**United States Department of Agriculture** | **Natural Resources Conservation Service** | **5 Radnor Corporate Center, Suite 200 Radnor, PA 19087-4585**

**Subject:** SOI -- Geophysical Assistance **Date:** 4 April 1996

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**Purpose:**
To use electromagnetic induction (EMI) and ground-penetrating radar (GPR) to characterize various sites in Tennessee and Kentucky.

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**Activities:**
All field activities were completed during the period of 18 to 27 March 1996.

**Equipment:**
The electromagnetic induction meters used in this study were the EM38 and EM31, manufactured by Geonics Limited. These meters are portable and require only one person to operate. Principles of operation have been described by McNeill (1980, 1986). No ground contact is required with these meters. Each meter provides limited vertical resolution and depth information. For each meter, lateral resolution is approximately equal to the intercoil spacing. The observation depth of an EMI meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface.

The EM38 meter has a fixed intercoil spacing of about 40 inches. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 30 and 60 inches in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter has a fixed intercoil spacing of about 12 feet. It operates at a frequency of 9.8 kHz. The EM31 meter has effective observation depths of about 10 and 20 feet in the horizontal and vertical dipole orientations, respectively (McNeill, 1980). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc. This unit is backpack portable and requires two people to operate. The use and operation of GPR have been discussed by Morey (1974), Doolittle (1987), and Daniels and others (1988). The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. The model 3110 (120 MHz) antenna was used in this investigation. The system was powered by a 12-VDC battery.

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc., was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search. All grids were smoothed using a cubic spline interpolation. In most of the enclosed plots, to help emphasize spatial patterns, colors and filled contour lines have been used. Other than showing trends and patterns in values of apparent conductivity (i.e., zones of higher or lower electrical conductivity), no significance should be attached to the colors themselves.

**Discussion:**
Electromagnetic induction techniques use 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 observation depth. Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the (i) volumetric water content, (ii) type and concentration of ions in solution, (iii) temperature and phase of the soil water, and (iv) amount and type of clays in the soil matrix, (McNeill, 1980). The apparent conductivity of soils increases with increases in the exchange capacity, water content, and clay content.

Electromagnetic inductive methods measure vertical and lateral variations in the apparent electrical conductivity of earthen materials. 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 earthen materials. Interpretations of the EMI data are based on the identification of spatial patterns within data sets.

Advantages of EMI methods include speed of operation, flexible observation depths (with commercially available systems from about 2.5 to 200 feet), and moderate resolution of subsurface features. Results of EMI surveys are interpretable in the field. This technique can provide in a relatively short time the large number of observations needed for site characterization and assessments. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions and for planning further investigations.

Electromagnetic induction techniques are not suitable for use in all investigations. Generally, the use of EMI techniques has been most successful in areas of undisturbed soils where subsurface properties are reasonably homogeneous, the effects of one property (e.g. clay, water, or salt content) dominates over the other properties, and variations in EMI response can be related to changes in the dominant property (Cook et al., 1989).

A principal goal of this investigation was to further evaluate the appropriateness of EMI techniques in areas of karst. Electromagnetic induction techniques have been used in areas of karst (Canace and Dalton, 1984; Pazuniak, 1989; Robinson-Poteet, 1989; Rumbens, 1990). In these studies, interpretations of EMI data enabled the delineation of larger subsurface voids, channels, and zones of higher permeability (such as fractures and karstified areas within carbonate bedrock). Typically, the shape and pattern of the subsurface anomaly have been used to identify the solution feature.

An essential assumption of this investigation is that subsurface cavities will appear as anomalies on plots of apparent conductivity measurements. It was assumed that negative (lower values) anomalies would indicate possible air-filled cavities. These cavities would have lower electrical conductivities than the surrounding medium. Positive (higher values) anomalies would indicate possible water- or sediment-filled cavities. These cavities would have higher electrical conductivities than the surrounding medium.

The detection of subsurface cavities is extremely challenging. Under favorable conditions, detection is possible, but is often fortuitous. Detection of subsurface anomalies often depends on the size of the survey area, and the number and spacing of observations. The spacing must be comparable to the size of the feature being investigated.

The success of an EMI survey will depend on the size, depth, shape, and spatial distribution of the cavities. Cavities must have a favorable size to depth ratio. Large and/or very shallow cavities are most often detected. Small and deep cavities are often not detected. As a rule, to be detected, the depth to a cavity should be less than 1.5 to 2 times its diameter. Assuming that this rule is correct, with an EM31 meter, a cavity with a minimum diameter of about 15 to 20 feet should be detected.

Because of low signal to noise ratios, cavities are more difficult to detect in highly variable materials. The presence of these contrasting materials made interpretations less straightforward and more ambiguous. Because of their more contrasting electrical conductivity, air-filled cavities are often easier to detect than water or sediment-filled cavities. However, the existence of either air- or sediment-filled cavities was unclear.

**<u>Christian County, 18 March 1996</u>**

*Site 1 -- Contaminated Well at the Bobby Wagner Farm:*

Domestic water well at the farm of Bobby Wagner had become contaminated. Manure had recently been applied to a nearby garden plot. As the well became tainted shortly after this event, the manure was the suspected source of contamination. A nearby animal-waste facility was also suspected as being a potential source or contributor to this contamination. This facility was located about 700 feet from the well. The site is located in areas of Henshaw silt loam (Froedge, 1980). Henshaw soils are members of the fine-silty, mixed, mesic Aquic Hapludalfs family. The estimated depth to limestone bedrock ranged from 10 to 15 feet.

A survey grid was established around the well. The grid interval was 50 feet. At each grid intersection, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was held at a height of about 40 inches (at waist level) above the ground surface.

Figures 1 and 2 are two-dimensional plots of the data collected with an EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 2 mS/m.

Figures 1 and 2 represents the spatial distribution of apparent conductivity for the upper 6.6 and 16.4 feet of the soil profile, respectively. Values of apparent conductivity increased with increasing observation depths. For the shallower-sensing horizontal dipole orientation (0 to 6.6 feet), one-half of the observations had values of apparent conductivity between 29 and 34 mS/m. For the deeper-sensing vertical dipole orientation (0 to 16.4 feet), one-half of the observations had values of apparent conductivity between 47.5 and 54.5 mS/m. Measurements averaged 31.9 mS/m and 51.8 mS/m in the horizontal and vertical dipole orientations, respectively. This trend is believed to reflect increasing moisture and possibly soluble salt contents with increasing soil depths.

In figures 1 and 2, values of apparent conductivity do not increase and isolines do not appear to be affected by the garden plot. Contamination from this source area is therefore considered improbable. In each figure, values of apparent conductivity increase towards the lower right hand corner of the plot. This is in the direction of the animal waste-holding facility. In Figure 2, a conspicuous zone of higher apparent conductivity values extends diagonally across the grid site from the lower right-hand to the upper left-hand corners. This zone of higher conductivity includes the well. It is very probable, that this zone of higher conductivity represents a plume of water containing noticeably higher amounts of nitrates and other soluble salts. However, this assumption could not be confirmed at the time of this investigation. In Figure 2, the isolines appear to indicate that this plume is moving laterally and decreasing in magnitude from the animal waste-holding facility towards the well.

In figures 1 and 2, higher values of apparent conductivity are evident in the upper right-hand corner of each plot. The high values are associated with “cultural noise” associated with an adjoining house.

*Site 1 - Assessing Potential Seepage from Animal Waste Facilities at the Tom Bennett Farm:*
Prior to sealing the bottom of a waste-holding facility with bentonite clay, the structure did not hold water. The operator was concerned about water quality, seepage, and possible contamination of a nearby stream. The site is located in areas of Pembroke silt loam, 2 to 6 percent slopes (Froedge, 1980). Pembroke soils are members of the fine-silty, mixed, mesic Mollic Paleudalfs family.

A survey grid was established along the side of two facilities that faced the stream. The grid intervals were 50 feet parallel and 25 feet orthogonal to the stream. At each grid intersection (72), a survey flag was inserted in the ground and served as an observation point. At each observation, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was held at a height of about 40 inches (at waist level) above the ground surface.

Figures 3 and 4 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 2 mS/m. Dark lines have been drawn to indicate the approximate locations of the embankments to the two waste-holding facilities. In each plot, these structures were located in the area that was not surveyed. The structure located to the right had been in operation for the longer time. This was the structure that required the bentonite clay seal.

Figures 3 and 4 represents the spatial distribution of apparent conductivity for the upper 6.6 and 16.4 feet of the soil profile, respectively. Values of apparent conductivity appear to increase with increasing observation depths. For the shallower-sensing horizontal dipole orientation (0 to 6.6 feet), one-half of the observations had values of apparent conductivity between 14 and 18 mS/m. For the deeper-sensing vertical dipole orientation (0 to 16.4 feet), one-half of the observations had values of apparent conductivity between 20 and 28 mS/m. Measurements averaged 16 mS/m and 24.3 mS/m in the horizontal and vertical dipole orientations, respectively. This trend is believed to reflect increasing moisture and possibly soluble salt contents with increasing soil depths.

In both figures, an area of lower apparent conductivity is evident in the left-central portion of the survey site. A drainageway occupies a portion of this area (between lines 100 and 200 feet). Within this drainageway the soils were reportedly composed of very cherty materials. Values of apparent conductivity are low in this portion of the study site and reflect the resistive nature of the underlying cherty materials.

In Figure 4, a weakly expressed zone of higher apparent conductivity values extends away from the older facility between grid lines 500 and 650 feet. This zone is believed to represent the effects of seepage. This zone appears to be largely confined to an area of less than 50 feet away from the top of the embankment. The extent and relative magnitude of apparent conductivity values within this potential plume are not considered exceptional or significant. Compared with the structure located in the upper left-hand portion of the site, values of apparent conductivity are higher surrounding the older structure located in the upper right-hand portion of the site. The higher values of apparent conductivity around this structure are believed to reflect its longer operation and the effects of seepage.

**Stewart County, Tennessee - 20 March 1996**

*Site 1 -- EMI Demonstration for Environmental Division, US Army, Ft. Campbell:*
A demonstration of the operation and use of EMI techniques was provided to members of the Environmental Division, US Army, Ft. Campbell. The EM31 meter was used to detect and locate buried tanks. Each participant had the opportunity to operate the meter. The meter successfully located two buried tanks and a utility line. Discussion followed demonstration.

*Site 2 -- Archaeological Investigation for Environmental Division, US Army, Ft. Campbell*
A portion of a suspected burial site was surveyed with an EM38 meter. The site was located in a wooded area. At the time of the survey, the area was covered with about 3 inches of snow. No graves or headstones were evident in the area.

A survey grid was established across the site. The grid interval was 5 feet. At each grid intersection (56), measurements were taken with an EM38 meter in the vertical dipole orientation. For these measurements, the meter was placed on the ground surface.

Figure 5 is a two-dimensional plot of the data collected with the EM38 meter in the vertical dipole orientations. In Figure 5, the isoline interval is 2 mS/m. Figure 6 represents the spatial distribution of apparent conductivity for the upper 6.0 feet of the soil. One-half of the observations had values of apparent conductivity between 5.5 and 6.2 mS/m. Within the relatively site and for the purpose of this investigation, values greater or less than 4 mS/m above or below this range were considered anomalous. Five anomalous areas were identified. This area represents the most probable locations for grave sites or buried artifacts. In Figure 5, these areas have been distinguished with the letter “A”. Three areas had negative values. These values indicate the presence of metallic objects in the subsurface.

The results of this survey indicate the presence of artifacts within the study site. However, without ground truth verification, the identity of these features remains unknown.

**Montgomery County, Tennessee - 21 March 1996**

*Site 1 -- Hunter’s Point Town site, Clarksville, Tennessee*
The site is being developed for residential homes. Two broad depressions were located within the central portion of the survey area. Water does not pond for long periods in these depressions. The purpose of this investigation was to use EMI techniques to ascertain whether any large dissolution feature exists under these depressions or within the study area.

A survey grid was established across the site. The grid interval was 50 feet. At each grid intersection (120), a survey flag was inserted in the ground and served as an observation point. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. At each observation points, the relative elevation of the surface was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum.

The topography of the survey area is shown in Figure 6. The contour interval is one foot. Relief is 11.5 feet. The two broad depressions are evident within the central portion of the survey area. A paved road parallels and is located immediately below the southern border of the site.

Figures 7 and 8 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 2 mS/m.

Figures 7 and 8 represent the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. Values of apparent conductivity decrease with increasing observation depths. Measurements averaged 11.0 mS/m and 8.7 mS/m in the horizontal and vertical dipole orientations, respectively. For the shallower-sensing horizontal dipole orientation (0 to 2 meters), one-half of the observations had values of apparent conductivity between 9.5 and 12.0 mS/m. For the deeper-sensing vertical dipole orientation (0 to 5 meters), one-half of the observations had values of apparent conductivity between 7.5 and 9.0 mS/m. This trend is believed to reflect the presence of limestone at lower soil depths. The underlying limestone is more resistance than the overlying soil which has higher clay and moisture contents.

In figures 7 and 8, values of apparent conductivity are relatively low and invariable across the site. In Figure 8, slightly lower values of apparent conductivity were measured in the center-east portion of the survey area. These values are assumed to reflect shallower depths to bedrock.

Large air-filled voids should produce noticeable anomalies with lower apparent conductivity values. In Figure 8, a relatively large area with lower values of apparent conductivity (< 7 mS/m) appears within the center-east portion of the survey area. These values do not appear to be highly contrasting with adjoining areas. While it is possible that this area represents the locations of large subsurface cavity, it is considered more plausible that the low values reflect an area underlain by bedrock at relatively shallow depths. It is very possible that cavities were missed (by the relatively coarse grid spacing), were too small to be detected, or were not present in the study area.

Higher values of apparent conductivity are evident in the lower right-hand corner of each plot. The source of these anomalously high values is presently unknown. These values could represent soils with higher clay contents, a clay-filled dissolution feature or "cultural noise" associated with the nearby road and utility lines. With the exception of this feature, the survey revealed no indication of large subsurface dissolution feature.

Figures 9 and 10 have been prepared as alternative presentations of the data collected with the EM31 meter in the horizontal and dipole orientations, respectively. In each of these figures, the two-dimensional patterns of apparent conductivity values have been overlaid upon a three-dimensional surface net diagram of the topography. These figures will hopefully allow the reviewers a better opportunity to visualize the data.

*Site 2 - Sinkhole on Sadlerville Road:*

A pond in the bottom of a sinkhole does not hold water. The purpose of this investigation was to ascertain whether the sinkhole is underlain by a large solution cavity. The site is located in areas of Cumberland soils, cherty variant, 10 to 25 percent slopes, eroded. Cumberland soils are members of the fine, mixed, thermic Rhodic Paleudalfs family.

A survey grid was established across the site. The grid interval was 50 feet. At each grid intersection (29), a survey flag was inserted in the ground and served as an observation point. At each observation, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. At each observation points, the relative elevation of the surface was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum.

The topography of the survey area is shown in Figure 11. The contour interval is one foot. Relief is 15.9 feet.

Figures 12 and 13 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 1 mS/m. Figures 12 and 13 represent the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. Values of apparent conductivity increased with increasing observation depths. For the shallower-sensing horizontal dipole orientation (0 to 3 meters), one-half of the observations had values of apparent conductivity between 11 and 12 mS/m. For the deeper-sensing vertical dipole orientation (0 to 6 meters), one-half of the observations had values of apparent conductivity between 9 and 11 mS/m. Measurements averaged 11.4 mS/m and 9.9 mS/m in the horizontal and vertical dipole orientations, respectively. This trend is believed to reflect the presence of limestone at lower soil depths. The underlying limestone is more resistance than the overlying soil which has higher clay and moisture contents.

Figures 14 and 15 have been prepared as alternative presentations of the data collected with the EM31 meter in the horizontal and dipole orientations, respectively. In each of these figures, the two-dimensional patterns of apparent conductivity values have been overlaid upon a three-dimensional surface net diagram of the topography. These figures will hopefully allow the reviewers a better opportunity to visualize the data.

**Montgomery County, Tennessee - 22 March 1996**

*Site 1 -- Proposed Site for Animal Waste-Holding Facility:*

"Wildcat" EMI and GPR surveys were conducted across a residential lot in an attempt to locate a buried septic tank. Neither technique proved satisfactory. High levels of *cultural noise* interfered with the EMI measurements. Though a drain was located, the large number of metallic objects underlying the site produced undesired EMI responses and ambiguous results. The soil materials were conductive and highly attenuating to the radar. The depth of radar observation was too restricted to detect the septic tank.

*Site 2 -- Proposed Site for Animal Waste-Holding Facility:*

The site is located on the farm of George Marks. The existing waste-holding structure is relatively old and does not have sufficient storage capacity for the existing herd. The operator is concerned with periodic spillovers of waste from the present structure. He is interested in constructing some form of waste-holding structures across the existing drainageway. The purpose of this investigation was to use EMI techniques to characterize the proposed site. The depth to bedrock was considered very deep at this site. The EMI survey could help ascertain whether any large dissolution feature exists under the site.

A survey grid was established across the site. The grid intervals were 25 and 50 feet. At each grid intersection (55), a survey flag was inserted in the ground and served as an observation point. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was held at hip height (1 meter above the ground surface). At each observation points, the relative elevation of the surface was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum.

The topography of the survey area is shown in Figure 16. The contour interval is one foot. Relief is about 38 feet. The contour lines bend around a drainageway in the central portion of the survey area. All points within the survey site slope into this drainageway. The drainageway has its origin near an animal holding area and a waste-holding structure. Also shown in Figure 16 are the locations of an electric fence and a concrete watering trough.

Figures 17 and 18 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 2 mS/m.

Figures 17 and 18 represent the spatial distribution of apparent conductivity for the upper 2 meters and the upper 5 meters of the soil profile, respectively. Values of apparent conductivity increased with increasing observation depths. Measurements averaged 11.0 mS/m and 13.6 mS/m in the horizontal and vertical dipole orientations, respectively. For the shallower-sensing horizontal dipole orientation (0 to 2 meters), one-half of the observations had values of apparent conductivity between 7.8 and 13.1 mS/m. For the deeper-sensing vertical dipole orientation (0 to 5 meters), one-half of the observations had values of apparent conductivity between 10.8 and

15.0 mS/m. This trend is believed to reflect strata with higher clay and moisture contents at lower soil depths. It is possible that the shallower soil and stratigraphic layers contain greater amounts of chert. The chert was assumed to be more resistive than the surrounding, more clay and water enriched matrix. It was unclear whether the site was underlain by limestone bedrock within the observation depth of the EM31 meter (0 to 5 m). Values of apparent conductivity increased with depth. Without some borehole observations, it is difficult to conclude that, within the observed depth interval, limestone (relatively resistive) underlies the unconsolidated (and more conductive) materials.

In figures 17 and 18, values of apparent conductivity appear highly variable across the site. In both figures, high values of apparent conductivity were recorded within the drainageway. This pattern is believed to reflect the higher moister contents, thicker layers of colluvium, and/or seepage and runoff of animal waste. Within the drainageway (and the site), the highest values of apparent conductivity were recorded nearest to the existing waste-holding structure and animal-holding areas. Values of apparent conductivity decrease down gradient and away from these features. It must be concluded that EMI responses have been affected by the seepage and runoff of waste products.

In figures 17 and 18, lower values of apparent conductivity were measured on the north-facing slope in the southern portion of the survey areas. It is suspected that these slopes are underlain by thicker deposits of cherty materials and/or shallower depths to limestone bedrock. Comparatively high values apparent conductivity were measured on the south-facing slopes in the northern portion of the study site. These values are believed to reflect the presence of finer-textured materials, less chert, and/or deeper depths to bedrock.

The patterns appearing in figures 17 and 18 do not suggest the presence of any large air-filled voids in the subsurface materials. Isolines appear to conform to the topography, reflect landscape components, and presumably dissimilar materials.

Figures 19 and 20 have been prepared as alternative presentations of the data collected with the EM31 meter in the horizontal and dipole orientations, respectively. In each of these figures, the two-dimensional patterns of apparent conductivity values have been overlaid upon a three-dimensional surface net diagram of the topography. These figures will hopefully allow the reviewers a better opportunity to visualize the data.

**<u>Simpson County, Kentucky - 25 March 1996</u>**

*Franklin-Simpson High School, Franklin:*

The purpose of this investigation was to use EMI techniques to characterize site. The town was seeking to know if the site was underlain by solution cavities. If so, these features could be developed as sources for geothermal heating and cooling.

The site was located on the north side of the Board of Education building. A parking lot and a street bordered the west and east boundaries of the site. Several buried utility lines (water) crossed the study site. In figures 21 and 22, the approximate locations of these lines are shown. In addition, shown in these figures are the approximate locations of storm and water drains.

A survey grid was established across the site. The grid interval was 25 feet. At each grid intersection (88), a survey flag was inserted in the ground and served as an observation point. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface

Figures 21 and 22 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 5 mS/m.

Figures 21 and 22 represent the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. In both figures, spatial patterns were largely influenced by the presence of buried utility lines. Values of apparent conductivity increased with increasing observation depths. Measurements averaged 19.8 mS/m and 31.3 mS/m in the horizontal and vertical dipole orientations, respectively.

For the shallower-sensing horizontal dipole orientation (0 to 3 meters), one-half of the observations had values of apparent conductivity between 13.0 and 16.0 mS/m. For the deeper-sensing vertical dipole orientation (0 to 6 meters), one-half of the observations had values of apparent conductivity between 14.0 and 35.0 mS/m. The data collected at this site is perhaps meaningless, as the use of EMI techniques were severely limited by the presence of buried utility lines.

**Warren County, Kentucky - 25 March 1996**

*North Warren Elementary School, Smiths Grove:*

The site is located on the north and northeast sides of the school. The North Warren Elementary School is being expanded. A suitable site is being sought for the new building. The school is located in karst and dissolution features have been a problem to the school. The purpose of this investigation was to use EMI techniques to characterize the proposed site. The depth to bedrock was considered very deep at this site. The EMI survey could help ascertain whether any large dissolution feature exists under the site.

The survey site was located on the north and northeast sides of the school. A survey grid was established across the site. The grid interval was 50 feet. At each grid intersection (60), a survey flag was inserted in the ground and served as an observation point. At each observation point, measurements were taken with an EM31 meter in both the horizontal and vertical dipole orientations. For each measurement, the meter was placed on the ground surface. At each observation points, the relative elevation of the surface was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest observation point served as datum.

The topography of the survey area is shown in Figure 23. The contour interval is one foot. Relief is about 13 feet. Also shown in Figure 23 are the approximate locations of a chain link fence and a small concrete structure. These features were sources of unwanted noise which were to interfere with EMI measurements.

Figures 24 and 25 are two-dimensional plots of the data collected with the EM31 meter in the horizontal and vertical dipole orientations, respectively. In each of these plots, the isoline interval is 1 mS/m.

Figures 24 and 25 represent the spatial distribution of apparent conductivity for the upper 3 meters and the upper 6 meters of the soil profile, respectively. Values of apparent conductivity increased with increasing observation depths. Measurements averaged 13.7 mS/m and 12.2 mS/m in the horizontal and vertical dipole orientations, respectively. For the shallower-sensing horizontal dipole orientation (0 to 3 meters), one-half of the observations had values of apparent conductivity between 11.0 and 15.0 mS/m. For the deeper-sensing vertical dipole orientation (0 to 6 meters), one-half of the observations had values of apparent conductivity between 9.0 and 13.0 mS/m. This trend is believed to reflect strata with higher clay and moisture contents at lower soil depths. It is possible that the shallower soil and stratigraphic layers contain greater amounts of chert. The chert was assumed to be more resistive than the surrounding, more clay and water enriched matrix. It was unclear whether the site was underlain by limestone bedrock within the observation depth of the EM31 meter (0 to 5 m). Values of apparent conductivity increased with depth. Without some borehole observations, it is difficult to conclude that, within the observed depth interval, limestone (relatively resistive) underlies the unconsolidated (and more conductive) materials.

In figures 24 and 25, values of apparent conductivity are noticeably higher in the southwest corner of the site. These values reflect interference from a chain linked fence.

The patterns appearing in figures 24 and 25 suggest influence of cultural features, the depth to limestone bedrock, and perhaps presence of large air-filled and/or clay-filled voids in the subsurface materials.

Figures 26 and 27 have been prepared as alternative presentations of the data collected with the EM31 meter in the horizontal and dipole orientations, respectively. In each of these figures, the two-dimensional patterns of apparent conductivity values have been overlaid upon a three-dimensional surface net diagram of the topography. These figures will hopefully allow the reviewers a better opportunity to visualize the data.

**Hart County, Kentucky - 26 March 1996**

*Munfordville Battlefield:*

The site is located south of the town of Munfordville. It overlooks the Green River. Archaeologists were interested in using ground-penetrating radar techniques to detect and map a series of fortification trenches. The trenches were assumed to have crossed the site of the battle site.

**Results:**

1. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations do not substitute for direct observations, but rather reduce their number, direct their placement, and supplement their interpretations. Interpretations should be verified by ground-truth observations.

2. In areas containing buried wastes, non-invasive geophysical techniques can reduce health and environmental hazards associated with soil borings and excavations.

3. Ground-penetrating radar and electromagnetic induction techniques are noninvasive. Compared with traditional survey methods, these geophysical techniques are faster and provide greater numbers of observations per unit time. These techniques are therefore more efficient and provide more comprehensive coverage. Geophysical methods can cover large areas at comparatively low costs and with minimal health and environmental risks. This report described procedures for conducting surveys and for displaying data. Areas having a dense cover of vegetation or rough terrain impede survey operations and the placement of profile lines.

With kind regards.

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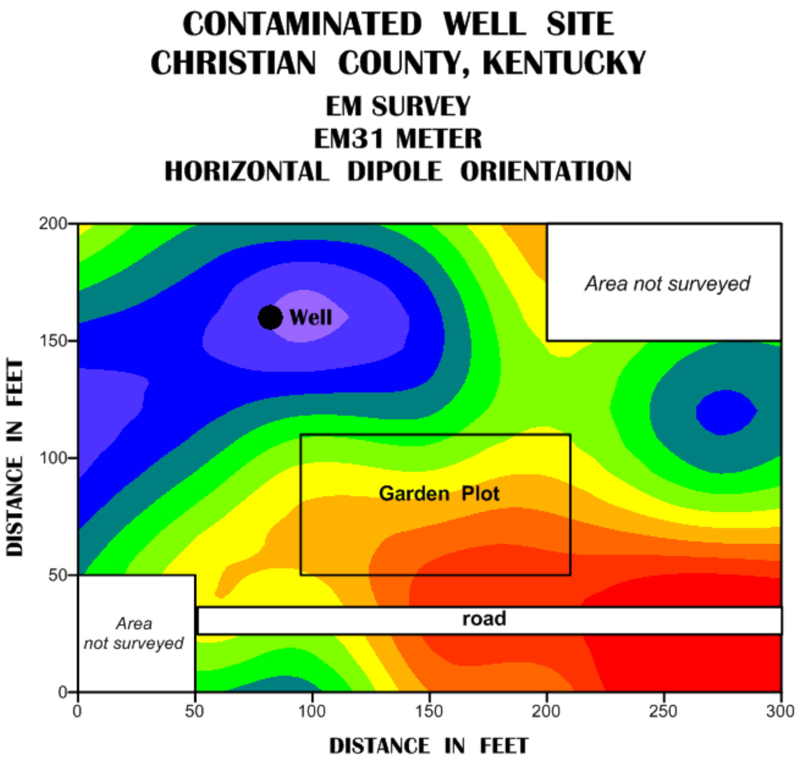



**Figure 1**

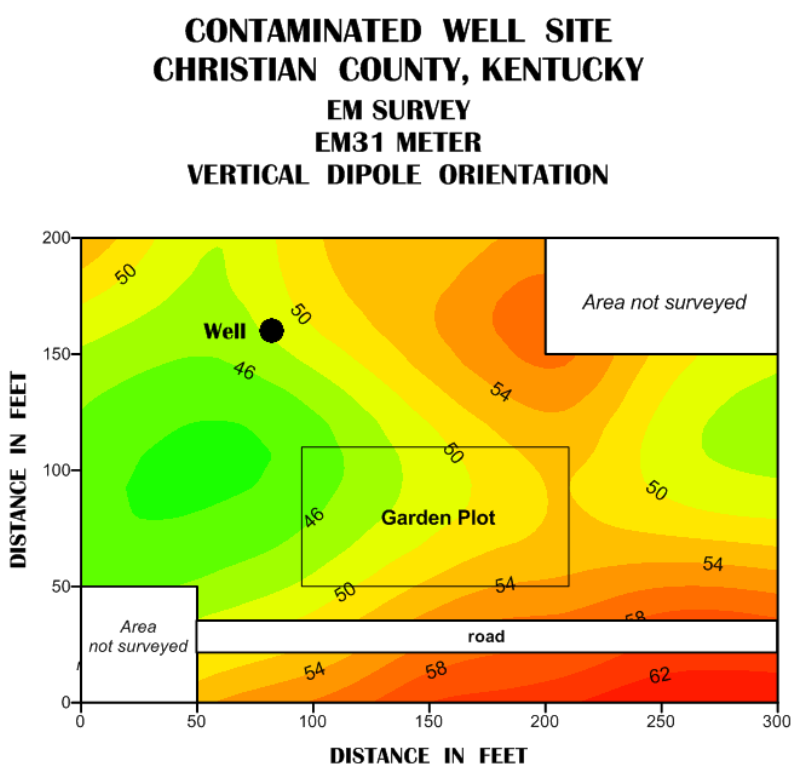



**Figure 2**

**ANIMAL WASTE FACILITY**
**CHRISTIAN COUNTY, KENTUCKY**

**EM SURVEY**
**EM31 METER**
**HORIZONTAL DIPOLE ORIENTATION**

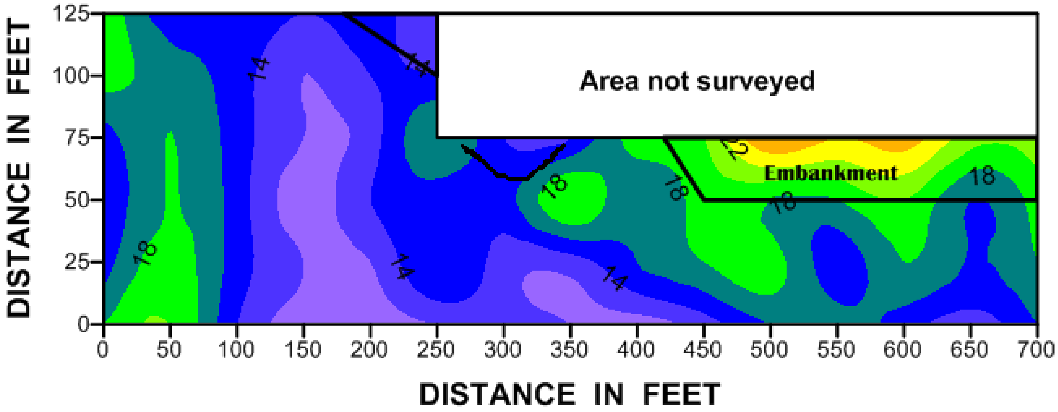



**Figure 3**

**ANIMAL WASTE FACILITY**
**CHRISTIAN COUNTY, KENTUCKY**

**EM SURVEY**
**EM31 METER**
**VERTICAL DIPOLE ORIENTATION**

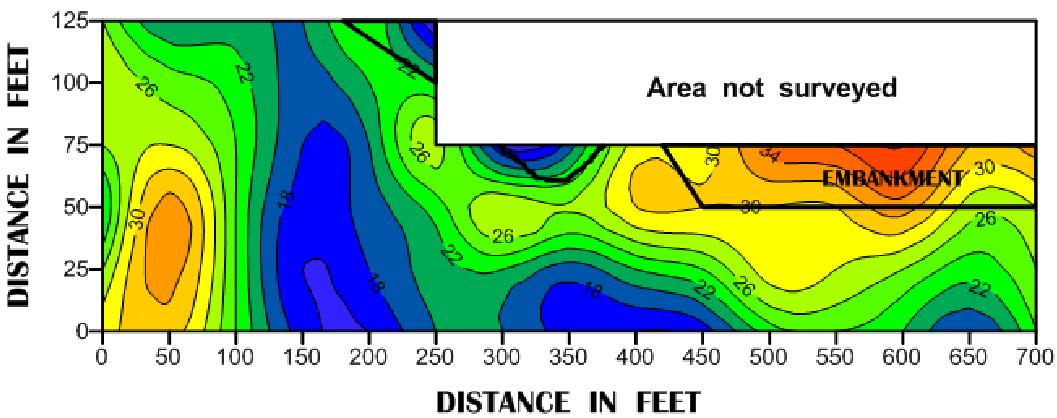



Figure 4

ARCHAEOLOGICAL SITE
FT. CAMPBELL
STEWART COUNTY, TENNESSEE

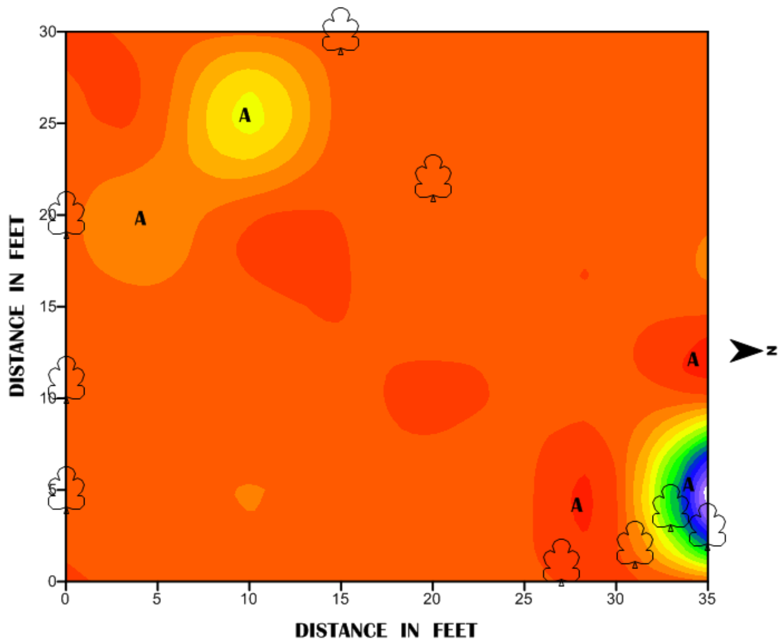
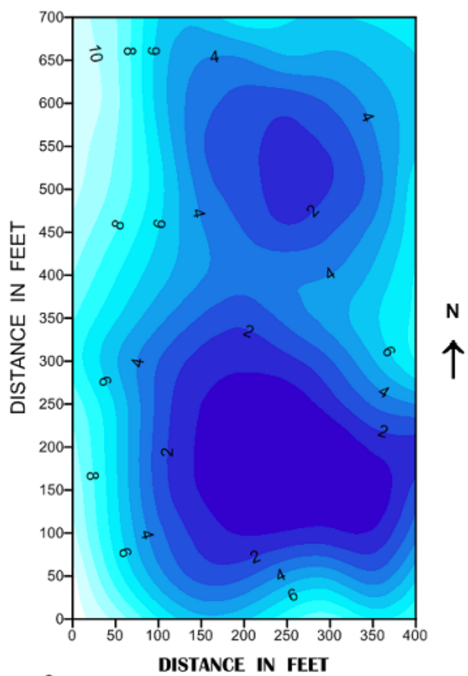



Figure 5 A - SUSPECTED ANOMALY

HUNTER'S POINT SUBDIVISION
CLARKSVILLE, TENNESSEE
RELATIVE ELEVATION
CONTOUR INTERVAL = 1 FOOT

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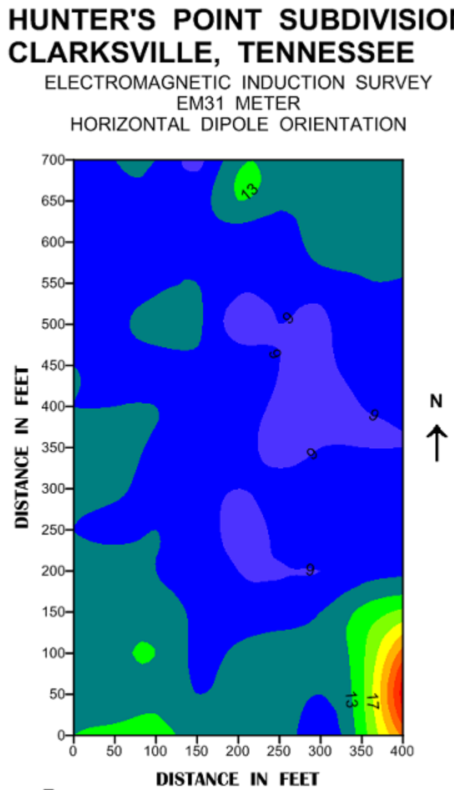


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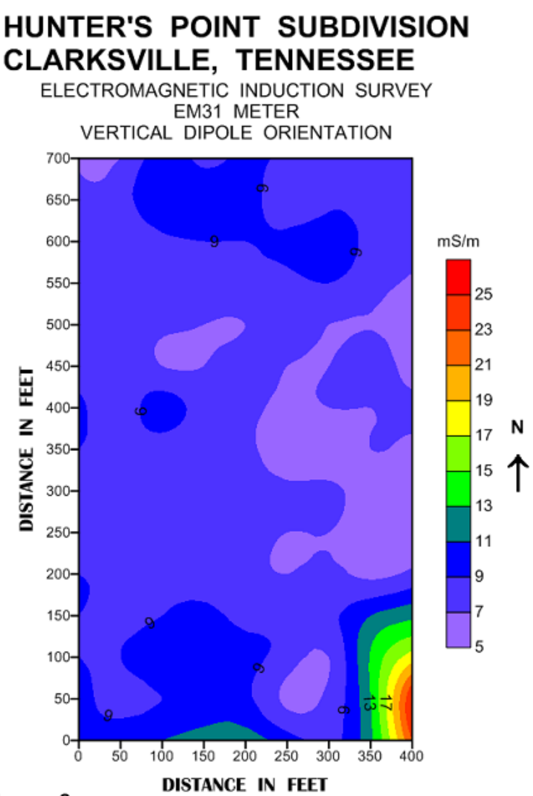


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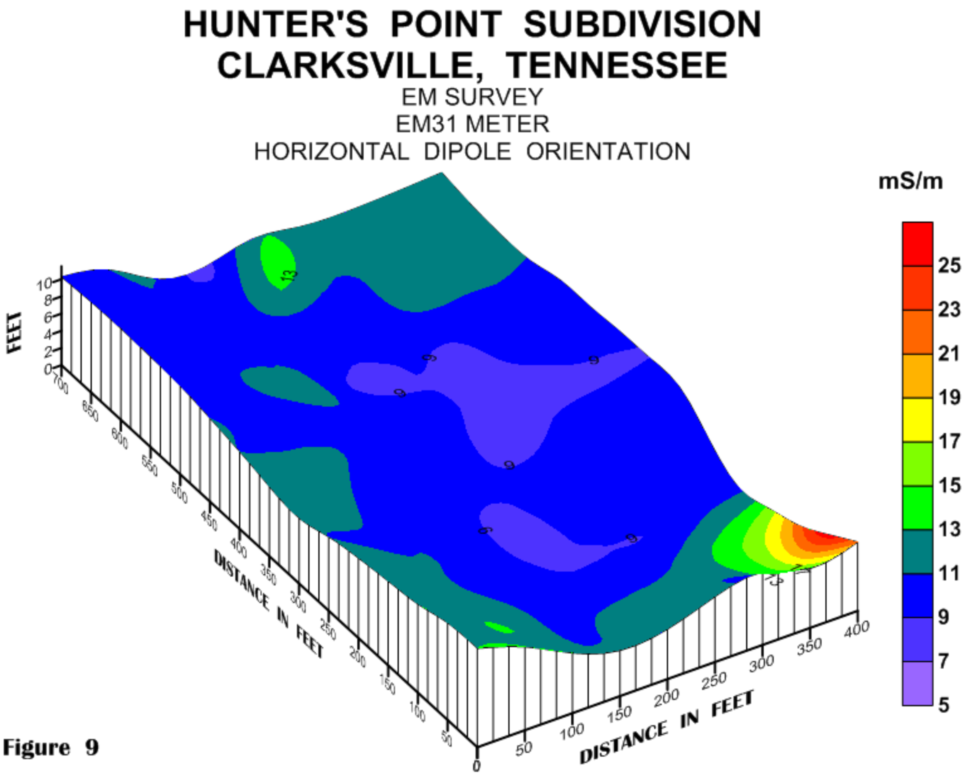


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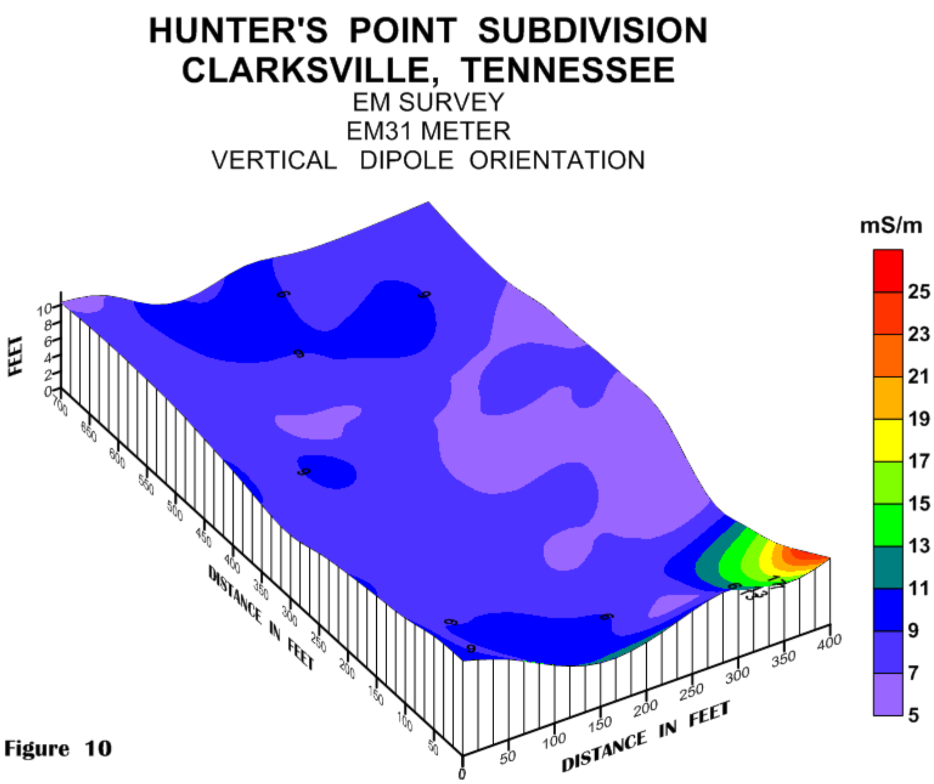


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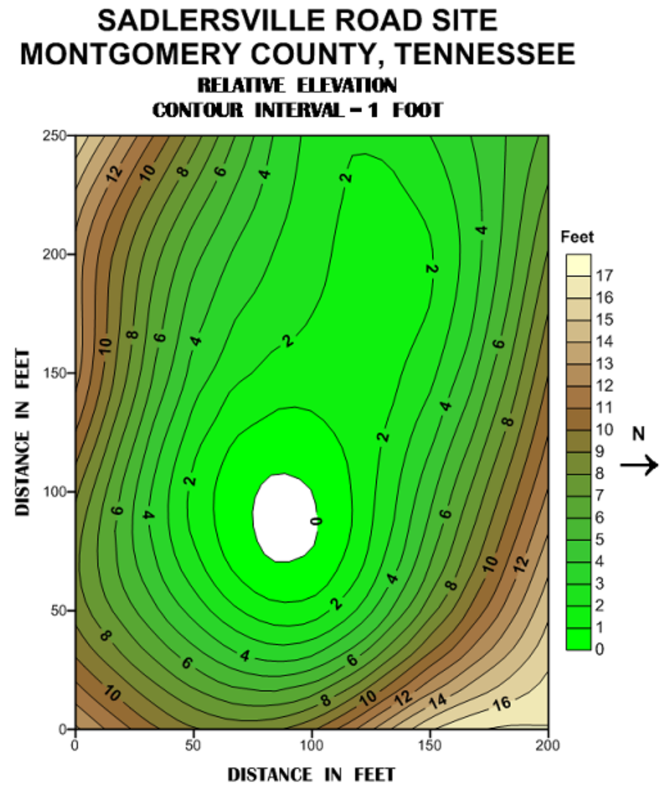


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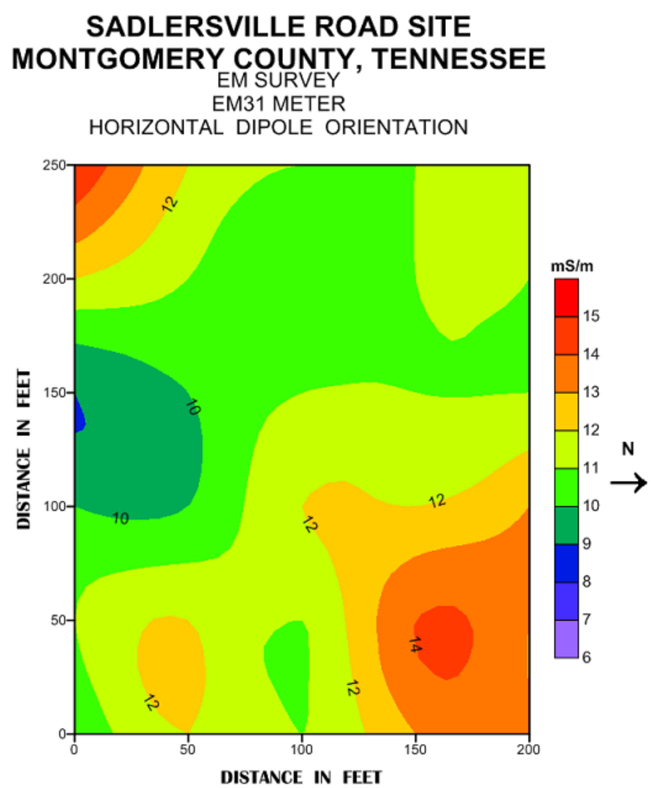


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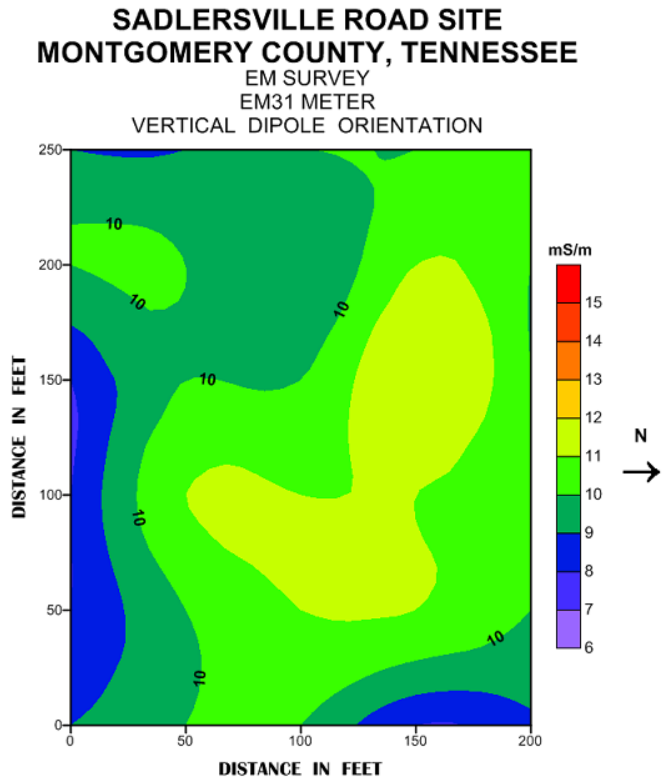


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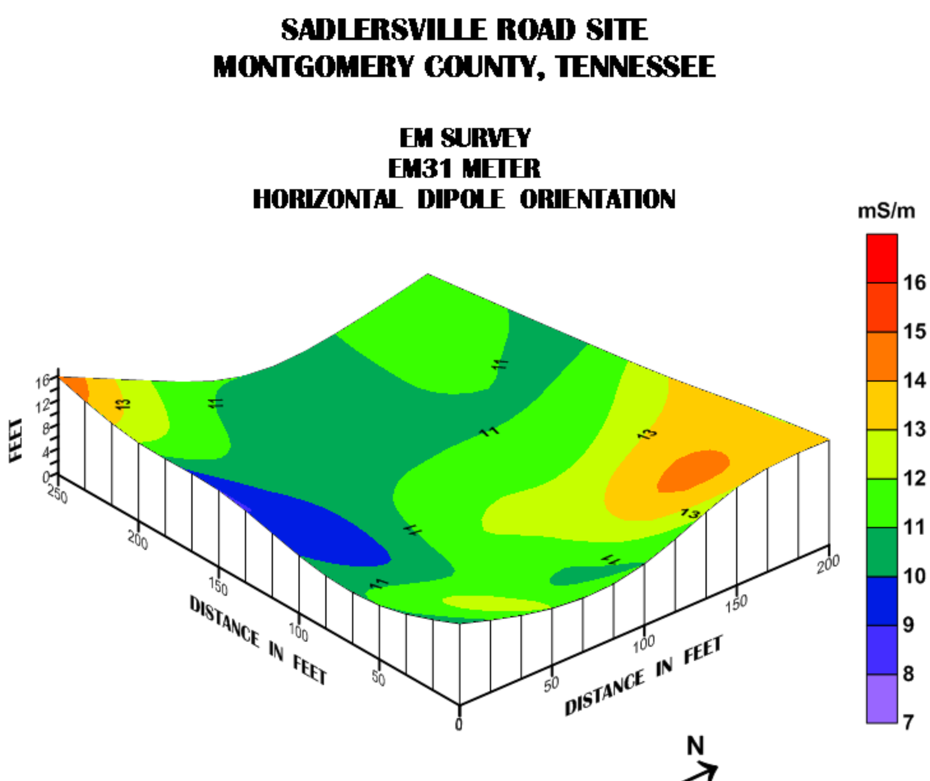


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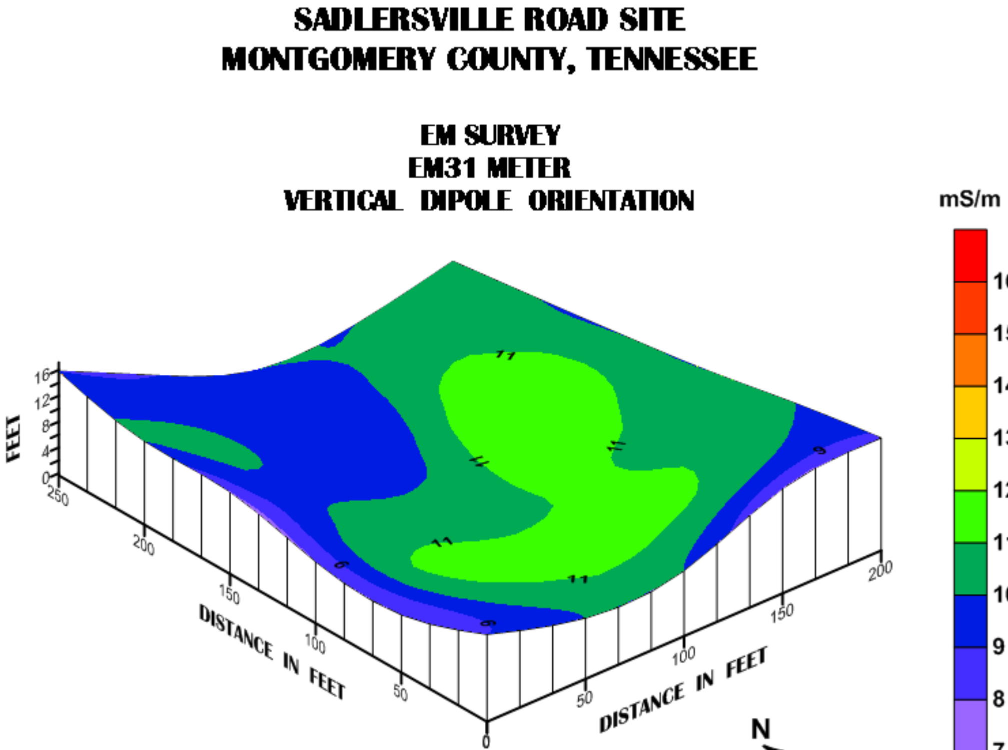


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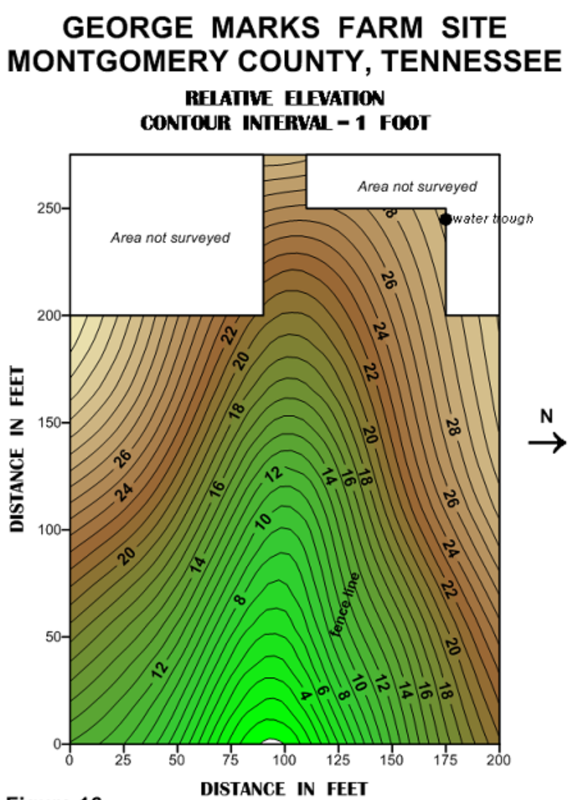


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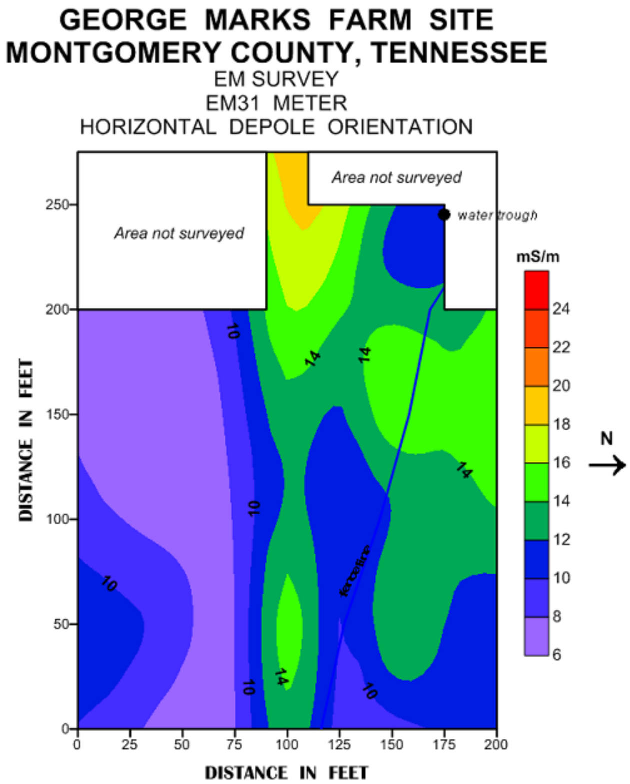


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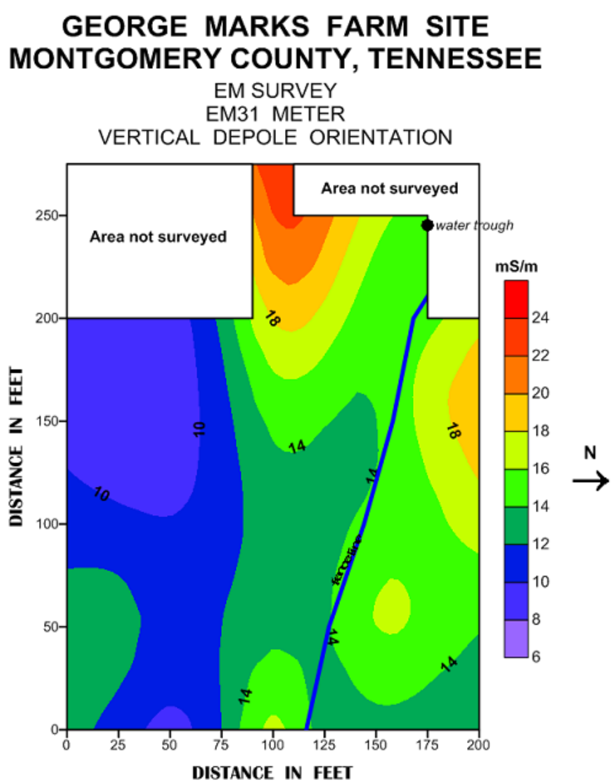



Figure 18

## GEORGE MARKS FARM SITE
## MONTGOMERY COUNTY, TENNESSEE

### EM SURVEY
### EM31 METER
### HORIZONTAL DEPOLE ORIENTATION

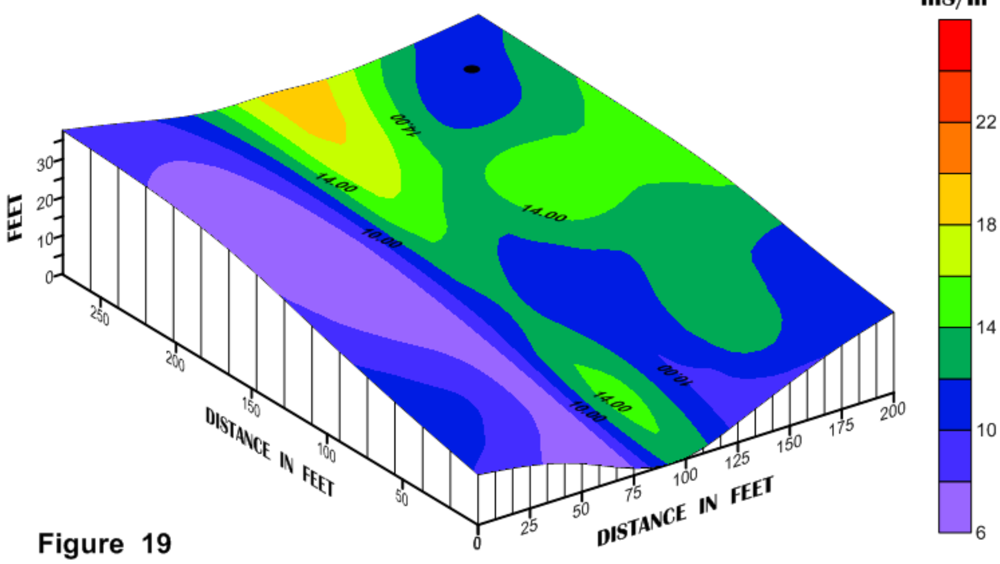
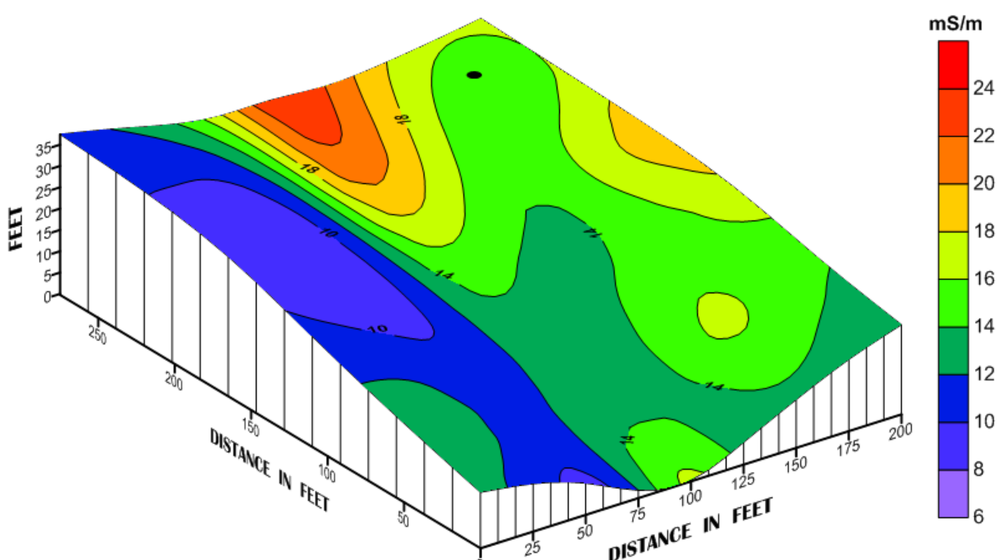



Figure 19

## GEORGE MARKS FARM SITE
## MONTGOMERY COUNTY, TENNESSEE

### EM SURVEY
### EM31 METER
### VERTICAL DEPOLE ORIENTATION

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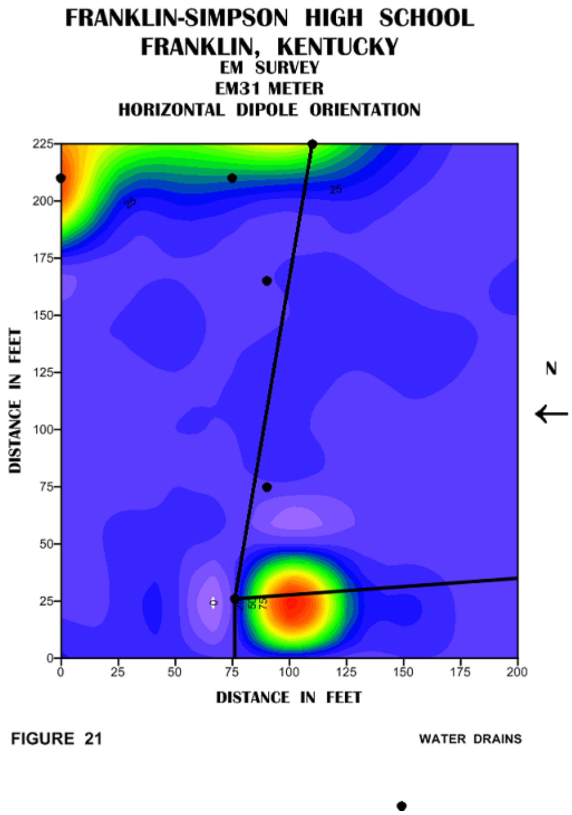


FIGURE 21

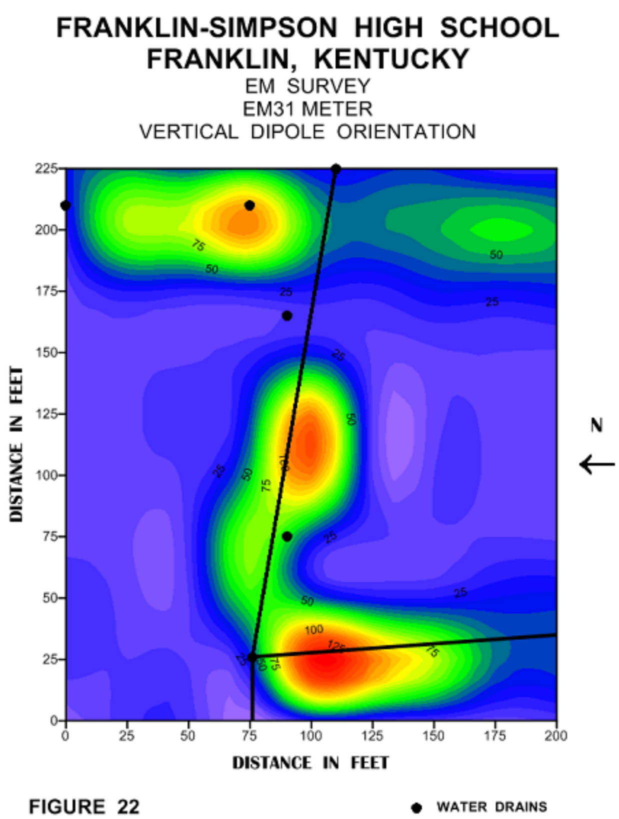


FIGURE 22

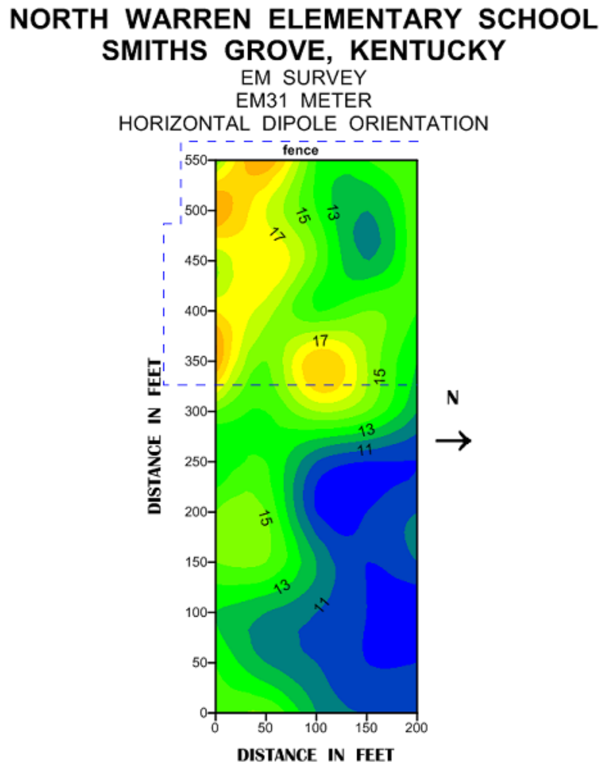


FIGURE 24

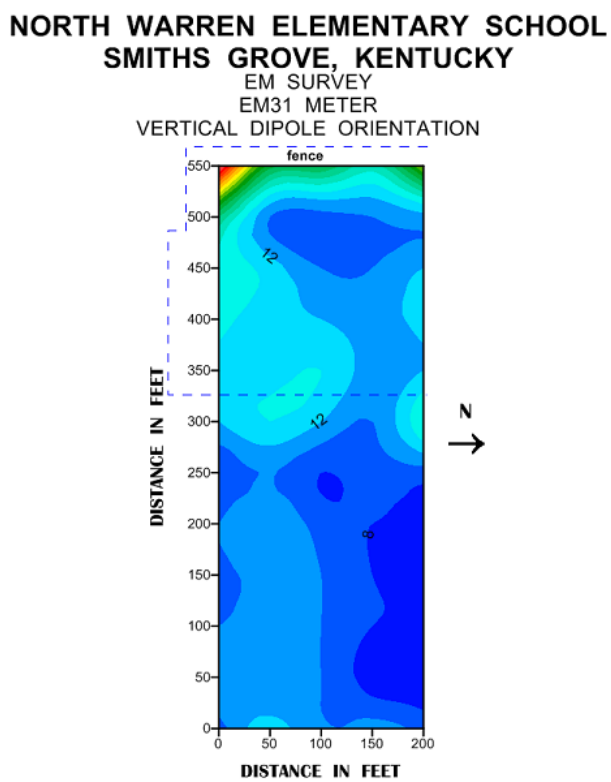


FIGURE 25

**NORTH WARREN ELEMENTARY SCHOOL**
**SMITHS GROVE, KENTUCKY**

**EM SURVEY**
**EM31 METER**
**HORIZONTAL DIPOLE ORIENTATION**

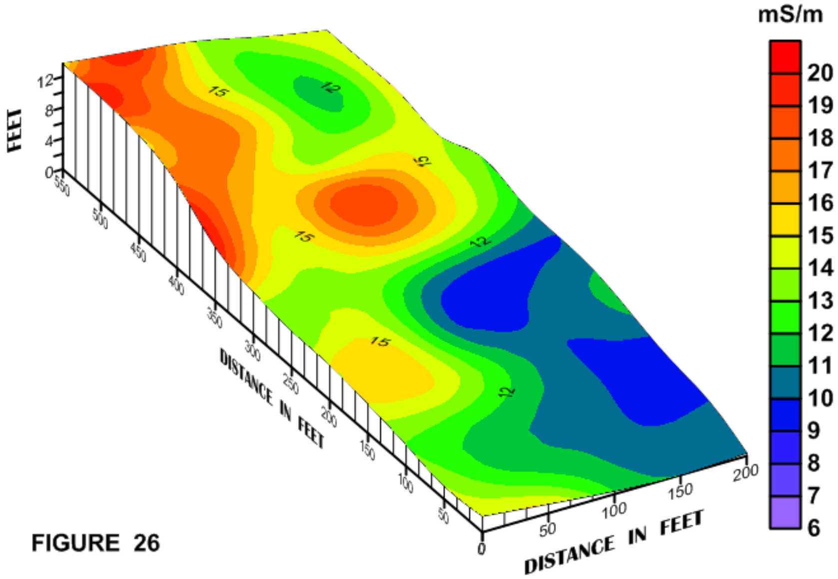


FIGURE 26

**NORTH WARREN ELEMENTARY SCHOOL**
**SMITHS GROVE, KENTUCKY**

**EM SURVEY**
**EM31 METER**
**VERTICAL DIPOLE ORIENTATION**

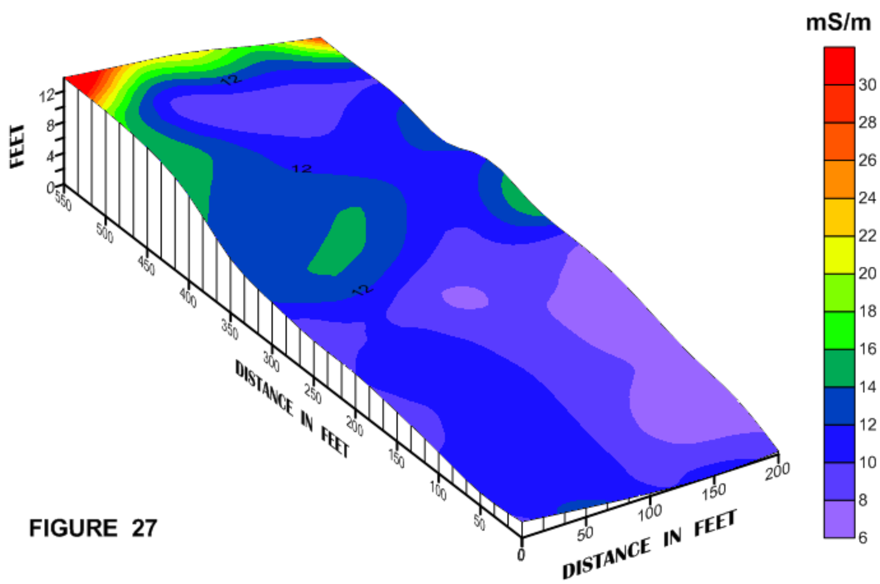


FIGURE 27