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Subject: Geophysical Assistance **Date:** 6 August 1998

To: John C. Titchner
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Purpose:
To provide electromagnetic induction (EMI) and ground-penetrating radar (GPR) field assistance. Surveys were conducted in support of on-going archaeological and animal-waste management investigations.

Participants:
Dan Delea, Geophysicist, Geophysical Survey Systems, Inc., North Salem, NH
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Dave Skinas, Archaeologist, USDA-NRCS, Berlin, VT
Randy Sterns, Soil Conservation Technician, USDA-NRCS, Middlebury, VT
Bob Thompson, Civil Engineer, USDA-NRCS, Winooski, VT

Activities:
All field activities were completed during the period of 21 to 23 July 1998.

Equipment:
The radar unit used was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.* The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A model 5103 (400 mHz) antenna was used in the archaeological investigation. The system was powered by a 12-VDC battery. The use and operation of GPR have been discussed by Morey (1974), Doolittle (1987), and Daniels and others (1988).

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 (1986). No ground contact is required with these meters. These meters provide limited vertical resolution and depth information. Lateral resolution is approximately equal to the intercoil spacing. The EM38 meter operates at a frequency of 14,600 Hz and has theoretical observation depths of about 0.75 and 1.5 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). The EM31 meter operates at a frequency of 9,800

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

Hz and has theoretical observation depths of about 3 and 6 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1980a). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

A demonstration of the new GEM-300 meter was given by Dan Delea of Geophysical Survey Systems, Inc. The demonstration was held at the David Child's site in Orange County. The GEM-300 is a new digital, multifrequency sensor. The GEM-300 is configured to simultaneously measure up to 16 frequencies between 330 and 20000 Hz with a fixed coil separation (1.3 m). Depth of observation is determined by the operating frequency and the conductivity of the soil. Mutifrequency sounding with the GEM-300 allows multiple depths to be profiled with one pass of the meter.

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.

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 contained in this report should be verified by ground-truth observations.

2. **Brady's Archaeological Site; Addison County** - The GPR detected a large number (77) of point anomalies. Many of these anomalies are believed to be artifacts. These anomalies are concentrated in the northern portion of the site. Most of these anomalies are presumed to represent buried roots, rock, and/or artifacts. Based on the survey design and radar interpretations, no major buried subsurface structure (such as a cellar or privy) exist within the survey area.

The electromagnetic induction survey revealed highly variable and intricate patterns in the northern and western portions of the study site. These patterns are presumed to reflect disturbances and possibly the presence of buried artifacts.

3. **Child's Waste Stacking Area; Orange County-** Areas of high electrical conductivity were confined largely to the stacking area. High values of apparent conductivity within the stacking area were attributed to animal wastes and the greater concentrations of specific cations and ions. Based on the results of the EMI survey, surface runoff of animal wastes from the stacking area is negligible. A plume-like pattern of high apparent conductivity extends in a southeasterly direction from the stacking area and towards a small tributary stream. Seepage of contaminants from the stacking area may be responsible for this pattern. Plots may be helpful to those contemplating the locations of monitoring wells or site assessment.

4. **Field Tests of GEM-300 Sensor; Orange County** - The field tests of the GEM-300 sensor have demonstrated that this device is easy to operate. The GEM-300 sensor collects more data in a shorter time than both the EM31 and EM38 meter. This sensor provides more comprehensive coverage of sites than the Geonics meter. All meters detected anomalously high apparent conductivity values within the stacking area. These values were attributed to the greater concentration of specific ions and cations in the animal wastes.

With the GEM-300 sensor, observation depths are dependent upon the conductivity of the soil and the selected frequency. The observation depths were ambiguous to the participants. The manufacturer's representative did not want to specify the observation depths. The lack of clarity concerning observation depths at different frequencies and the resort by the operator to relative depth scales (a lower frequency should profile deeper depths), is a major concern for use of this meter. In addition, closely similar plots were produced from GEM-300 data recorded at two frequencies (9810 and 15210 Hz). It was therefore concluded that the GEM-300 sensor appears to scan similar depths at different frequencies. It was noted that the dipole orientation appears to be a more critical factor than frequency for determining the depth of observation. The GEM-300 sensor appears to be insensitive to materials in the upper meter of the soil profile. More testing of the GEM-300 sensor is recommended.

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

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:

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Brady's Archaeological Site, Addison County -

Study Site:
This site is located on a promontory that extends into Lake Champlain. The point is north of Crane Point and immediately south of the DAR State Park on the eastern shore of Lake Champlain. Short, steep escarpments formed the western boundary of the site. Extensive erosion has occurred along this escarpment. The landowner wishes to protect the area from further erosion. The site is in a soil delineation of Vergennes clay, 2 to 6 percent slopes (Griggs, 1971). Vergennes soil is a member of the very-fine, illitic, mesic Glossaquic Hapludalfs family. This very deep, moderately well drained soil formed in calcareous glaciolacustrine clays.

Field Procedures:
An irregular shaped, 40 foot by 95 foot rectangular grid (0.07 acres) was established across the site. The grid interval was 5 feet. At each of the grid intersections survey flags were inserted in the ground and served as observation points. At each of the 151 equally spaced observation points, measurements were taken with an EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

A radar survey was completed by pulling the 400 mHz antenna along each of the nine, parallel, north-south trending, grid lines. This procedure provided about 715 feet of continuous radar imagery. Each radar profile was reviewed for anomalies. Relative distances were recorded and anomalies were identified on each radar profile.

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 surface) 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):

$$v = 2d/t$$

The velocity of propagation is principally affected by the dielectric permittivity (e) of the profiled earthen material(s) according to the equation:

$$e = (c/v)^2$$

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 earthen materials.

Calibration trials were carried out at the site. The averaged velocity of propagation through the surface layers was determined to be 0.093 m/ns. The dielectric permittivity was estimated to be 10.43 in the surface layers. Based on an average velocity of propagation of 0.093 m/ns, a scanning time of 30 ns provided a maximum observation depth of about 1.39 meter. However, because of rapid rates of signal attenuation in Vergennes soils, observation depths were restricted to depths of less than 0.5 m .

Results:

Radar Survey:

The most conspicuous anomalies (n = 77) detected with the radar are shown in Figure 1. These anomalies are concentrated in the northern portion of the site. Most of these anomalies are presumed to represent buried roots, rock, and/or artifacts. No ground-truth observations were conducted at this site to identify any of the detected, subsurface reflectors. If cultural features appear on radar profiles, they produced no unique and readily identifiable graphic signature. However, based on the survey design and radar interpretations, no major buried subsurface structure (such as a cellar or privy) exist within the survey area. In the northwest corner of the site, distinct soil layers were apparent in the upper part of three radar profiles. The location of these layers ("linear reflector") has been shown in Figure 1. These layers are located near an excavated structure. The excavated structure is located to the immediate west of the study site.

EMI Survey:

Electromagnetic induction measures vertical and lateral variations in the apparent electrical conductivity of earthen materials. Actual values of apparent conductivity are seldom diagnostic, but lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Interpretations of the EMI data are based on the identification of spatial patterns within data sets.

The EMI survey was designed to help characterize the site. Several areas with the study site contained anomalous or highly variable values of apparent conductivity.. These areas are presumed to contain dissimilar materials. Dissimilar materials could imply the locations of buried cultural features and disturbed soils. Variations in values of apparent conductivity were assumed to principally reflect variations in the depth to finer-textured materials (argillic horizon), and the presence of buried artifacts or disturbed soils.

Basic statistics for the EMI data collected within the study site are displayed in Table 1. These statistics characterize the site as being underlain by comparatively conductive materials. One-half of the observations had values of apparent conductivity between 27 and 31 mS/m in the shallower-sensing (0 to 30 inches), horizontal dipole orientation. In the deeper-sensing (0 to 60 inches), vertical dipole orientation, one-half of the observations had values of apparent conductivity between 34 and 38 mS/m. In general, values of apparent conductivity were high and increased slightly with increasing observation depths. The high values were assumed to reflect the high concentration of clays in the soil profile. The vertical trend was attributed to higher clay and moisture contents in the lower part of the soil profile.

Table 1
Basic Statistics
EMI Survey
Brady Study Site
(All values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM38	Horizontal	19	35	27	29	31	28.68
EM38	Vertical	22	42	34	37	38	35.74

Figure 2 contains two-dimensional plots of data collected with the EM38 meter in the horizontal (upper plot) and vertical (lower plot) dipole orientations. In Figure 2, the upper plot represents the spatial distribution of apparent conductivity within the upper 30 inches of the soil profile. The lower plot represents the spatial distribution of apparent conductivity within the upper 60 inches of the soil profile. In each plot, the isoline interval is 2 mS/m. Areas having anomalous, more variable, or intricate patterns are presumed to reflect disturbances and possibly the presence of buried artifacts. Highly contrasting patterns over short distances often reflect buried cultural features. These patterns are most apparent in the northern and western portions of each plot.

Agricultural-Waste Stacking Area, Orange County -

The number of dairy farms has decreased in Vermont, but the number of dairy cows has increased. The increased number of cows at concentrated sites have raised concerns regarding the potential for ground and surface water degradation. Seepage and runoff of animal wastes into ground and surface waters are associated with threats to human health and the environment. State and local regulatory agencies have required more stringent permit and monitoring requirements for the protection of surface and ground waters. In Vermont, state laws restrict the application of animal wastes to fields during the months of December through April. Stacking has been an acceptable management method for storing animal wastes during these months.

Owners and operators wish to demonstrate the low risk to the environment of animal-waste management systems. To satisfy the demands of regulators and operators, studies have been encouraged by both groups.

Potential threats to human health and the environment associated with animal-waste management systems have prompted increased attention on the methods used to assess their effectiveness and to analyze water quality. The Agricultural Waste Management Field Handbook specifies that once an animal-waste management system has been constructed, it should be monitored continuously to determine its effectiveness (Conservation Engineering Division, 1997). Monitoring provides a method to assess efficacy and to estimate solute loss and contamination risks from animal-waste management systems.

Estimates of solute loss and contamination risks from animal-waste management systems can be made using modeling methods. However, models seldom account for the variability (soils, weather patterns, animal densities and/or management practices) at specific sites and are therefore vulnerable to error.

Monitoring wells, soil coring and chemical analysis protocols provide direct measurements of contaminant levels at specific sites. Monitoring wells placed near animal-waste management systems have been used to determine the distribution of contaminant plumes caused by seepage (Collins et al., 1975). However, the number of wells is often limited and the direction of ground-water flow can not be determined from surface observations alone. As a consequence, multiple wells are often located on the sides of a waste-holding facility. Monitoring wells and sampling conventions are expensive, time consuming, and do not provide comprehensive coverage of sites (can miss contaminant plumes). The frequency of collecting samples varies with the age of the system and presumed, associated risks. By the time traces of contamination are detected in samples, the surrounding aquifer may already be adversely affected by the contaminants. Seepage does not occur uniformly around the perimeter of animal-waste management systems, but often occurs at specific, unpredictable locations (Ritter et al., 1984). Because of the nonuniform and unpredictable nature of seepage from animal-waste management systems, it is difficult to assess groundwater and surface water contamination from localized monitoring and sampling techniques. In studies conducted by Ritter and others (1984), samples from only some distant monitoring wells were contaminated. In this study (Ritter et al., 1984), contamination of the wells could not be directly linked to the waste management systems. Because of the unpredictable and site specific nature of contaminant plumes, results based on a limited number of observations can be conflicting or inconclusive. Alternative, more comprehensive sampling techniques are needed.

Electromagnetic induction (EMI) is a noninvasive geophysical tool that can be used for detailed site investigations. Advantages of EMI are its portability, speed of operation, flexible observation depths (with commercially available systems from about 0.75 to 60 m), moderate resolution of subsurface features, and comprehensive coverage. Results of EMI surveys are interpretable in the field. This geophysical method can provide in a relatively short time the large number of observations needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and siting monitoring wells.

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 observation depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the 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, 1980b). The apparent conductivity of soils 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 apparent electrical conductivity. Values of apparent conductivity are seldom diagnostic in themselves, but lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used.

Electromagnetic induction has been successfully used to investigate the migration of contaminants from waste sites (Brune and Doolittle, 1990; Drommerhausen, 1995; Eigenberg et al., 1998; Radcliffe et al., 1994; Ranjan and Karthigesu, 1995; Siegrist and Hargett, 1989; and Stierman and Ruedisili, 1988). When soils are effected by animal wastes, their conductivity will be higher than adjoining soils that are unaffected by these contaminants. Electromagnetic induction has been used to infer the relative concentration, extent, and movement of contaminants from animal-waste management systems. Electromagnetic induction does not provide a direct measurement of specific ions or compounds. However, measurements of apparent conductivity have been correlated with specific ions that are mobile in the soil and associated with animal wastes. Apparent conductivity has been correlated with concentrations of chloride, ammonia, and nitrate nitrogen in the soil (Brune and Doolittle, 1990; Ranjan and Karthigesu, 1995; Eigenberg et al., 1998).

Study Site:

The site is located near the town of Orange in Orange County. The stacking area is used to help manage the wastes from about 40 Jersey cows. At the time of this survey, soils were moist. Principal soil mapped within the site include members of the Merrimac, Buckland, and Winooski series. The very deep, somewhat excessively drained, Merrimac soil formed on terraces in stratified outwash sands and gravels. Permeability is moderately rapid or rapid in the solum, and rapid or very rapid in the substratum. Runoff is slow or medium. The Merrimac soils are members of the sandy, mixed, mesic Typic Dystrochrepts family.

The well drained and moderately well drained Buckland soil formed in glacial till. Buckland soils are shallow (0 to 20 inches) to moderately deep (20 to 40 inches) to a restrictive layer of dense till. Permeability is moderate in the solum and slow in the dense till. Runoff is medium. The Buckland soils are members of the coarse-loamy, mixed, frigid Aquic Haplumbrepts family.

The very deep, moderately well drained Winooski soil formed in alluvial deposits on flood plains. Permeability is moderate or moderately rapid. Areas of Winooski soil are subject to flooding. The Winooski soils are members of the coarse-silty, mixed, nonacid, mesic Aquic Udifluvent family.

Field Procedures:
A 400 by 500 foot, rectangular grid was established across the site. The grid interval was 50 feet. Survey flags were inserted in the ground at each grid intersection and served as observation point. The relative elevation of each grid intersection was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest measured observation point served as the 0.0 foot datum. Measurements were taken at each observation point with an EM38 meter and an EM31 meter placed on the ground surface in both the horizontal and vertical dipole orientation.

The topography of the survey area has been simulated in the two-dimensional contour plot shown in Figure 3. The contour interval is 1 foot. Relief is about 16.4 feet. The surface slopes towards the west or the lower right-hand corner of the survey area. This direction is towards the major stream, Jail Branch, that pass through the area. Based on surface observations alone, this was the presumed direction of ground-water flow. A small tributary to Jail Branch is near the right-hand (southern) border of the study site. This tributary is the nearest stream to the site. The location of the stacking area is moved each year with a restricted area. The location of the present as well as the expanded former stacking areas are shown in Figure 3 (and in each succeeding plot of the site).

Results:
Table 2 summarizes the apparent conductivity measurements recorded with the two meters and coil orientations. The averaged apparent conductivity values were lower and less variable for the shallow-sensing EM38 meter (0 to 1.5 m) than for the deeper-sensing EM31 meter (0 to 6 m). This relationship was principally associated with changes in soil water and clay contents. Negative apparent conductivity values appearing in Table 2 are presumed to reflect proximity to metallic objects.

Table 2
Basic Statistics
EMI Survey
Agricultural-Waste Stacking Area, Orange County
(All values are in mS/m)

				Quartiles			
Meter	Orientation	Minimum	Maximum	1st	Median	3rd	Average
EM38	Horizontal	-0.5	124.6	2.5	4.0	5.75	6.4
EM38	Vertical	-23.8	38.4	1.5	2.75	5.05	3.9
EM31	Horizontal	2.6	47.4	5.15	6.9	9.00	8.2
EM31	Vertical	-145.8	57.2	6.4	8.8	11.05	8.55

At the time of the survey, water was observed on some lower-lying areas. Measured values of apparent conductivity were slightly higher in these lower-lying areas. As discussed above, apparent conductivity increases with increases in water contents.

Figure 4 is a two-dimension plot of apparent conductivity within the upper 0.75 m of the soil profile. Measurements were obtained with the EM38 meter in the horizontal dipole orientation. The isoline interval is 10 mS/m. Within the site, with this meter and dipole orientation, apparent conductivity averaged 6.4 mS/m. One-half the observations had values of apparent conductivity between 2.5 and 5.75 mS/m. An area of high (greater than 15 mS/m) apparent conductivity occurs within the stacking area. The high values of apparent conductivity within the stacking area are attributed to greater concentrations of soluble salts.

In Figure 4, the area of high apparent conductivity is restricted principally to the stacking area. Based on these shallow (0 to 0.75 m) measurements, it is assumed that surface runoff of animal wastes is negligible from the stacking area.

Values of apparent conductivity are relatively invariable across the remainder of the site. Negative values are attributed to interference from metallic objects occurring in the upper part of the soil profile.

Figure 5 is a two-dimension plot of apparent conductivity within the upper 1.5 m of the soil profile. Measurements were obtained with the EM38 meter in the vertical dipole orientation. The isoline interval is 5 mS/m. Within the site, with this meter and dipole orientation, apparent conductivity averaged 3.9 mS/m. One-half the observations had values of apparent conductivity between 1.5 and 5.05 mS/m. These values are lower than those obtained with the EM38 meter in the shallower-sensing, horizontal dipole orientation. This relationship suggests that, if higher values of apparent conductivity are associated with specific ions that are mobile in the soil, ions are more concentrated in the surface layers. Manure had recently been spread across the site and was concentrated on the surface of the stacking area.

In Figure 5, an area of high (greater than 15 mS/m) apparent conductivity occurs within the stacking area. It is assumed that, within the upper 1.5 m of the soil profiles, contaminants from animal wastes are largely confined to the stacking area.

Values of apparent conductivity are relatively invariable across the remainder of the site. An area of moderate (5 to 15 mS/m) apparent conductivity occurs in the lower-lying and wetter southeast quarter of the site. These moderate values are attributed to an increase moisture content of the soil. Negative values are attributed to interference from metallic objects occurring in the profiled depths.

Figure 6 is a two-dimension plot of apparent conductivity within the upper 3.0 m of the soil profile. Measurements were obtained with the EM31 meter in the horizontal dipole orientation. The isoline interval is 5 mS/m. Within the site, with this meter and dipole orientation, apparent conductivity averaged 8.2 mS/m. One-half the observations had values of apparent conductivity between 5.15 and 9.0 mS/m. These values are higher than those obtained with the shallower-sensing EM38 meter. This relationship is assumed to principally reflect increases in clay and moisture contents with depth.

In Figure 6, an area of high (greater than 15 mS/m) apparent conductivity occurs within the stacking area. It is assumed that, within the upper 3.0 m of the soil profiles, contaminants from animal wastes are largely confined to the stacking area.

Values of apparent conductivity are relatively invariable across the remainder of the site. An area of moderate (5 to 15 mS/m) apparent conductivity occurs in the lower-lying and wetter southeast quarter of the site. These moderate values are attributed to an increase moisture content of the soil.

Figure 7 is a two-dimension plot of apparent conductivity within the upper 6.0 m of the soil profile. Measurements were obtained with the EM31 meter in the vertical dipole orientation. The isoline interval is 5 mS/m. Within the site, with this meter and dipole orientation, apparent conductivity averaged 8.55 mS/m. One-half the observations had values of apparent conductivity between 6.4 and 11.05 mS/m. These values are higher than those obtained with the EM31 meter in the shallower-sensing, horizontal dipole orientation. This relationship is believed to principally reflect increases in clay and moisture contents with depth.

In Figure 7, an area of high (greater than 15 mS/m) apparent conductivity occurs within the stacking area. Negative values within the stacking area suggest interference from buried cultural features.

In Figure 7, a plume-like pattern of higher conductivity appears to emanate from the southern portion of the stacking area. This plume-like pattern appears to extend in a southeasterly direction across the site and toward a small tributary stream. Higher concentrations of specific ions associated with animal wastes may be responsible for this pattern. This pattern was not apparent in measurements collected with the shallower-sensing (0 to 3 m) EM31 meter in the horizontal dipole orientation. It was therefore assumed that a more conductive layer occurs between depths of 3 to 6 m. This plot may be helpful to those contemplating the siting of monitoring wells or site assessments.

Values of apparent conductivity are relatively invariable across the remainder of the site. An area of moderate (10 to 15 mS/m) apparent conductivity occurs in the lower-lying and wetter southeast quarter of the site. These moderate values are attributed to an increase moisture content of the soil.

Figure 8 provides an alternative presentation of the EMI data. In each of the plots appearing in this figure, a two-dimensional plot of apparent conductivity has been overlaid upon a three-dimensional surface net diagram of the site. In each of these plots, the isoline interval is 10 mS/m. The upper plot represents data collected with the EM38 meter in the horizontal dipole orientation. The lower plot represents data collected with the EM31 meter in the vertical dipole orientation. These plots provide a different view of the data and may be of assistance to those involved with any assessment of this site.

Field Evaluation of the GEM-300 Multifrequency Electromagnetic Profiler

Background:
The National Soil Survey Center (NSSC) specializes in the use electromagnetic induction (EMI) for site and resource assessments. This noninvasive geophysical method has been used to support soil, environmental, engineering, and archaeological investigations. The NSSC actively uses this technology to support research in soil science, geomorphology, and hydrology.

The NSSC operates EMI meters developed by Geonics Limited (Mississauga, Ontario). The electromagnetic induction meters used are the EM38, EM31, and EM34-3. Basic theory and principles of operation were developed in the early 1980s by Duncan McNeill (1980a, 1980b, 1986). A new multifrequency EMI meter has been developed (Won et al., 1996) and a basic operational principle of McNeill has been refuted as a *pervasive misconception* (Won et al., 1998).

Won and others (1998) noted that the depth of exploration is not governed by the separation between the transmitter and receiver as theorized by McNeill (1980b). These researchers contend that the depth of observation can only be changed by changing the transmitter frequency. Won (1980 and 1983) has noted that observation depths are governed by the skin-depth effect: low frequency signals travel farther through conductive mediums than high frequency signal.

The new meter, Model GEM-300, is a multifrequency, one person operable meter. It can simultaneously measure up to 16, user-defined frequencies between 330 Hz and 20,000 Hz with a single coil separation (1.6 m). The operator can select the frequencies and the depths that provide the desired information and best results.

Field Procedures:
The 400 by 500 foot, rectangular grid was used to evaluate the GEM-300. Data was continuously recorded with the GEM-300 sensor as the operator walked each of the nine, 500 foot grid lines. The operator conducted two surveys (horizontal and vertical dipole orientations) of the site in less than 1 hour. Surveys were completed with the EM38 and EM31 meters in about 4 hours. With the GEM-300 sensor, the operator can pause and insert a fiduciary mark on the data record at each of the 99 survey flags (spaced at 50 foot intervals). Totals of 2025 and 2222 observations were recorded in the horizontal and vertical dipole orientation, respectively. Observations were recorded with the EM38 and EM31 meters only at the 99 grid intersections. At each observation point, the inphase, quadrature phase, and conductivity data was recorded with the GEM-300 sensor at four different frequencies (1350, 7290, 9810, and 15210 Hz). These frequencies are comparable to the EM38 meter (14600 Hz), the EM31 meter (9800), and the EM34-3 meter (not used in this survey) with an intercoil spacing of 10 m (6400 Hz) and 20 m (1600 Hz).

Results:
Conductivity data collected with the GEM-300 sensor in the vertical dipole orientation is shown in Figure 9. The frequency at which data was collected is shown above each plot. The depth of observation is assumed to increase as the frequency decreases. In each plot, a zone of higher apparent conductivity was detected within the stacking area. The actual values and spatial patterns of this zone are closely similar in each plot and at each frequency. This phenomenon is inexplicable unless the sensor is more responsive to features occurring near the surface or measures the essentially the same depth at different frequencies. Spatial patterns appear to be more complex and intricate at lower frequencies and greater observation depths. This may be due to the sensor being more responsive to background noise at lower frequencies.

In Figure 9, besides the stacking area, two conspicuous anomalies occur in the plot of the 1350 Hz conductivity data. If these anomalies are deeply buried, they may represent bedrock (composed of highly conductive materials) knobs. However, this interpretation seems dubious. A more likely interpretation is that these anomalies represent interference from shallowly buried cultural features. It is possible that these cultural features were only detectable at the lower frequency. Data recorded at 9810 Hz are closely similar to data recorded at 15210 Hz. This suggests that the sensor is profiling essentially the same depths at these two frequencies. The broad spatial patterns evident in the 7290, 9810, and 15210 Hz plots are similar and are believed to conform with the distribution of outwash and till deposits.

Figure 10 compares data collected with the GEM-300 sensor at a frequency of 15210 Hz with data collected with the EM38 meter (14600 Hz). The stacking area has been detected with each meter and dipole orientation. Geonics' meters are more sensitive to materials at the surface in the horizontal dipole orientation. The high apparent conductivity within the stacking area confirms this observation (see lower left-hand plot in Figure 10). The GEM-300 sensor is reported to be relatively insensitive to materials in the upper meter of the soil profile. The low conductivity values within the stacking area confirm this observation (see upper left-hand plot in Figure 10). In the vertical dipole orientation, the GEM-300 sensor appears to have detected a more continuous zone of moderate to high (10 to 20 mS/m) conductivity in the right-hand portion of the plot (see upper right-hand plot). This broad zone is attributed principally to increased moisture and clay contents within the substratum. This zone is not expressed in the data collected with the EM38 meter in the vertical dipole orientation. The EM38 meter has detected an area with anomalously low apparent conductivity in the upper right-hand corner of the plot. The presence of a buried cultural feature is often suggested by low values of apparent conductivity.

Figure 11 compares data collected with the GEM-300 sensor at a frequency of 9810 with data collected with the EM31 meter (9800 Hz). The stacking area has been detected with each meter and dipole orientation. The EM31 data more closely conforms with inferences of soil moisture and potential flow paths made in the field. These inferences were based on the topography of the site. At frequencies of 9810 and 15210 Hz , the GEM-300 sensor appears to scan similar depths. Comparing plots with similar dipole orientations in figures 10 and 11, data collected with the GEM-300 sensor at these two frequencies are closely similar. This suggests that dipole orientation is a more critical than frequency in determining the depth of observation or the detectability of subsurface features. In the horizontal dipole orientation, the comparatively low conductivity values within the stacking area attest to the relative insensitivity of the GEM-300 sensors to materials in the upper meter of the soil profile (see upper left hand-plot in Figure 11).

The field tests of the GEM-300 sensor have demonstrated that this device is easy to operate. The GEM-300 sensor collects more data in a shorter time than both the EM31 and EM38 meter. This sensor provides more comprehensive coverage of sites than the Geonics meter. All meters detected anomalously high apparent conductivity values within the stacking area. These values were attributed to the greater concentration of specific ions and cations in the animal wastes.

With the GEM-300 sensor, observation depths are dependent upon the conductivity of the soil and the selected frequency. The observation depths were ambiguous to the participants. The manufacturer's representative did not want to specify the observation depths. The lack of clarity concerning observation depths at different frequencies and the resort by the operator to relative depth scales (a lower frequency should profile deeper depths), is a major concern for use of this sensor. In addition, closely similar plots were produced from GEM-300 data recorded at two frequencies (9810 and 15210 Hz). It was therefore concluded that the GEM-300 sensor appears to scan similar depths at different frequencies. It was noted that the dipole orientation appears to be a more critical factor than frequency for determining the depth of observation. The GEM-300 sensor appears to be insensitive to materials in the upper meter of the soil profile. More testing of the GEM-300 sensor is recommended.

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Data Collected at David Child's Stacking Area
Orange County, Vermont

X	Y	ELEV.	EM38H	EM38V	EM31H	EM31V
0	0	3.7	4.0	3.5	4.4	7.0
50	0	3.7	3.0	3.5	5.0	7.6
100	0	3.1	4.5	5.0	6.4	9.2
150	0	3.3	2.0	4.0	7.2	9.8
200	0	2.9	5.0	4.0	5.8	9.8
250	0	1.5	4.0	6.0	10.0	11.0
300	0	0.6	4.5	8.5	10.4	12.0
350	0	0.0	7.0	7.0	11.2	13.0
400	0	1.6	0.5	2.5	9.8	10.4
0	50	5.1	2.0	1.5	3.4	6.2
50	50	5.1	2.5	1.0	4.8	6.8
100	50	4.1	3.0	2.0	6.4	9.2
150	50	5.0	3.0	3.0	6.2	8.8
200	50	2.7	3.0	2.5	8.8	11.4
250	50	0.3	13.0	11.0	13.6	12.6
300	50	0.4	2.0	10.0	13.6	13.2
350	50	1.1	-0.5	6.0	11.0	11.4
400	50	4.0	5.0	5.5	7.6	8.8
0	100	6.0	2.0	1.5	4.6	6.0
50	100	6.2	1.0	2.0	4.2	6.4
100	100	5.5	3.5	3.0	6.6	8.2
150	100	5.7	4.2	2.5	5.8	9.2
200	100	1.5	7.5	6.3	11.0	11.8
250	100	1.6	7.8	7.8	11.8	13.0
300	100	1.7	8.5	8.0	12.4	11.8
350	100	3.2	4.2	4.8	8.8	10.4
400	100	5.0	5.0	4.4	8.2	8.4
0	150	7.1	2.7	1.3	4.6	5.8
50	150	7.4	2.5	1.8	4.0	6.4
100	150	7.2	4.0	2.7	4.8	7.8
150	150	4.4	7.0	2.3	9.0	10.6
200	150	3.5	5.5	5.2	9.4	11.8
250	150	2.6	7.5	6.7	11.6	13.8
300	150	2.6	6.4	6.3	11.0	11.2
350	150	5.2	6.5	4.0	7.4	8.6
400	150	6.2	4.7	4.0	7.6	7.4
0	200	8.1	2.5	1.0	4.2	5.4
50	200	8.9	2.6	1.2	2.6	5.8
100	200	6.6	3.2	3.2	8.0	9.6
150	200	5.5	2.9	2.8	8.6	10.8
200	200	4.8	3.7	3.6	8.2	11.6
250	200	4.7	5.5	2.1	10.2	12.2
300	200	5.5	2.6	2.2	7.2	9.8
350	200	6.8	4.2	3.1	6.0	8.0
400	200	6.9	4.4	3.0	7.2	8.0
0	250	7.7	3.6	0.5	5.8	6.2
50	250	9.5	1.5	0.6	5.2	6.4
100	250	7.2	1.9	2.4	6.8	10.0
150	250	8.2	2.0	1.1	6.8	9.2
200	250	7.0	6.5	1.6	7.6	11.2

Data Collected at David Child's Stacking Area
Orange County, Vermont (continued)

X	Y	ELEV.	EM38H	EM38V	EM31H	EM31V
250	250	7.3	5.2	3.0	8.6	10.8
300	250	8.1	4.4	1.0	7.8	8.8
350	250	7.9	3.6	2.0	6.4	7.6
400	250	7.9	5.2	3.7	7.0	7.6
0	300	8.9	3.2	1.4	4.0	5.4
50	300	10.3	1.5	0.6	3.8	6.4
100	300	8.9	2.4	1.7	8.0	8.2
150	300	8.7	1.7	1.6	6.4	9.4
200	300	9.7	1.9	2.2	5.8	9.6
250	300	8.9	2.6	2.8	8.2	16.4
300	300	9.0	7.5	10.2	8.2	21.8
350	300	8.5	4.6	-1.2	6.4	7.4
400	300	8.5	3.2	2.3	6.4	7.4
0	350	10.5	2.2	0.5	4.4	5.0
50	350	11.2	2.8	1.2	4.6	5.2
100	350	11.0	6.6	3.4	8.0	6.6
150	350	10.4	22.4	1.6	10.6	10.6
200	350	11.1	48.4	14.2	40.6	-1.4
250	350	10.3	124.6	21.3	19.0	57.2
300	350	9.4	12.4	-1.3	12.2	29.0
350	350	9.0	6.2	2.6	6.8	8.4
400	350	8.7	4.0	3.2	6.8	7.8
0	400	12.6	1.8	0.3	4.2	3.8
50	400	12.4	2.2	0.4	4.8	5.0
100	400	12.6	5.5	6.4	10.0	2.4
150	400	12.8	9.8	12.4	14.2	10.2
200	400	13.0	23.0	9.6	23.0	11.2
250	400	12.4	7.7	38.4	47.4	-145.8
300	400	10.7	3.3	15.7	6.4	52.8
350	400	9.6	11.7	-23.8	9.0	15.0
400	400	9.9	5.7	3.3	7.2	7.6
0	450	15.3	2.2	0.5	3.0	3.6
50	450	13.9	2.3	1.0	2.6	4.4
100	450	14.0	4.6	2.1	5.6	7.4
150	450	14.3	9.3	7.1	10.2	12.0
200	450	14.5	11.6	7.6	9.0	3.4
250	450	12.7	5.9	4.4	7.2	10.4
300	450	12.1	3.8	2.1	6.0	10.2
350	450	10.6	5.1	4.5	5.8	21.2
400	450	10.3	6.6	6.7	8.2	23.6
0	500	16.4	2.3	1.2	3.6	3.6
50	500	16.0	1.4	0.2	3.4	4.8
100	500	15.8	4.3	1.0	3.6	5.4
150	500	15.5	4.3	5.2	7.6	8.8
200	500	15.8	3.4	2.4	6.2	7.6
250	500	14.5	1.4	1.5	4.0	7.4
300	500	11.3	3.5	2.4	6.4	7.8
350	500	11.0	4.0	2.3	5.8	6.4
400	500	10.7	5.4	3.5	5.0	10.2

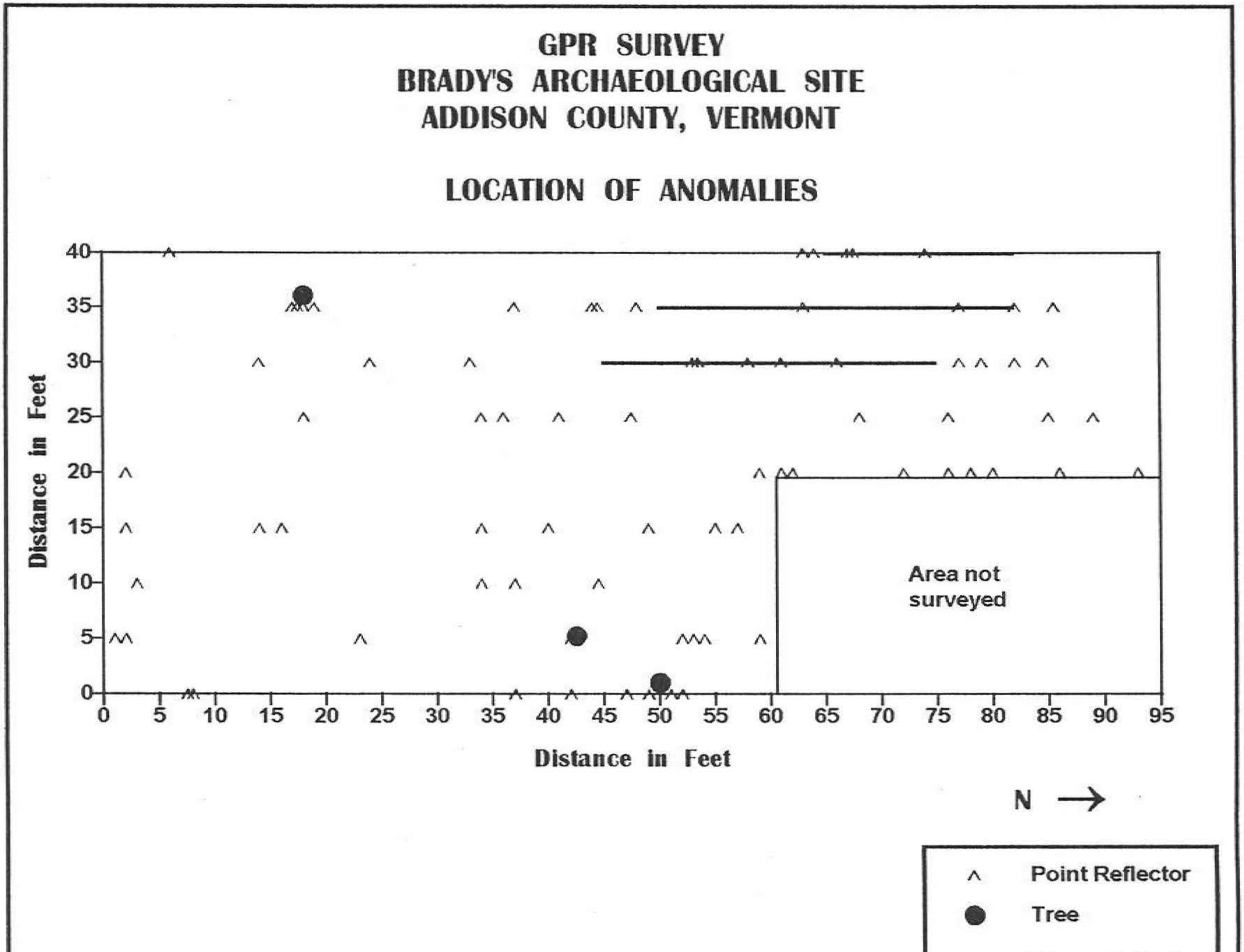
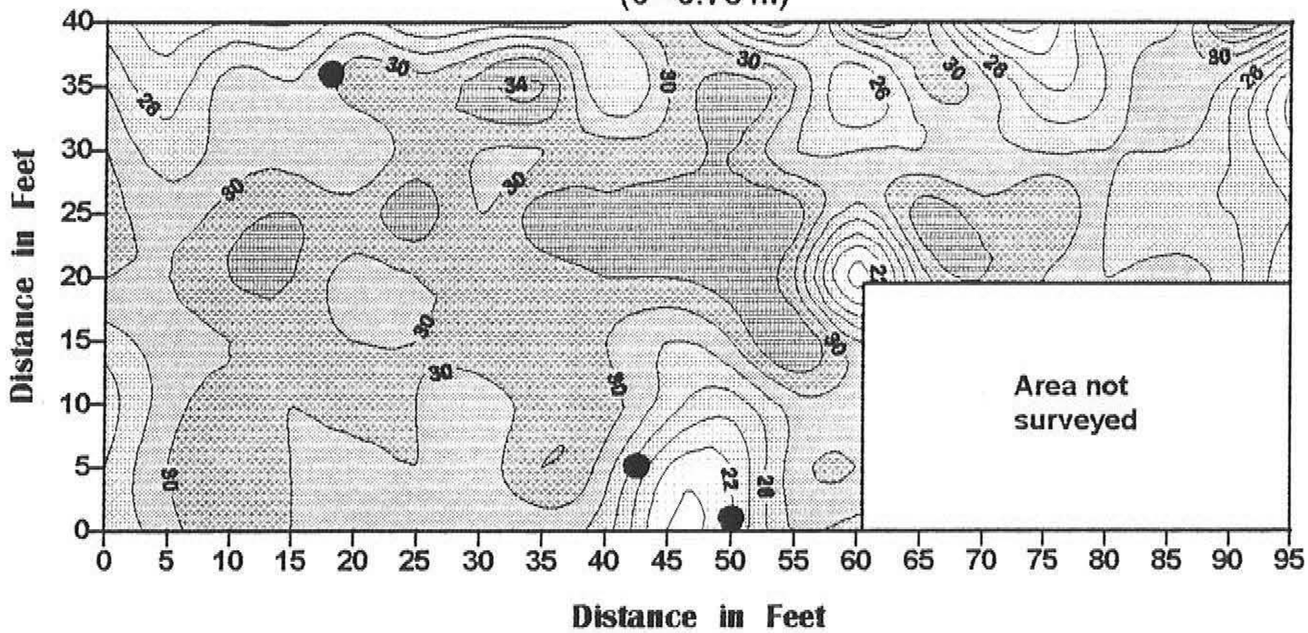

GPR SURVEY
BRADY'S ARCHAEOLOGICAL SITE
ADDISON COUNTY, VERMONT
LOCATION OF ANOMALIES
Distance in Feet
0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
Distance in Feet
Area not surveyed
N
Point Reflector
Tree
Linear Reflector

Figure 1

EM SURVEY
BRADY SITE
EM38 METER

Horizontal Dipole Orientation
(0 - 0.75 m)



N →

Vertical Dipole Orientation
(0 - 1.5 m)

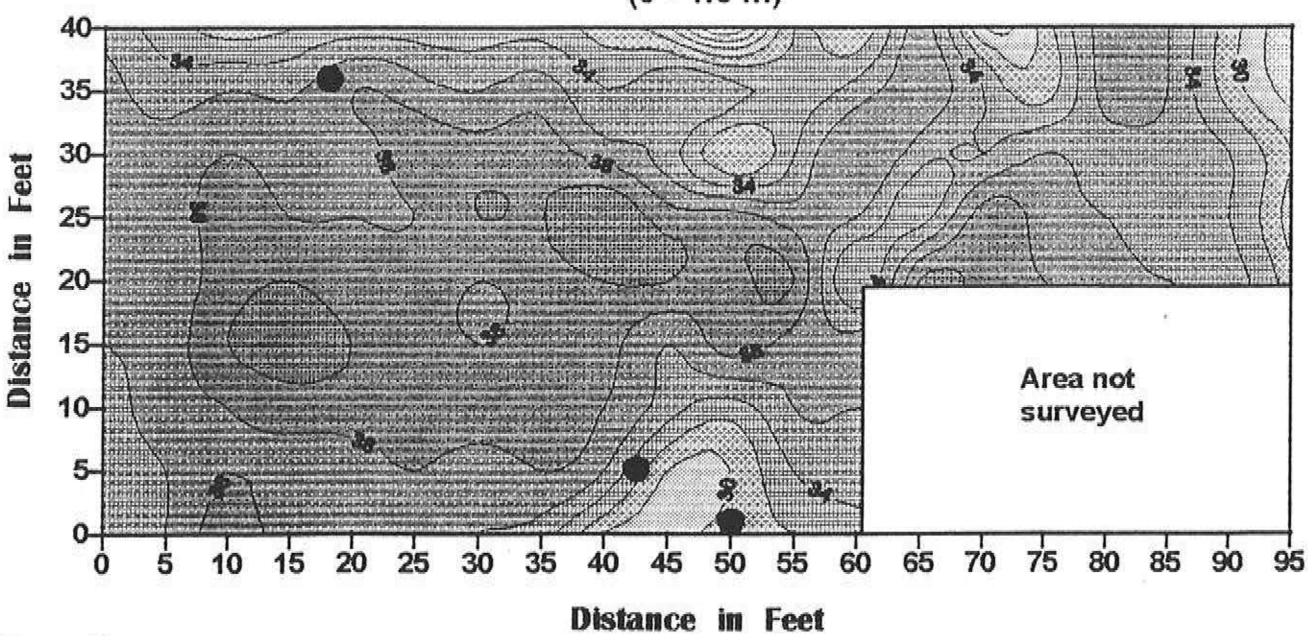


Figure 2

ANIMAL-WASTE STACKING AREA
ORANGE COUNTY, VERMONT
RELATIVE TOPOGRAPHY

Contour Interval = 1 foot

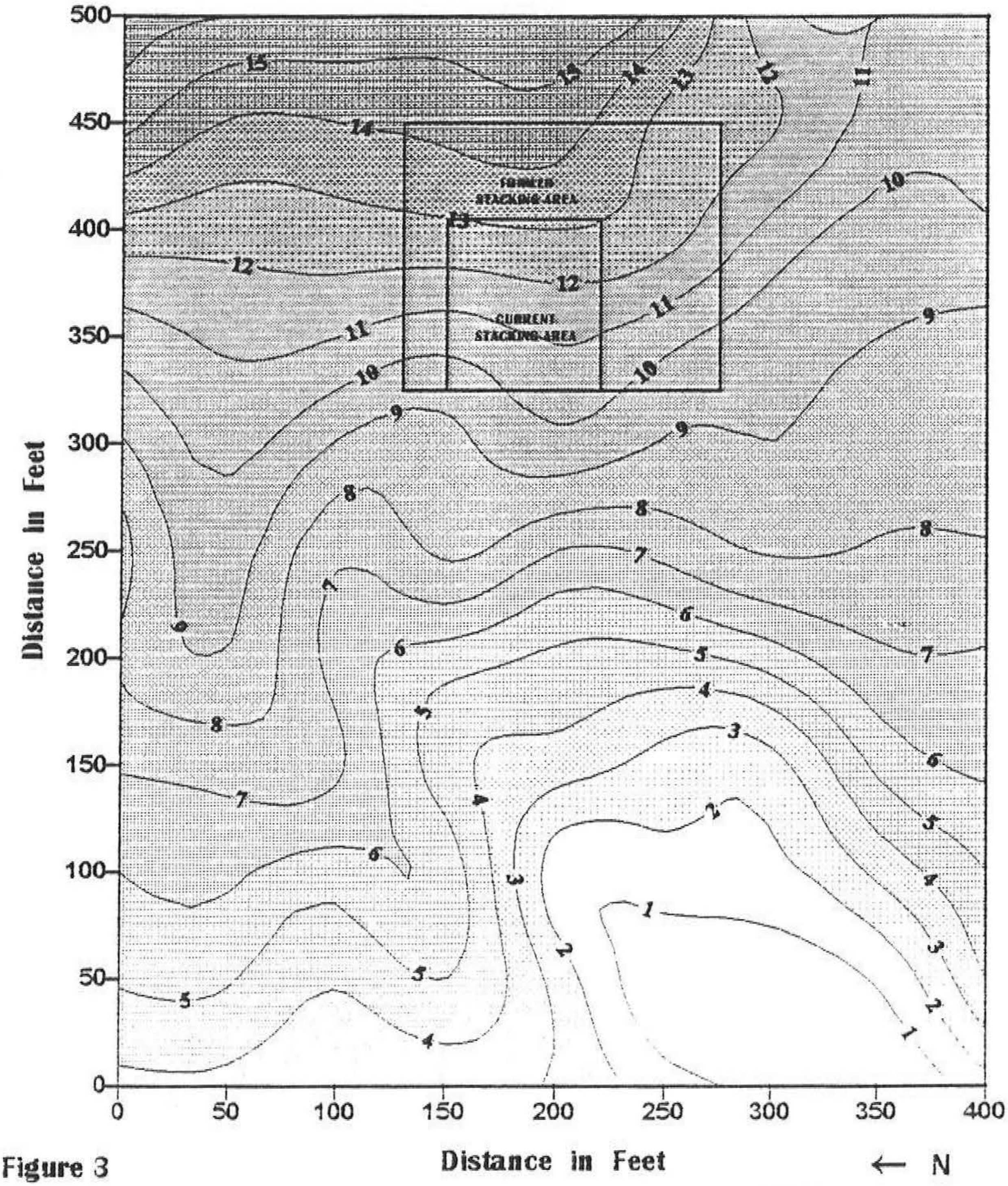


Figure 3

EMI SURVEY
ANIMAL-WASTE STACKING AREA
ORANGE COUNTY, VERMONT
EM38 METER - HORIZONTAL DIPOLE ORIENTATION

Isoline Interval = 10 mS/m

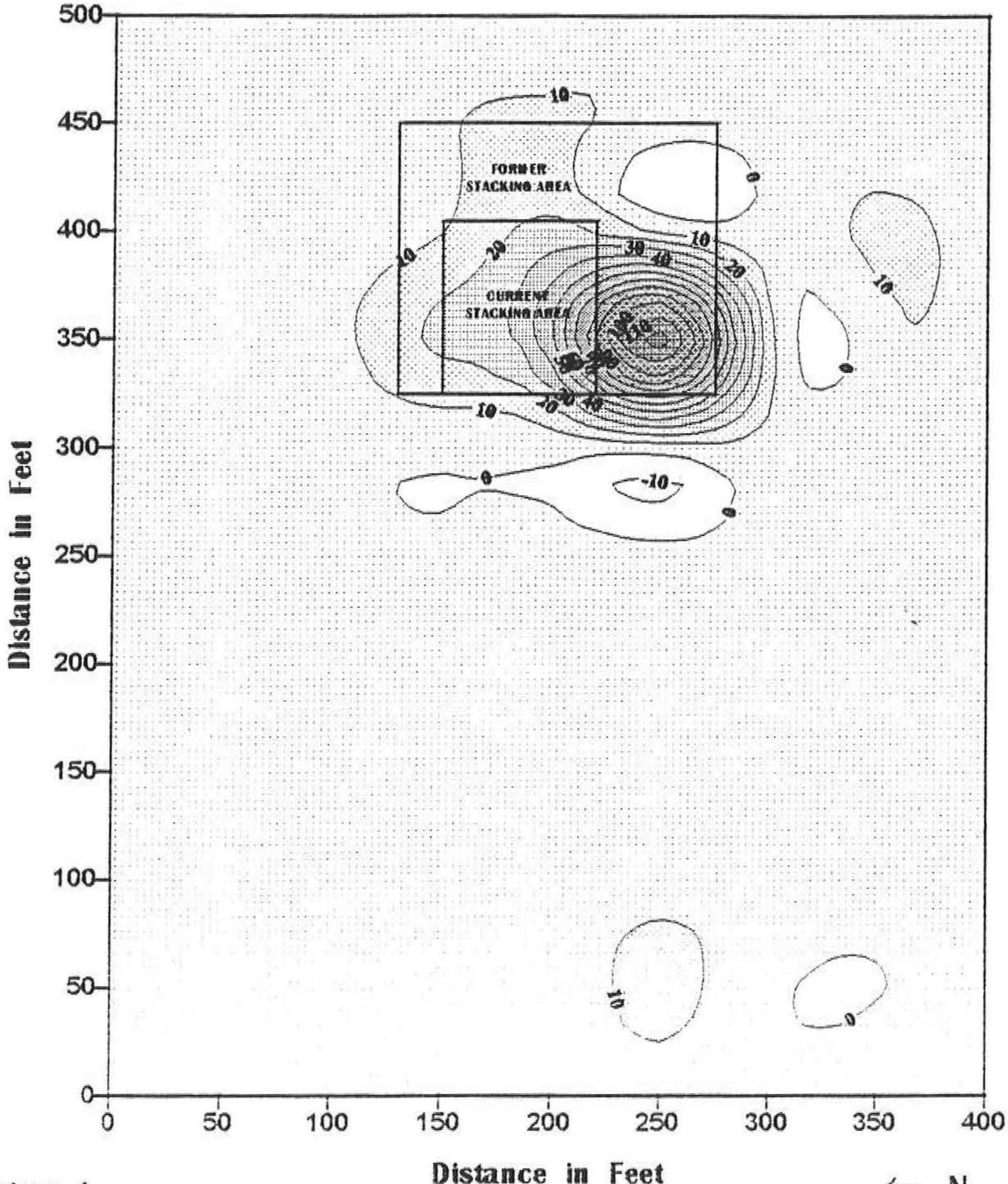


Figure 4

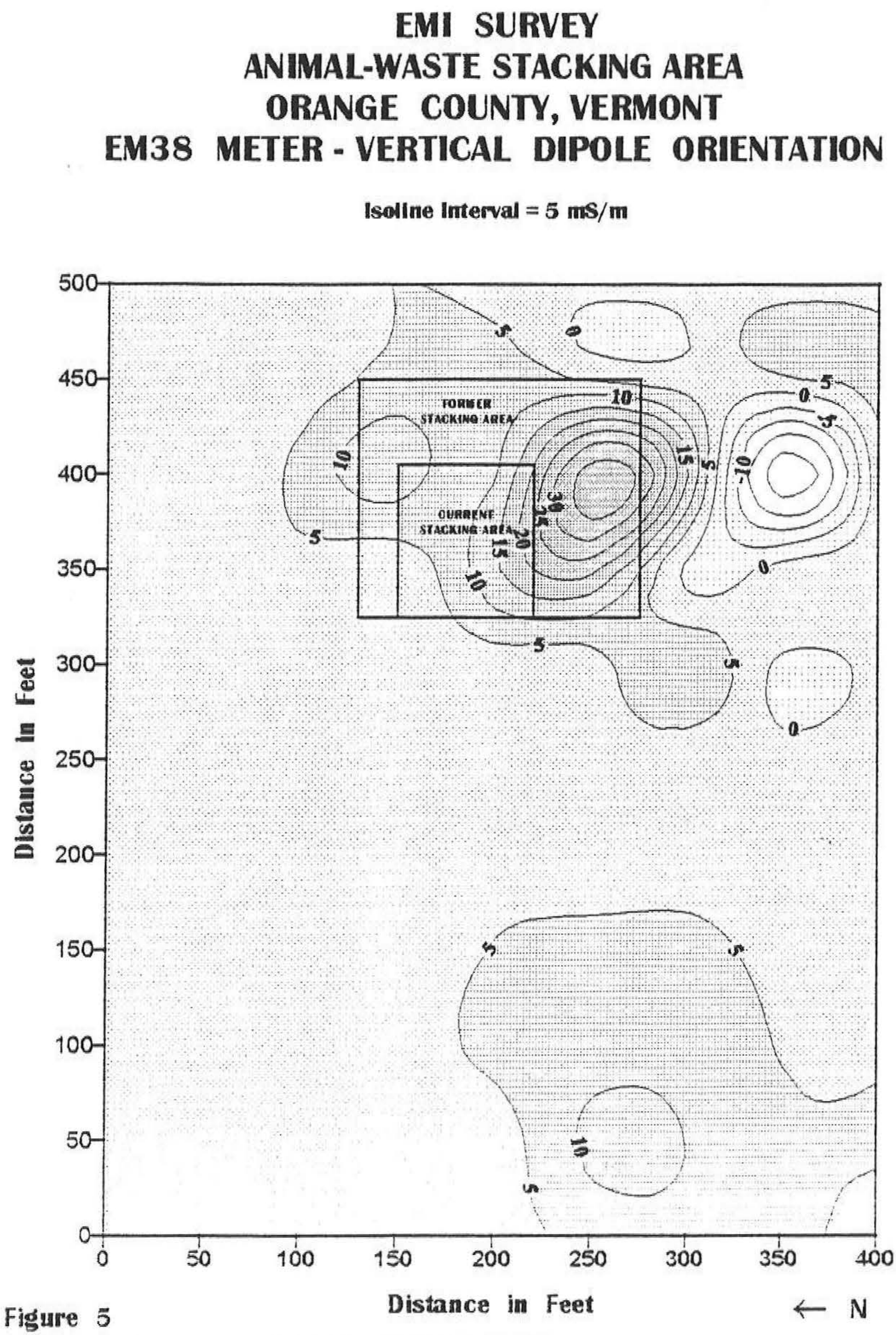

EMI SURVEY
ANIMAL-WASTE STACKING AREA
ORANGE COUNTY, VERMONT
EM38 METER - VERTICAL DIPOLE ORIENTATION
Isoline Interval = 5 mS/m
FORMER STACKING AREA
CURRENT STACKING AREA
Distance in Feet
Distance in Feet
← N
0
50
100
150
200
250
300
350
400
450
500

Figure 5

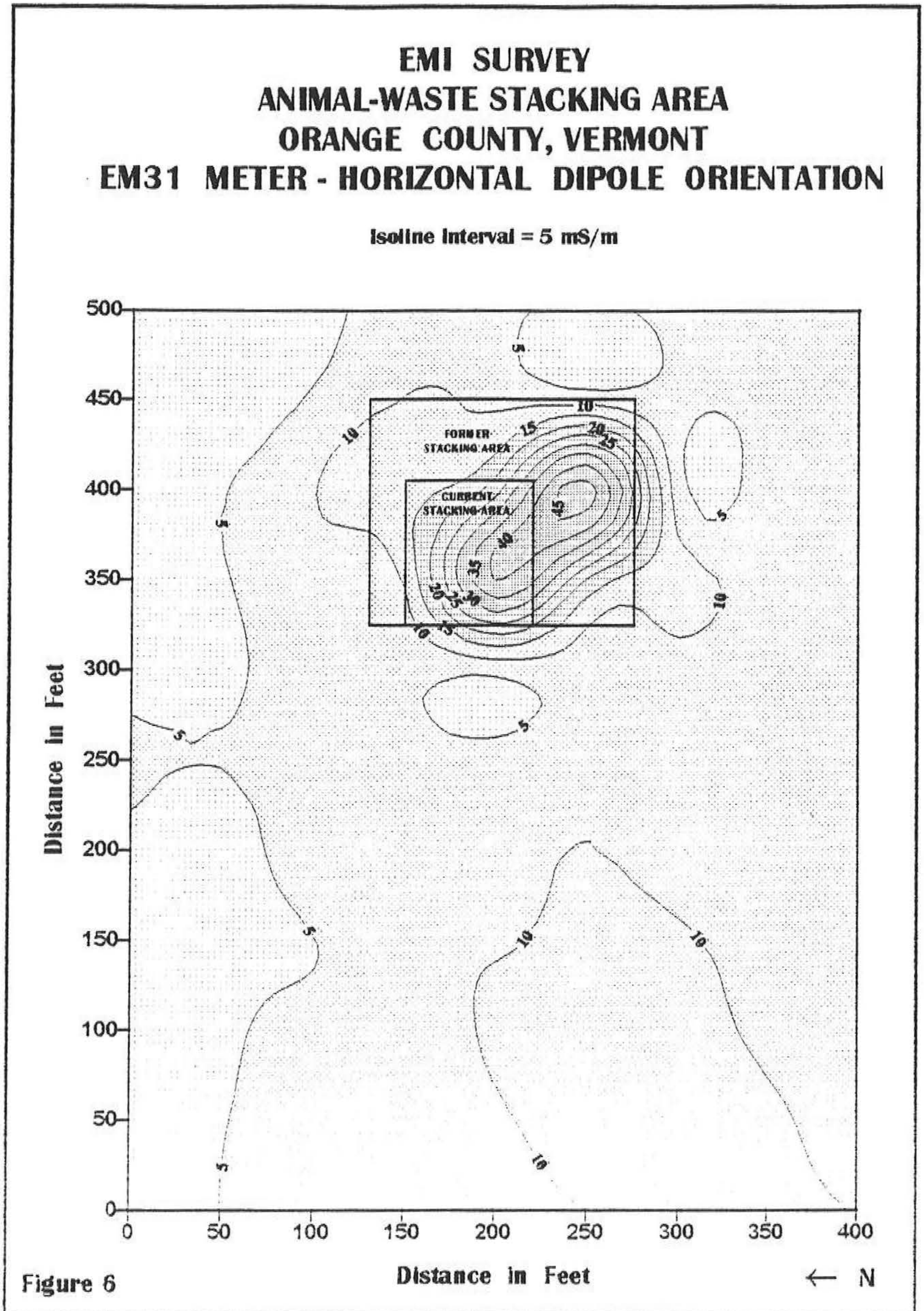

EMI SURVEY
ANIMAL-WASTE STACKING AREA
ORANGE COUNTY, VERMONT
EM31 METER - HORIZONTAL DIPOLE ORIENTATION
Isoline Interval = 5 mS/m
FORMER STACKING AREA
CURRENT STACKING AREA
Distance in Feet
Distance in Feet
← N

Figure 6

EMI SURVEY
ANIMAL-WASTE STACKING AREA
ORANGE COUNTY, VERMONT
EM31 METER - VERTICAL DIPOLE ORIENTATION

Isoline Interval = 5 mS/m

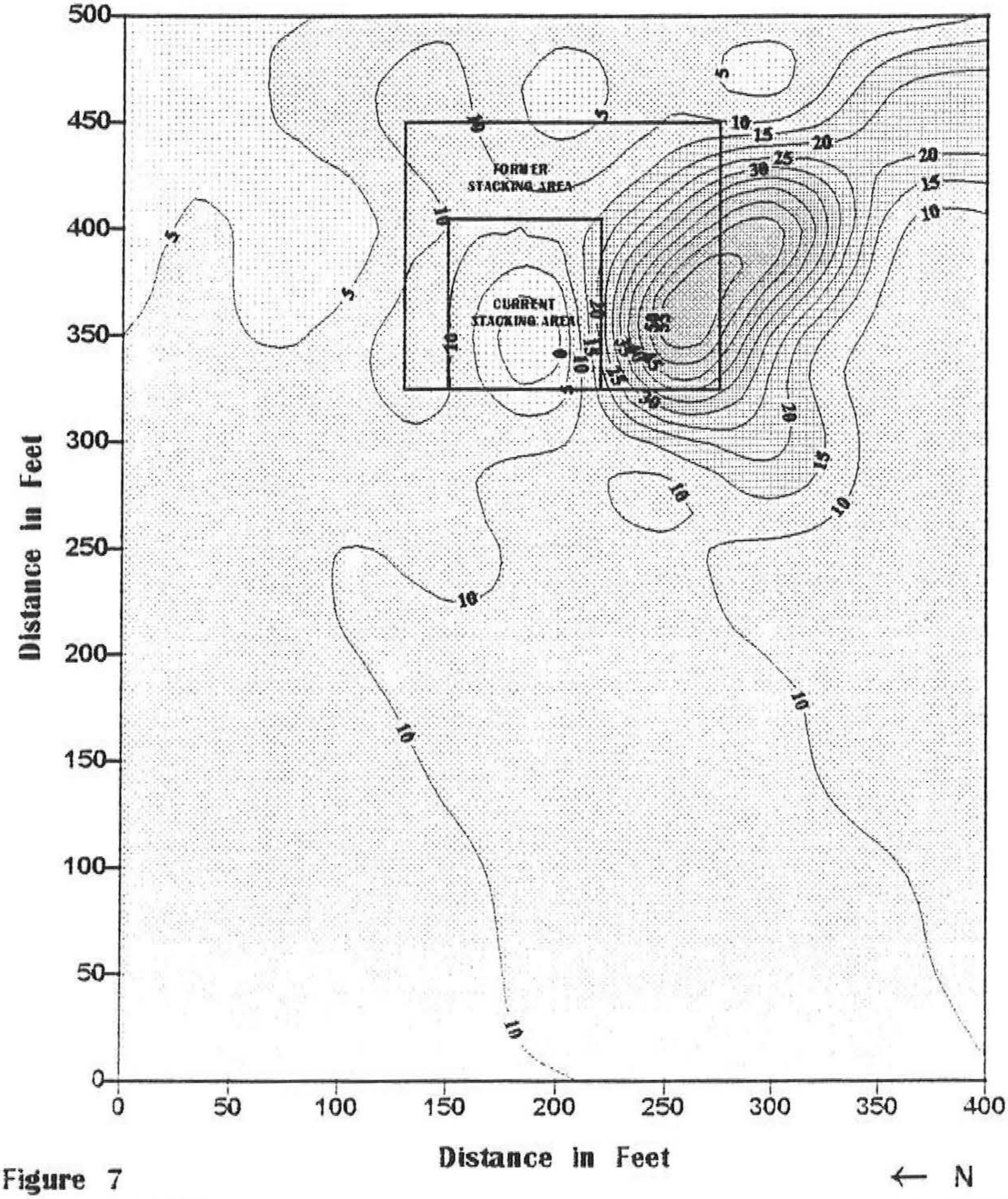


Figure 7

GEM-300 SENSOR
VERTICAL DIPOLE ORIENTATION

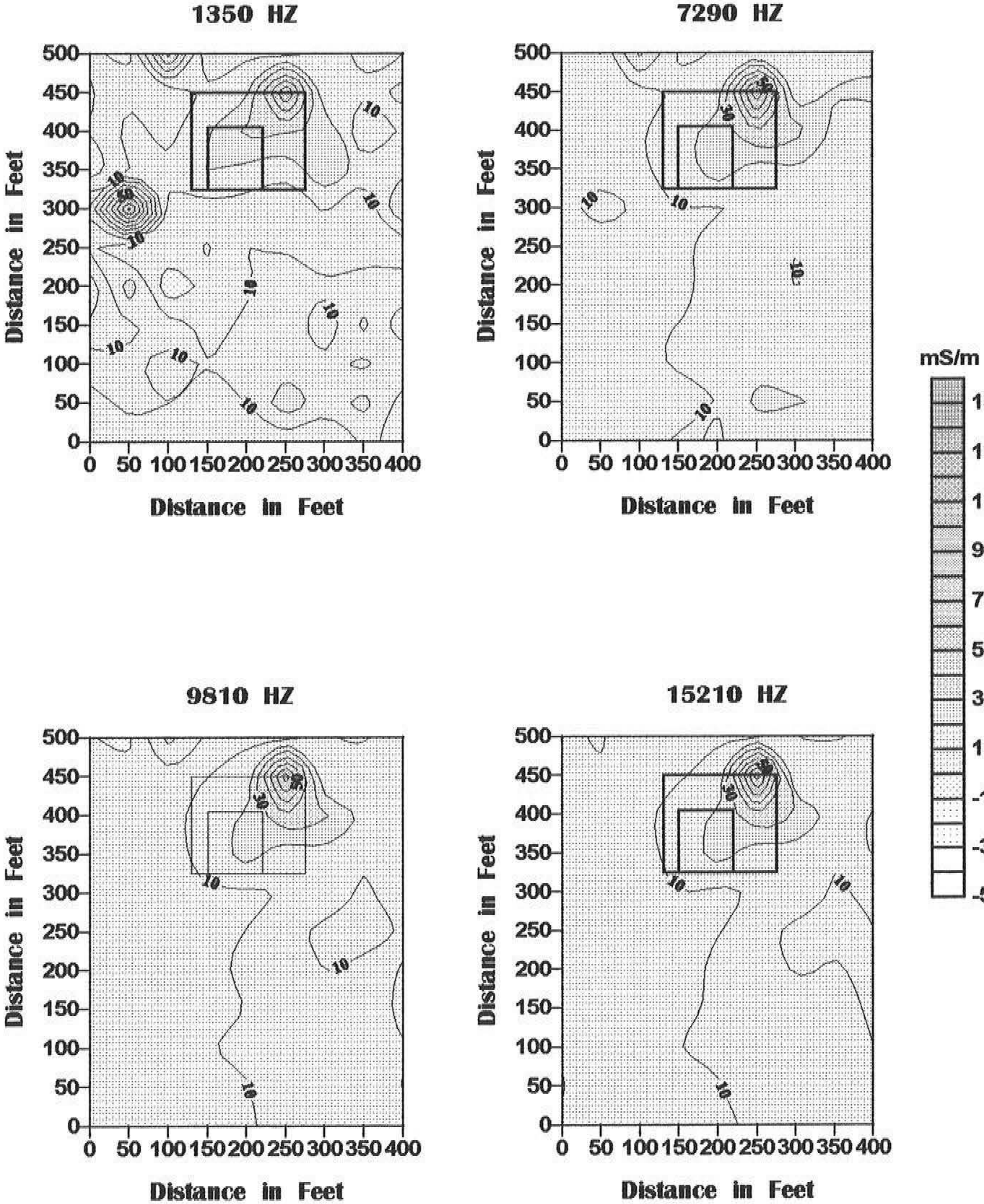


Figure 9

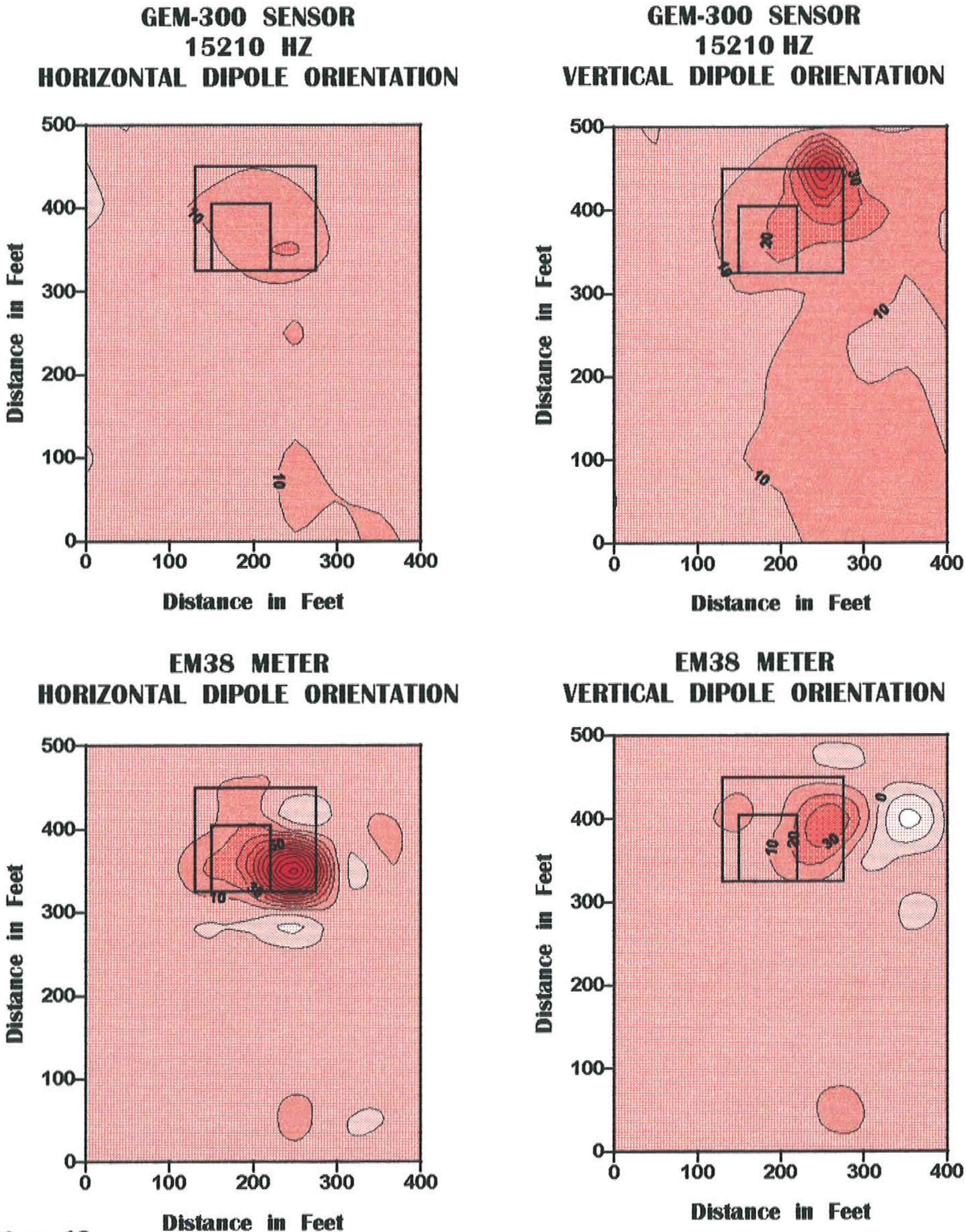

GEM-300 SENSOR
15210 HZ
HORIZONTAL DIPOLE ORIENTATION
Distance in Feet
Distance in Feet
0
100
200
300
400
500
10
GEM-300 SENSOR
15210 HZ
VERTICAL DIPOLE ORIENTATION
Distance in Feet
Distance in Feet
10
20
30
EM38 METER
HORIZONTAL DIPOLE ORIENTATION
Distance in Feet
Distance in Feet
10
30
50
EM38 METER
VERTICAL DIPOLE ORIENTATION
Distance in Feet
Distance in Feet
0
10
20
30

Figure 10

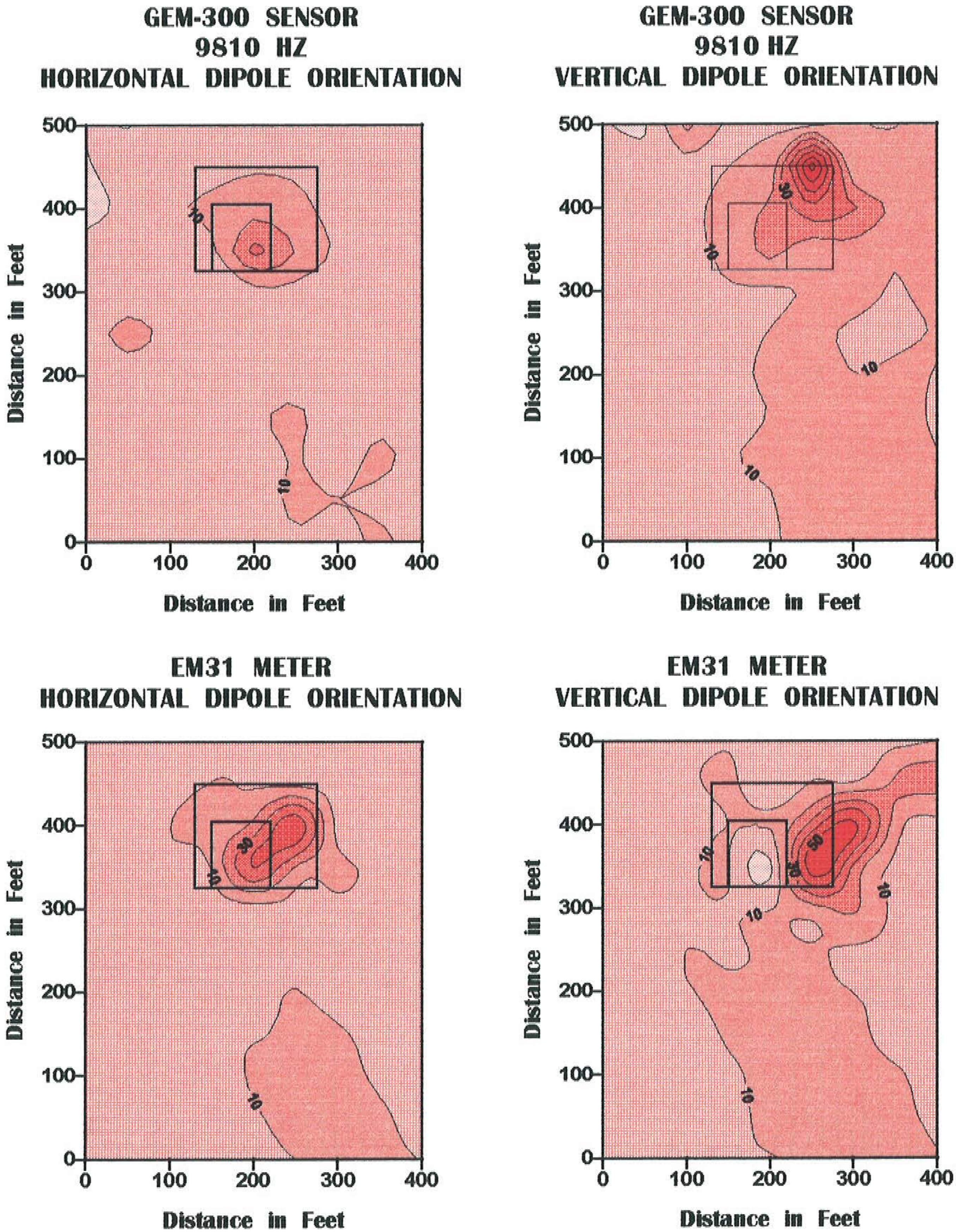

GEM-300 SENSOR
9810 HZ
HORIZONTAL DIPOLE ORIENTATION
GEM-300 SENSOR
9810 HZ
VERTICAL DIPOLE ORIENTATION
EM31 METER
HORIZONTAL DIPOLE ORIENTATION
EM31 METER
VERTICAL DIPOLE ORIENTATION
Distance in Feet
Distance in Feet
0
100
200
300
400
500
10
30
50

Figure 11