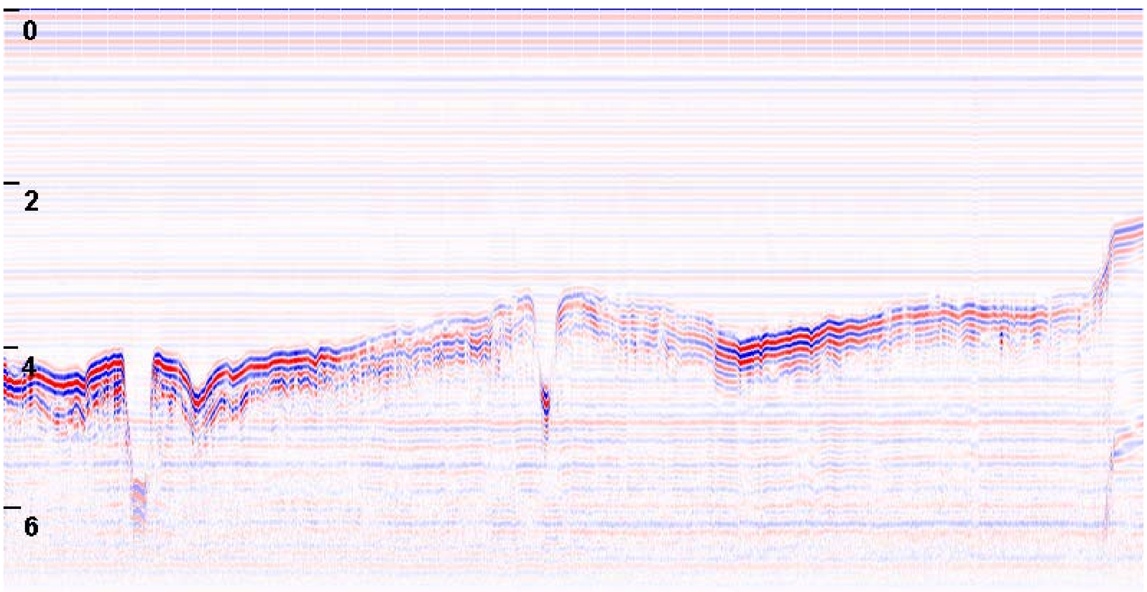

Figure 3. Representative radar profile from lake sedimentation survey in Adam County.

The 70 MHz antenna provided adequate penetration depths (traced lake bottom to depths greater than 6 m) and acceptable resolution of the lake bottom. Radar profiles were straightforwardly interpreted. Figure 3 is a representative radar profile from the lake. In Figure 3, in order to show the complete record, the radar profile has been compressed. The depth scale is meter and is plotted on the left-hand side of this figure. Although the radar provides a continuous profile of the lake bottom, measurements of the water depth were restricted to observation points (vertical lines at the top of the radar profile). In Figure 3, the lake bottom is readily apparent. In this profile, the lake bottom interface varies in depth from about 2.4 to 5.7 m.

Lake depths were recorded at 108 points. Based on the results of the radar survey, at the time of this investigation, the average depth of water within this reservoir is 3.76 m. Measured depths ranged from 1.45 to 6.46 m. One half of the radar observation points had depths between 2.86 and 4.51 m.

The 70 MHz antenna provided highly interpretable images of the lake bottom. However, sediments along the lake bottom rapidly attenuated the radar signal and limited penetration depths. High amplitude, multiple reflections helped to identify the lake bottom. These layers consist of smooth, parallel lines. In places, sub-bottom reflections believed to be the original bottom were apparent. However, these reflections were often faint, discontinuous, and superimposed on reflections from the lake bottom. Because the radar did not satisfactorily or consistently penetrate the sub-bottom materials nor resolve the underlying layers, its use for lake sedimentation surveys should be restricted to lakes and reservoirs in which data on the original bottom depth is know and available. On these lakes and reservoirs, comparisons can be made between these data sets and radar data sets, and the amount and rates of sedimentation can be computed.

Electromagnetic Induction:
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 tool 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 delineating and 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 is not suitable for use in all investigations. Generally, the use of EMI has been most successful in soils and earthen materials 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).

Land leveling Site, Tunica County
Land leveling is used in the *Delta Counties* of Mississippi to improve crop uniformity and yields, and enhances surface drainage. In addition, in areas of rice production, land leveling helps reduce the amount of water that must be applied and therefore improves water use efficiency.

Alluvial soils are recognized for their high textural variability over short distances (Daniels and Hammer, 1992). Older soil maps often show intricate patterns of contrasting soils on alluvial lands. Land leveling alters soils. After leveling, depths to some root or water restricting layers may be shallower in the cut areas and deeper in the fill areas. The leveling process may also cause stratification because soil materials of varying texture may comprise the fill.

Soils and soil patterns were often more obvious in the landscape before land leveling. These patterns, while still present, have been masked by land leveling. Land leveling has not only disturbed soils, but has eliminated many “topographic breaks” that are used by soil scientists to identify and map soils. Soil scientists tasked with mapping leveled lands within the *Delta* have a difficult task as soils and topographic patterns are visually masked and indistinguishable. Soil mapping is slowed and field cost increase, as soil scientist must grid map these areas. In addition, land leveling often creates greater uncertainty for soil scientists involved in mapping activities. The use of EMI may help to improve and expedite soil mapping in areas that have been leveled. To be useful, these methods must be accurate, inexpensive, fast, and provide meaningful maps of soils and soil properties at a level of resolution that is comparable with current and future technologies (Jaynes, 1996).

A study site was located in a leveled, cultivated field near St. Paul’s Church south of Tunica (Section 24, T. 5 S., R. 12 W). . The dominant soil that had been mapped within the site is Bosket. However, the field is known to contain multiple soil delineations. The very deep, well drained Bosket soil formed in loamy alluvium. Bosket is a member of the fine-loamy, mixed, active, thermic Mollic Hapludalf family.

Survey procedures were simplified to expedite fieldwork. Two parallel lines were laid out. These two lines defined the perimeter of a rectangular grid. Dimensions of the grid were 200 by 1200 feet (5.5 acres). Along each line, survey flags were inserted in the ground at intervals of 50 feet. These flags served as grid line end points and provided ground control. Walking at a fairly uniform pace between similarly numbered flags on the two opposing parallel lines in a back and forth manner across the grid area completed the survey.

When operated in the continuous mode, the GEM300 sensor cannot be rotated to simultaneously record measurements in both dipole orientations. As a consequence, measurements were obtained only in the deeper-sensing vertical dipole orientation. An operating frequency of 14790 Hz was used. Surveys were completed with the GEM300 sensor held at hip height with its long axis parallel to the direction of traverse. The GEM300 sensor was operated in the continuous mode with measurements recorded at 2-sec intervals. For each traverse line, the location of each measurement was adjusted to provide a uniform interval between observation points.

The survey was completed in a very brief period of time (32 minutes). The GEM300 sensor provided comprehensive coverage of the site with 654 observations. Apparent conductivity averaged 20.2 mS/m with a range of 3.2 to 31.8 mS/m. Half of these observations had values of apparent conductivity between 17.8 and 23.7 mS/m.

Interpretations of EMI data are based on identification of spatial patterns within data sets. Though seldom diagnostic in themselves, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. On level, graded fields within the southern Mississippi River Valley, because of comparatively low soluble salt contents and relatively uniform water table depths, variations in apparent conductivity are principally associated with differences in clay content (Wolf et al., 1998). Soils with high apparent conductivity were assumed to have more clay than soils with low apparent conductivity.

Figure 4 shows the results of the EMI survey. In this plot the isoline interval is 5 mS/m. Distinct bands of contrasting apparent conductivity are evident in Figure 4. These bands were presumed to represent differences is soils and soil properties (clay content). Soils were observed at two observation points in the southwest portion of the site. An area of low (7 mS/m) and high (24 mS/m) were selected. The clay contents and particle size distributions of these two soils were strikingly different as shown in Table 1.

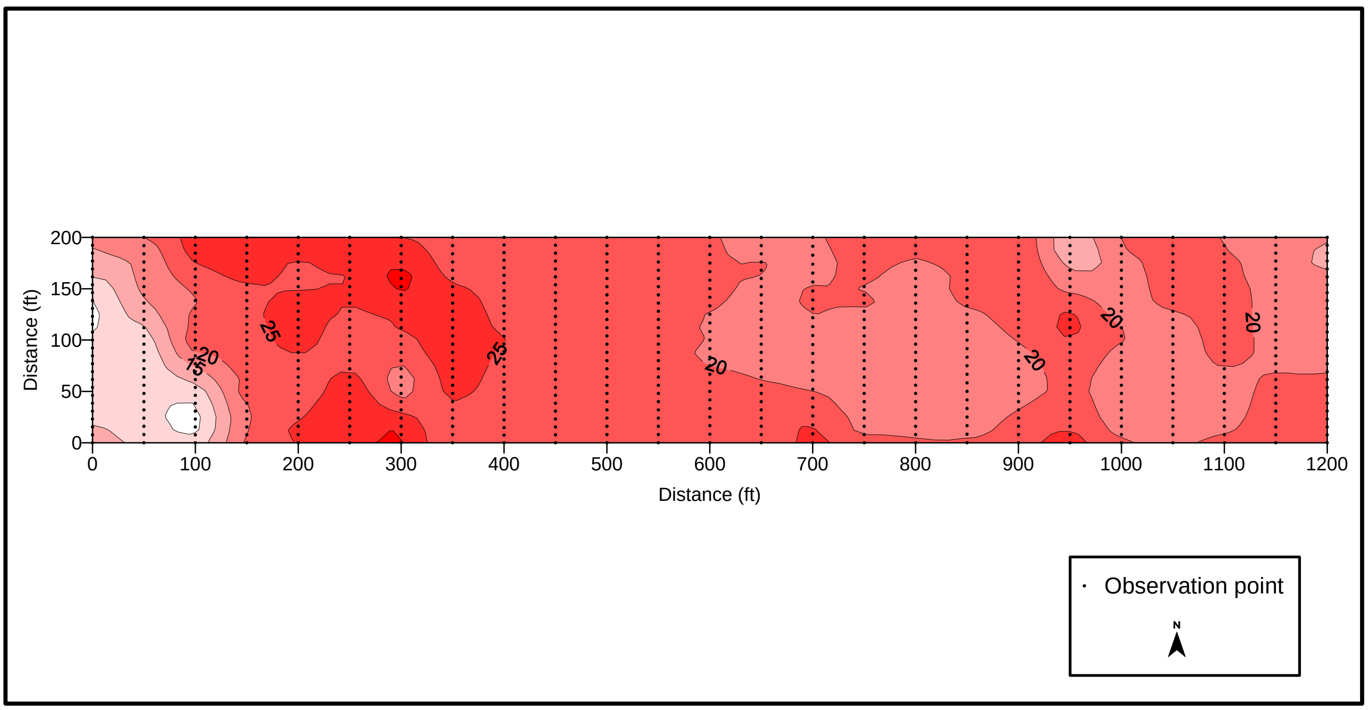

Figure 4. Spatial patterns of apparent conductivity collected with the GEM300 sensor in a land-leveled area of predominantly Bosket soil, Tunica County.

Table 1
Brief Profile Descriptions and Associated Apparent Conductivity Measurements

Apparent Conductivity = 7 mS/m

Horizon	Depth	Texture
A	0-6	vfsl
C1	6-10	vfsl
C2	10-15	vfsl
C3	15-40	vfsl
C4	40-60	lfs

Apparent Conductivity = 24 mS/m

Horizon	Depth	Texture
A	0-7	vfsl
C1	7-12	sil
C2	12-20	sicl
C3	20-36	sicl
C4	36-40	sl
C5	40-60	vfsl

The study in Tunica County demonstrates that EMI can be used effectively to map soils within leveled lands and help design soil map units.

Greenville Airport

The site was located at a demonstration farm on the grounds of the former Greenville Air Force Base. The field, located directly south of the present Greenville Airport's runways was in cotton stubble. The site contained two mapped soil consociations: Bosket very fine sandy loam, nearly level and Crevasse sandy loam. The Bosket delineation occupied all but the extreme eastern portion of the site.

A 550 by 450 grid was established across the site. Observations were made at about 50 foot intervals along 10 east-west trending grid lines that were spaced about 50 feet apart. This procedure provided 114 observations. The coordinates of each observation point were determined with GPS.

As measurements were obtained in both the horizontal and vertical dipole orientations, the GEM300 sensor was operated in a station-to-station rather than a continuous mode. At each observation point, measurements were taken at hip-height with the GEM300 sensor held in both the horizontal and vertical dipole orientations.

At all observation points, apparent conductivity increased with increasing depth of observation (measurements obtained in the shallow-sensing, horizontal dipole orientation were lower than those obtained in the deeper-sensing, vertical dipole orientation). This relationship was assumed to be associated with higher water and clay contents at lower soil depths. In the shallower-sensing, horizontal dipole orientation, apparent conductivity averaged 38.3 mS/m with a range of 32.2 to 46.9 mS/m. Half of these observations had values of apparent conductivity between 36.1 and 40.4 mS/m. In the deeper-sensing, vertical dipole orientation (lower plot, Figure 5), apparent conductivity averaged 66.6 mS/m with a range of 56.2 to 77.1 mS/m. Half of these observations had values of apparent conductivity between 63.8 and 69.2 mS/m.

Bosket is the dominant soil within the site. Compared with the Bosket soils mapped at the land level site in Tunica County, values of apparent conductivity measured in the vertical dipole orientation are conspicuously higher at the Greenville Airport site.

Three soil cores were obtained from this site. The cores spanned the observed range of apparent conductivity measured at this site. No significant differences were observed in these cores. All were coarse-loamy (very fine sandy loam) to depths of about 2.1 to 2.4 m, where a layer of fine (silty clay) textured materials was observed. Compared with the Tunica site, soils observed within the Greenville site contained less clay within the upper 1.5 m. As no significant differences in texture, horizonation, or moisture were observed in the three profiles at the Greenville site, variations in apparent conductivity were attributed to changes in the soluble salt contents of these soils. Contaminants in the groundwater, possibly related to the use of the site as a military base, are suspected.

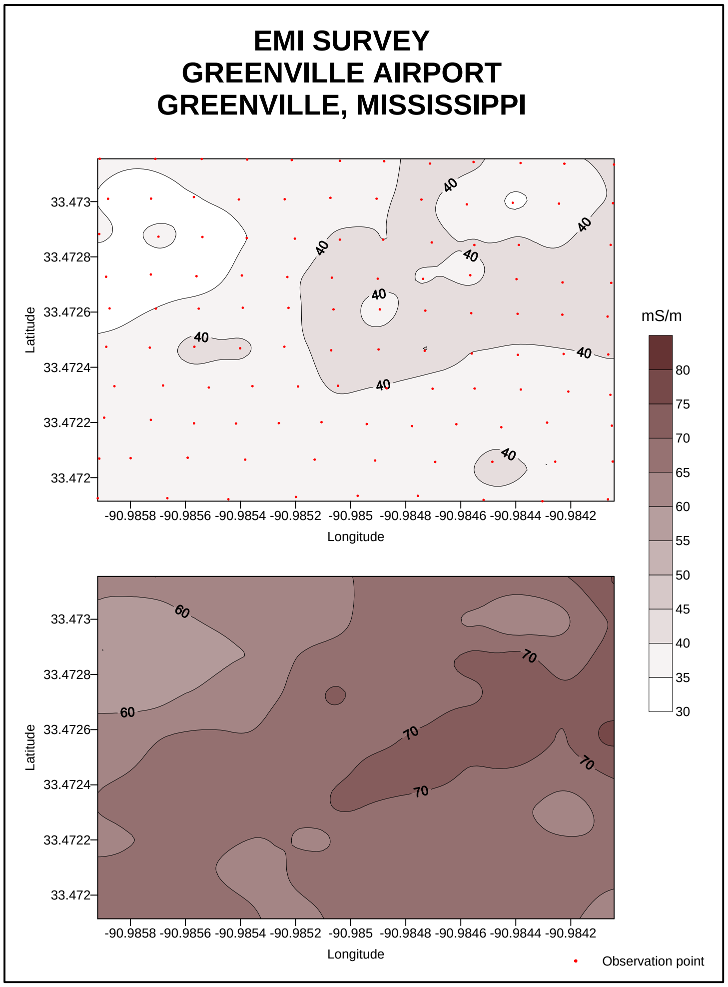

Figure 5. Spatial patterns of apparent conductivity collected with the GEM300 sensor in a land-leveled area of predominantly Bosket soil, Greenville County

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