United States Department of Agriculture

Natural Resources Conservation Service

11 Campus Boulevard
Suite 200
Newtown Square, PA 19073
Phone 610-557-4233; FAX 610-557-4136

Subject: SOI-Electromagnetic Induction (EMI) Field Assistance **Date:** 5 December 2001

To: Francis M. Keeler
State Conservationist
USDA - NRCS
69 Union Street
Winooski, Vermont 05404

Purpose:
Electromagnetic induction (EMI) was used to assess potential ground and surface water contamination from agricultural wastes.

Participants:
Heather Cecchinato Soil Conservationist, USDA-NRCS, St. Johnsbury, VT
Jeff Comstock, Soil Scientist, Vermont Dept. of Agriculture, Food & Markets, Montpelier, VT
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Ben Gabos, Vermont Farm Assist Coordinator, Berlin Corners, VT
Dave Gauvin, Agricultural Engineer, USDA-NRCS, Newport, VT
Lisa Krall, Soil Scientist, USDA-NRCS, Vernon, CT
Michel Lapointe, SDA-NRCS, Morrisville, VT
Timothy McKay District Conservationist, USDA-NRCS, St. Johnsbury, VT
Kip Potter, Environmental Specialist, USDA-NRCS, Winooski, VT
Bob Thompson, Civil Engineer, USDA-NRCS, Winooski, VT

Activities:
All activities were completed during the period of 30 October to 2 November 2000.

Equipment:
A GEM300 multifrequency sensor, manufactured by manufactured by Geophysical Survey systems, Inc., was used in this study. [1] This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation (1.6 m). Won and others (1996) have described the use and operation of this sensor. With the GEM300 sensor, the penetration depth is considered "skin depth limited" rather than "geometry limited." The skin-depth represents the maximum depth of penetration and is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signal. Theoretical penetration depths of the GEM300 sensor are dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequencies. Multifrequency sounding with the GEM300 allows multiple depths to be profiled with one pass of the sensor. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

To help summarize the results of this study, SURFER for Windows (version 7.0), developed by Golden Software, Inc.,[1] was used to construct three- and two-dimensional simulations. Grids were created using kriging methods with an octant search.

Results:
1. Electromagnetic induction is suited to surface and ground water contamination studies. This method 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 assessing site conditions and for planning further investigations.

2. At the Fairmont Farm in East Montpelier, EMI surveys detected a zone of higher subsurface conductivity extending from a waste dump towards two contaminated wells. The zone of higher apparent conductivity is believed to be confined to fracture

traces in the underlying bedrock. Higher moisture and soluble salt contents are believed to be responsible for the relatively higher apparent conductivity measured within this zone. No surface source of contaminants was detectable with EMI. Because of interference from a house, road, and utility lines, no meaningful interpretation could be made in a second survey area that surrounded a nearby contaminated well.

3. At the Laggis Farm in Harwick, EMI surveys revealed a plume of higher apparent conductivity extending down slope from a lagoon but largely confined within a filter strip. The western third of this plume is in a field of corn stubble that adjoins the filter strip and receives seasonal overland flow from areas that adjoin the lagoon (concrete pad and farm structures). The plume-like pattern dissipates and becomes unrecognizable at a distance of about 300 feet from the lagoon. However, a weakly expressed zone of slightly higher apparent conductivity continues southward across the filter strip and follows the course of an intermittent watercourse. Conductivity within this zone decreases in a down slope direction. Slightly higher apparent conductivity along this weakly expressed zone is attributed to higher soil moisture contents.

4. At the Laggis Farm, an EMI survey was also completed in a cultivated field that is situated close to several contaminated wells. Differences in apparent conductivity were slight and attributed to differences in soil moisture and soil type. Differences in apparent conductivity resulting from the application of manure on this field do not appear to be measurable with EMI and were indistinguishable in simulated plots.

5. At the Brown Farm in Derby, a zone of higher apparent conductivity appears to emanate from the base of the lagoon embankment and can be traced for about 300 feet down slope. This pattern is confined to the filter strip where soil moisture contents are high. The pattern suggests excess soil moisture and possibly subsurface flow of contaminants from the lagoon. However, compared with the other surveys, apparent conductivity was low. A second survey was conducted in the vicinity of two contaminated wells. Because of interference from surrounding structures, utility and fence lines, no meaningful EMI interpretation could be made.

6. 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.

7. Kip Potter and Lisa Krall are commended for their leadership and excellent organization of these field studies.

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

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:

R. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866

J. Comstock, Vermont Dept. of Agriculture, Food & Markets, 116 State St., Montpelier, Vermont 05620

S. Gourley, State Soil Scientist, USDA – NRCS, 69 Union Street, Winooski, Vermont 05404

L. Krall, Agronomist IRTS, USDA-NRCS, 5 Godfrey Drive, Orono, ME 04473-1100

H. Smith, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250

B. Thompson, State Soil Scientist/MLRA Office Leader, USDA-NRCS, 451 West Street, Amherst, MA 01002

Electromagnetic Induction

Electromagnetic induction (EMI) 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 penetration 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 type and concentration of ions in solution, volumetric water content, 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 relative values and 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 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, and moderate resolution of subsurface features. Results of EMI surveys are interpretable in the field. This geophysical method 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 assessing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction has been used to investigate the movement of contaminants from agricultural waste sites (Bowling et al., 1997; Brune and Doolittle, 1990; Drommerhausen, 1995; Eigenberg et al., 1998; Radcliffe et al., 1994; Ranjan and Karthigesu, 1995; Siegrist and Hargett, 1989; Stierman and Ruedisili, 1988). Soils affected by animal wastes have higher apparent conductivity values 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 waste-holding facilities. 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 soils (Brune and Doolittle, 1990; Ranjan and Karthigesu, 1995; Eigenberg et al., 1998).

Fairmont Farm

The site is located in East Montpelier, Washington County. The farm is a dairy operation with about 600 cows. Several homes located along a road north of the farm have unacceptable levels (> 10 ppm) of nitrate in their wells. Fairmont Farm has ceased spreading manure in fields that adjoin these homes. EMI surveys were conducted in a field south of several contaminated wells and in an area surrounding a house with a contaminated well. The first site was mostly in hay land, but includes a field of corn stubble and some idle land. The idle land is in a draw that had been used for manure, sludge, and trash disposal.

Grid 1

The study site is located in an area that has been mapped as Vershire-Dummerston complex, 3 to 8 percent slopes. The moderately deep, well drained Vershire soil and the very deep, well drained Dummerston soil formed in loamy till over bedrock. The underlying bedrock is a member of the Waits River formation. Vershire soil is a member of the coarse-loamy, mixed, active, frigid Humic Dystrudepts family. Dummerston soil is a member of the coarse-loamy, mixed, active, frigid Typic Dystrudepts family.

A 600 by 200-ft grid was established across the field immediately north of the idle land that was formerly used for waste disposal. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 225 observation points. The relative elevation of each observation points was determined with a level and stadia rod. The lowest measured ground surface was 73.3 feet. Figure 1 is a three-dimensional surface net of the grid area. In Figure 1, the contour interval is two feet. Relief is 25.3 feet. In Figure 1, the approximate locations of the waste disposal dump and a farm lane have been shown. The waste disposal dump is located at the head of a trough that extends across the grid area from south to north. Soils in lower-lying areas of the trough are wetter and presumed to be deeper to bedrock. These factors were expected to produce slightly higher apparent conductivity measurements in the trough than on the drier, higher-lying areas that are presumably shallower to bedrock.

Measurements were taken at each observation point with a GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity (mS/m) was measured at frequencies of 6030, 9810, and 14730 Hz. A large number of negative measurements were recorded with the GEM300 sensor. Negative values reflect, in part, the resistive nature of the soils and underlying bedrock, the calibration of the GEM300 sensor, and the cool operating. As spatial patterns and relative values of apparent conductivity are important to interpretations, these negative values are not a cause for any concerns. Measurements were also obtained at this site with an EM34-3 meter using a 10-m intercoil spacing. Data were collected with this meter for comparative testing. Comparing the results of surveys conducted with the EM34-3 meter and the GEM300 sensor, spatial patterns and relative values were similar. The results of the survey collected with the EM34-3 meter are not discussed in this report.

Table 1
Basic Statistics
EMI Survey
Fairmont Farm
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H	EM34-H	EM34-3-V
Average	3.9	1.8	0.2	-1.6	-5.0	-6.7	0.7	-0.8
Minimum	-17.6	-16.4	-15.3	-14.2	-16.1	-15.3	-1.69	-75.8
Maximum	559.8	722.2	369.6	438.9	257.8	279.0	8.76	53.6
First	-6.6	-8.0	-6.9	-8.4	-10.2	-11.3	0.22	-7.92
Third	-3.5	-6.6	-3.9	-6.2	-7.6	-9.3	0.84	7.83

Table 1 summarizes the apparent conductivity measurements collected at Grid 1, Fairmont Farm. In general, values of apparent conductivity were extremely low across most of the site. Anomalously high values of apparent conductivity were recorded in the waste disposal dump and reflect the presence of metallic objects and contaminants. The range in measured apparent conductivity reflects the presence of a portion of the waste site within the grid. One half of the observations are between the first and third quartiles. As shown in Table 1, the inter-quartile range reflects the extremely low conductivity of the soil and underlying bedrock.

Figure 2 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor. In each plot, the isoline interval is 2 mS/m. All measurements have been *zero adjusted* (for each frequency, the lowest recorded value (absolute) is added to each measurement). In Figure 2, the upper plots represent data collected in the horizontal dipole orientation. The lower plots represent data collected in the vertical dipole orientation. The plot of data collected in the horizontal dipole orientation and at a frequency of 14730 Hz (see upper left-hand plot) represents the shallowest depth of penetration. The plot of data collected in the vertical dipole orientation and at a frequency of 6030 Hz (see lower right-hand plot) represents the deepest depth of penetration. In general, depths of penetration increase from left to right, and from the top to bottom rows. What is most interesting in these plots is that, with increasing depth of penetration, a linear feature of higher apparent conductivity becomes more apparent in these simulations. This linear feature extends northward from the waste disposal dump. For about 400 feet, this linear zone of higher conductivity is confined to the trough. At a distance of about 400 feet, the linear pattern bifurcates into two arms, one extends in a northwest direction, and the other extends in a northeast direction. What is most noteworthy is the fact that these arms of higher conductivity extend in the directions of the contaminated well. While the cause for these high conductivity values is presently unknown, the relatively high values and conspicuous spatial patterns suggest deeper, moister columns of soil materials. In view of the resistive nature of the adjoining soils and bedrock, the anomalously higher apparent conductivity values within the trough suggest the presence of soluble salts presumably flowing from the waste site.

At the onset of this investigation, Jeff Comstock, Soil Scientist with the Vermont Department of Agriculture, was concerned with the possible occurrence of fracture zones in the underlying bedrock and the ability of EMI to detect and map these features. EMI has been used to locate and map water-bearing fault or fracture zones in bedrock (Beeson and Jones, 1988; Edet, 1990; Hazell et al., 1988; McNeill, 1991; Olayinka, 1990). In these studies, areas of high conductivity were associated with the more weathered and moist materials within fractures. The linear and bifurcating spatial patterns apparent in Figure 2 suggest fracture zones in the underlying bedrock. If these linear patterns are fracture zones, they extend from the waste disposal dump towards two of the contaminated wells. While the higher apparent conductivity within these linear patterns may reflect deeper, moister soil materials, their significantly higher amplitudes suggest the probable presence of contaminants.

Figure 3 contains two representations of the spatial distribution of apparent conductivity measured with the GEM300 sensor. In this figure, two-dimensional plots of apparent conductivity have been overlaid upon three-dimensional surface net diagrams of the site. The upper plot represents data collected in the horizontal dipole orientation and at a frequency of 14730 Hz. This simulation represents the shallowest depth of penetration. The lower plot represents data collected in the vertical dipole orientation and at a frequency of 6030 Hz. This simulation represents the deepest depth of penetration. In each of these plots, the isoline interval is 2 mS/m. The farm lane and the waste dump are shown in each plot. These plots provide improved visualizations the relationship between apparent conductivity and the landscape. With deeper penetration a distinct channel of comparatively high apparent conductivity is detected. This channel is initially confined to the trough and extends down slopes from the waste dump. At lower elevations, this zone of higher apparent conductivity splits into two arms. The noticeably higher apparent conductivity within these two arms may be the result of lateral flow and seepage toward the surface on these lower slope positions. The higher values may reflect shallower depths and greater columns of the more highly conductive materials being averaged into the depth-weighted response of the GEM300 sensor.

Grid 2

The study site is also located in an area that has been mapped as Vershire-Dummerston complex, 3 to 8 percent slopes. This grid site was located to the northeast of Grid Site 1. A 325 by 100-ft grid was established in the area surrounding a home with a contaminated well. The well has high levels (> 10 ppm) of nitrate. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 70 observation points. The survey area included the house, well, and a township road.

Measurements were taken at each observation point with a GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity (mS/m) was measured at frequencies of 6030, 9810, and 14730 Hz. A large number of negative numbers were recorded with the GEM300 sensor in both grids. The negative values reflect, in part, the resistive nature of the soils and underlying bedrock, calibration of the GEM300 sensor, and cool operating temperatures. As spatial patterns and relative values of apparent conductivity are important to interpretations, these negative values should not cause the reader any concerns.

Table 2
Basic Statistics
EMI Survey
Fairmont Farm
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H
Average	-1.9	-1.6	-4.9	-4.6	-10.1	-8.6
Minimum	-27.4	-8.4	-33.4	-16.9	-145.3	-18.6
Maximum	97.8	107.5	47.4	56.9	22.3	29.2
First	-5.5	-6.2	-7.2	-7.4	-10.2	-10.6
Third	-3.2	-3.3	-5.0	-5.6	-8.2	-8.0

Table 2 summarizes the apparent conductivity measurements. In general, values of apparent conductivity were extremely low and largely negative across the site. Higher values were recorded adjacent to the house and reflect *cultural noise.* The range in measured apparent conductivity reflects the influence of this structure and other cultural features within the grid. One half of the observations are between the first and third quartiles. As shown in Table 2, for each frequency, the inter-quartile range reflects the extremely low conductivity of the soil and underlying bedrock.

Figure 4 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor. In each plot, the isoline interval is 1 mS/m. Measurements have not been *zero adjusted.* In each plot, the approximate locations of the house, well, and road are shown. The locations of the 70 observation points are shown in the upper left-hand plot.

In Figure 4, the upper plots represent data collected in the horizontal dipole orientation. The lower plots represent data collected in the vertical dipole orientation. The plot of data collected in the horizontal dipole orientation and at a frequency of 14730 Hz (see upper left-hand plot) represents the shallowest depth of penetration. The plot of data collected in the vertical dipole orientation and at a frequency of 6030 Hz (see lower right-hand plot) represents the deepest depth of penetration. In general, depths of penetration increase from left to right, and from the top to bottom rows. The plots do not provide evidence supporting the flow of contamination from the adjoining field (located directly south of grid) to the contaminated well. The most conspicuous patterns in these plots represent signal interference from cultural sources (structures, wells, road, utility lines, and septic fields). Because of the interference caused by cultural features within this site, spatial patterns attributable to animal wastes, if present, have been obscured. This survey highlights the limitations of EMI in urban or developed areas.

Laggis Farm in Hardwick

The site is located in Harwick, Caledonia County. The farm is a dairy operation with about 400 cows. Several homes located south of the farm have reported unacceptable levels (> 10 ppm) of nitrate in their wells. Laggis Farm has ceased spreading manure in the fields that are closest to these home sites. Two sites were surveyed with the GEM300 sensor: a filter strip that adjoins a lagoon and the cultivated field that is the closest to the contaminated wells. The filter strip was in pasture; the other survey area was in corn stubble.

The filter strip site is located in an area that has been mapped as Vershire-Dummerston complex, 8 to 15 percent slopes. The moderately deep, well drained Vershire soil and the very deep, well drained Dummerston soil formed in loamy till over bedrock. A 150 by 600-ft grid was established across the filter strip area. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 175 observation points. The filter strip is located immediately south and southeast of the lagoon. The filter strip contains a small intermittent watercourse that flows under a township road (beyond the limits of this survey) and into a swamp. The swamp is located down slope and to the east and northeast of several homes with contaminated wells.

The relative elevation of each observation points was determined with a level and stadia rod. The lowest measured ground surface was 71.4 feet. Figure 5 is a three-dimensional surface net diagram of the grid area. In Figure 5, the contour interval is two feet. Relief is about 22 feet.

Measurements were taken at each observation point with a GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity (mS/m) was measured at frequencies of 6030, 9810, and 14730 Hz. Once again, a large number of negative numbers were recorded with the GEM300 sensor. The negative values reflect, in part, the resistive nature of the soils and underlying bedrock, the calibration of the GEM300 sensor, and the cool operating temperatures. As spatial patterns and relative values of apparent conductivity are important to interpretations, these negative values should not be a cause of concern.

Table 3 summarizes the apparent conductivity measurements collected in the filter strip. Values of apparent conductivity were largely negative or extremely low across the site. In general, apparent conductivity values increased slightly with decreasing frequency and increasing penetration depths. For all frequencies, the highest apparent conductivity values were recorded in the area that is immediately down slope of the lagoon. This area was noticeably wetter than other portions of the survey area. Higher apparent conductivity values in this portion of the survey area are believed to reflect increased moisture and soluble salt contents. One half of the observations are between the first and third quartiles. As shown in Table 3, the inter-quartile range reflects the extremely low conductivity of the soil and underlying bedrock.

Table 3
Basic Statistics
EMI Survey
Filter Strip, Laggis Farm
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H
Average	-2.8	-0.4	-4.2	-3.8	-7.6	-7.9
Minimum	-7.5	-2.8	-7.4	-6.5	-11.0	-10.2
Maximum	0.7	3.0	-0.2	-1.5	-3.4	-5.5
First	-4.3	-1.4	-5.7	-4.7	-9.3	-8.9
Third	-1.2	0.5	-2.6	-2.9	-5.8	-7.1

Figure 6 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor. The upper row of plots represents data collected with the GEM300 sensor in the horizontal dipole orientation. The lower row of plots represents data collected with the GEM300 sensor in the vertical dipole orientation. In each plot, the isoline interval is 1 mS/m. All apparent conductivity measurements have been *zero adjusted* (for each frequency, the lowest recorded value (absolute) is added to each measurement). In Figure 6, the locations of the 175 observation points are shown in the upper left-hand plot. Also shown in upper row of plots is the approximate location of the lagoon (please note the reversal in the orientations of the survey areas in figures 5, 6, and 7).

The plot of data collected in the horizontal dipole orientation and at a frequency of 14730 Hz (see upper left-hand plot) represents the shallowest depth of penetration. The plot of data collected in the vertical dipole orientation and at a frequency of 6030 Hz (see lower right-hand plot) represents the deepest depth of penetration. In general, depths of penetration increase from left to right, and from the top to bottom rows. In each plot, a plume-like area of higher apparent conductivity extends outwards and down slope from the lagoon. Within this plume-like area, the highest values of apparent conductivity are adjacent to the lagoon. The plume extends about 300 feet due south of the lagoon. The western third of this plume is in a field of corn stubble that adjoins the filter strip and receives season overland flow from the areas that adjoin the lagoon (concrete pad and farm structures). The plume-like pattern dissipates and becomes unrecognizable at a distance of about 300 feet from the lagoon. A fragmented zone of slightly higher apparent conductivity continues southward following the course of an intermittent watercourse. This zone becomes almost indistinguishable near the southern edge of the survey area and the most downstream portion of the watercourse. Within the watercourse, values of apparent conductivity though low, non-uniform and fragmented, are slightly higher than values recorded on adjoining upland areas. This difference is believed to principally reflect differences in soil moisture content.

Figure 7 contains two representations of the spatial distribution of apparent conductivity measured with the GEM300 sensor. In this figure, two-dimensional plots of apparent conductivity have been overlaid upon three-dimensional surface net diagrams of the site. The upper plot represents the data collected in the horizontal dipole orientation and at a frequency of 14730 Hz. This plot represents the shallowest depth of penetration. The lower plot represents the data collected in the vertical dipole orientation and at a frequency of 6030 Hz. This plot represents the deepest depth of penetration. In each of these plots, the isoline interval is 1mS/m. These plots may help the reader to better visualize the relationship between apparent conductivity and the landscape.

<u>Cultivated Field</u>

A cultivated field on the Laggis Farm that is located nearest to the contaminated wells was also surveyed. The cultivated field is located in an area that has been mapped as Dummerston very fine sandy loam, 8 to 15 percent slopes. A 150 by 475-ft grid was established across the southern end of the field. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 140 observation points. Woodlands enclose the field on the south and west. The affected wells are located to the southeast of the southern woodland.

The relative elevation of each observation points was determined with a level and stadia rod. The lowest measured ground surface was 70.8 feet. Figure 8 is a three-dimensional surface net of the grid area. In Figure 8, the contour interval is two feet. Relief is about 36 feet.

Table 4
Basic Statistics
EMI Survey
Cultivated Field, Laggis Farm
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H
Average	-2.8	-0.4	-4.2	-3.8	-7.6	-7.9
Minimum	-7.5	-2.8	-7.4	-6.5	-11.0	-10.2
Maximum	0.7	3.0	-0.2	-1.5	-3.4	-5.5
First	-4.3	-1.4	-5.7	-4.7	-9.3	-8.9
Third	-1.2	0.5	-2.6	-2.9	-5.8	-7.1

Measurements were taken at each observation point with a GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity (mS/m) was measured at frequencies of 6030, 9810, and 14730 Hz. Table 4 summarizes the apparent conductivity measurements obtained within the cultivated field. In general, values of apparent conductivity were very low and invariable across the site. One half of the observations are between the first and third quartiles. As shown in Table 4, the inter-quartile range reflects the low conductivity of the soil and underlying bedrock, the calibration of the GEM300 sensor, and the cool operating temperatures. Apparent conductivity increased slightly with decreasing frequency and increased penetration depths.

Figure 9 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor within the cultivated field. All measurements obtained with the GEM300 sensor have been zero adjusted (for each frequency, the lowest value (absolute) was added to the recorded measurements). The left-hand plots represent data collected with the GEM300 sensor in the horizontal dipole orientation. The right-hand plots represent data collected with the GEM300 sensor in the vertical dipole orientation. The plots are arranged in rows by frequency. In each plot, the isoline interval is 2 mS/m. Because of the low range in apparent conductivity within this site, alternative colors have been used in these plots to help emphasize the weak spatial patterns and trends.

In each plot, apparent conductivity is highest in the right-hand and lowest in the left-hand portions of the survey area. These spatial patterns are believed to principally reflect differences in topography, soil moisture, and soil type. The right-hand portion of the survey area contains the lowest elevations, is more imperfectly drained and presumably deeper to bedrock. The left-hand portion contains the highest elevations, is better drained, and probably shallower to bedrock. The effects of the application of manure on this field are not detectable with EMI. Differences in apparent conductivity resulting from the application of manure to this field do not appear to be measurable with EMI and are indistinguishable in these plots.

Figure 10 contains two representations of the spatial distribution of apparent conductivity measured with the GEM300 sensor. In this figure, two-dimensional plots of apparent conductivity have been overlaid upon three-dimensional surface net diagrams of the site. The upper plot represents the data collected in the horizontal dipole orientation and at a frequency of 14730 Hz. This plot represents the shallowest depth of penetration. The lower plot represents the data collected in the vertical dipole orientation and at a frequency of 6030 Hz. This plot represents the deepest depth of penetration. In each of these plots, the isoline interval is 2 mS/m. These plots may help the reader to better visualize the relationship between apparent conductivity and the landscape.

Sand Mound Septic Field

The site is located across the road from the previously discussed sites on the Fairmont Farm, East Montpelier, Washington County. The survey area was located immediately up slope (south) of two sand mound systems. The site is in hay land. The grid site is located in an area that has been mapped as Buckland silt loam, 8 to 15 percent slopes. The moderately deep to a densic contact and very deep to bedrock, moderately well drained Buckland soil formed in dense, loamy till on uplands. Buckland soil is a member of the coarse-loamy, mixed, semiactive, frigid Aquic Dystric Eutrudepts family.

A 300 by 100-ft grid was established across the area. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 65 observation points. The relative elevation of each observation points was determined with a level and stadia rod. The lowest measured ground surface was 91.7 feet. Figure 11 is a three-dimensional surface net diagram of the topography within the survey area. In Figure 11, the contour interval is one foot. Relief is 11.2 feet. The approximate locations of two sand mound systems have been shown.

Table 5
Basic Statistics
EMI Survey
Sand Mound Septic Fields
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H
Average	-1.8	-5.2	-2.9	-6.3	-6.2	-9.2
Minimum	-5.0	-7.9	-5.1	-8.3	-8.4	-11.5
Maximum	4.1	-1.7	2.4	-2.9	-0.8	-5.7
First	-3.3	-6.3	-4.5	-7.1	-7.6	-10.1
Third	-1.3	-4.3	-2.2	-5.4	-5.1	-8.8

Measurements were taken at each observation point with a GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity (mS/m) was measured at frequencies of 6030, 9810, and 14730 Hz. A large number of negative numbers were recorded with the GEM300 sensor. As spatial patterns and relative values of apparent conductivity are meaningful to interpretations, these negative values should not cause the reader any concerns.

Table 5 summarizes the apparent conductivity measurements. In general, values of apparent conductivity were negative or extremely low, and relatively invariable across the site. The range in measured apparent conductivity reflects the resistive nature of the soils and underlying bedrock, the calibration of the GEM300 sensor, and the cool operating temperatures. Apparent conductivity increased slightly with decreasing frequency and increased penetration depths.

Figure 12 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor at the Sand Mound Site. In this figure, all measurements have been *zero adjusted* (for each frequency, the lowest recorded value (absolute) is added to each measurement). The left-hand plots represent data collected with the GEM300 sensor in the shallow-sensing, horizontal dipole orientation. The right-hand plots represent data collected with the GEM300 sensor in the deeper-sensing, vertical dipole orientation. The plots are arranged in rows by frequency. In each plot, the isoline interval is 2 mS/m. The relative locations of the two sand mounds have been shown in the plots of the data that were collected at 6030 Hz (lower pair of plots). Because of the low range in apparent conductivity within this site, alternative colors have been used in these plots to help emphasize weak spatial patterns and trends.

In Figure 12, the plot of data collected in the horizontal dipole orientation and at a frequency of 14730 Hz (see upper left-hand plot) represents the shallowest depth of penetration. The plot of data collected in the vertical dipole orientation and at a frequency of 6030 Hz (see lower right-hand plot) represents the deepest depth of penetration. In general, depths of penetration increase from top to bottom in the left-hand and then right-hand rows. Patterns are similar in each plot and principally reflect differences in soil moisture and soil type. The upper left-hand portion of each plot is the lowest lying and the more imperfectly drained portion of the survey area. Apparent conductivity is highest in this portion of the survey area and is believed to reflect higher soil moisture contents. Apparent conductivity values are not conspicuously higher in this portion of the survey area to contemplate contaminants from the sand mounds.

Figure 13 contains two representations of the spatial distribution of apparent conductivity measured with the GEM300 sensor. In this figure, two-dimensional plots of apparent conductivity have been overlaid upon three-dimensional surface net diagrams of the site. The upper plot contains data collected in the horizontal dipole orientation and at a frequency of 14730 Hz and represents the shallowest depth of penetration. The lower plot contains data collected in the vertical dipole orientation and at a frequency of 6030 Hz and represents the deepest depth of penetration. In each of these plots, the isoline interval is 1 mS/m. The affect of topography on soil moisture content and apparent conductivity is apparent in each plot. In the right-hand portion (west) of these plots, the higher apparent conductivity is believed to principally reflect wetter soil conditions, deeper depths to bedrock, and/or differences in soil types. However, because of its proximity to a sand mound and location between the sand mound and a nearby house (south of grid area), seepage of contaminants, though considered improbable, can not be ruled out.

Brown Farm

Brown Farm is located in Derby, Orleans County. The farm is a dairy operation with about 60 cows. Two areas were surveyed with the GEM300 sensor: the area between farm structures and a home with contaminated wells, and a filter strip that adjoins a lagoon. The filter strip was in pasturage.

The two study areas were located in an area that has been mapped as Vershire-Glover complex, 3 to 8 percent slopes, rocky. The moderately deep, well drained Vershire soil and the very deep, somewhat excessively Glover soil formed in loamy till over bedrock. Glover soil is a member of the loamy, mixed, active, frigid Humic Lithic Dystrudepts family.

<u>Area between Barn and House</u>

A 150 by 200-ft grid was established in the area between farm structures and a home with a contaminated well. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 63 observation points. A township road and a farm lane crossed the grid area. The grid area was crisscrossed by several utility lines, fences, and was bordered by both the barn and farmstead. These features interfered with the electromagnetic fields of the GEM300 sensor and produced unwanted noise.

The relative elevation of each observation points was determined with a level and stadia rod. The lowest measured ground surface was 97.8 feet. Figure 14 is a three-dimensional surface net diagram of the topography within the grid area. In Figure 14, the contour interval is one foot. Relief is 9.8 feet. In Figure 14, the approximate locations of the road, farm lane, and wells have been shown.

Measurements were taken at each observation point with a GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity (mS/m) was measured at frequencies of 6030, 9810, and 14730 Hz. Table 6 summarizes the apparent conductivity measurements obtained within the survey area. In general, values of apparent conductivity were very low and invariable across most of the site. However, measurements obtained adjacent to the barns and the farmstead were more extreme. These extreme values were attributed to interference induced by these features. In general, values of apparent conductivity were essentially invariable with dipole orientations and frequency.

Table 6
Basic Statistics
EMI Survey
Sand Mound Septic Fields
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H
Average	-7.8	-5.2	-8.4	-8.8	-9.8	-8.0
Minimum	-33.8	-33.1	-28.3	-35.4	-25.4	-39.5
Maximum	134.2	55.2	69.7	26.3	37.0	20.9
First	-14.7	-10.2	-14.4	-13.8	-14.6	-13.3
Third	-7.0	-2.9	-4.9	-4.0	-7.6	-5.4

Figure 15 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor. Measurements have not been *zero adjusted.* The left-hand plots represent data collected with the GEM300 sensor in the shallower-sensing, horizontal dipole orientation. The right-hand plots represent data collected with the GEM300 sensor in the deeper-sensing, vertical dipole orientation. The plots are arranged in rows by frequency. In each plot, the isoline interval is 1 mS/m. The relative locations of the road, farm lane, and wells have been shown in each plot.

No recognizable spatial patterns that can be attributed to the migration of contaminants are discernible in the plots shown in Figure 15. Based on the information that is available at this time no meaningful interpretations can be made about this site.

<u>Filter Strip</u>

A 200 by 400-ft grid was established across the filter strip area that adjoins a waste-holding lagoon. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation points. This procedure provided 153 observation points.

The relative elevation of each observation points was determined with a level and stadia rod. The lowest measured ground surface was 69.1 feet. Figure 16 is a three-dimensional surface net of the topography within the grid area. The approximate location of the lagoon has been shown in this plot. In Figure 16, the contour interval is two feet. Relief is 23.6 feet. The grid area contains a partially enclosed basin with saturated soils on lower slope positions.

Measurements were taken at each observation point with a GEM300 sensor held at hip-height in both the horizontal and vertical dipole orientations. Apparent conductivity (mS/m) was measured at frequencies of 6030, 9810, and 14730 Hz. Table 7 summarizes the apparent conductivity measurements obtained within the filter strip. At first glance, values of apparent conductivity appear variable across the site. However, much of this variability is attributed to interference induced by the metallic fence that enclosed the lagoon. In Table 7, negative values reflect, in part, the resistive nature of the soils and underlying bedrock, the calibration of the GEM300 sensor, and the cool operating temperatures.

Figure 17 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the GEM300 sensor. Measurements have been *zero adjusted.* The upper plots represent data collected with the GEM300 sensor in the shallower-sensing, horizontal dipole orientation. The lower plots represent data collected with the GEM300 sensor in the deeper-sensing, vertical dipole orientation. The plots are arranged in columns by frequency. In each plot, the isoline interval is 2 mS/m. The relative location of the lagoon is shown in the upper plots.

Table 7
Basic Statistics
EMI Survey
Filter Strip at Brown's Farm
(All values are in mS/m)

	6030V	6030H	9810V	9810H	14730V	14730H
Average	-6.2	-4.6	-4.4	-4.8	-6.6	-7.3
Minimum	-21.5	-24.1	-18.1	-17.5	-17.5	-16.5
Maximum	13.1	57.6	11.8	36.7	8.3	21.4
First	-9.9	-7.9	-8.1	-8.3	-11.1	-11.4
Third	-2.4	-1.4	-0.8	-1.5	-2.7	-3.2

In Figure 17, the plot of data collected in the horizontal dipole orientation and at a frequency of 14730 Hz (see upper left-hand plot) represents the shallowest depth of penetration. The plot of data collected in the vertical dipole orientation and at a frequency of 6030 Hz (see lower right-hand plot) represents the deepest depth of penetration. In general, depths of penetration increase from left to right, and from the top to bottom row. High values of apparent conductivity were recorded near the lagoon. A chain link fence surrounds the lagoon. The fence caused interference and produced anomalous values. At the base of the embankment of the lagoon, a linear zone of higher conductivity extends down slope and away from the lagoon. This pattern occurs in areas of more imperfectly drained soils and reflects, in part, higher moisture contents and differences in soil type. However, values in excess of 26 mS/m probably reflect significant concentrations of soluble salts. The portion of this zone that contains these high values is restricted to the grid area and the upper 250 to 275 feet of filter strip. This zone is better expressed in the plots of data collected at low frequencies and suggests possible deeper layers of more conductive materials.

In Figure 18, two-dimensional plots of apparent conductivity have been overlaid upon three-dimensional surface net diagrams of the filter strip. The upper plot represents data collected in the horizontal dipole orientation and at a frequency of 14730 Hz. This plot represents the shallowest depth of penetration. The lower plot represents data collected in the vertical dipole orientation and at a frequency of 6030 Hz. This plot represents the deepest depth of penetration. In each of these plots, the isoline interval is 2 mS/m. The affect of topography on soil moisture content and apparent conductivity is apparent in each plot. A zone of noticeably higher apparent conductivity is evident in the lower plot. This zone appears to emanate from the base of the lagoon embankment and can be traced for about 275 feet down slope. This pattern suggests possible subsurface flow of contaminants from the lagoon. Ground truth observations are needed to confirm these interpretations.

References

Beeson, S. and R. C. Jones. 1988. The combined EMT/VES geophysical method for siting boreholes. Ground Water 26:54-63.

Bowling, S. D., D. D. Schultz, W. E. Wolt. 1997. A geophysical and geostatistical method for evaluating potential surface contamination from feedlot retention ponds. ASAE Paper 972087. ASAE, St. Joseph, MI. 20 p.

Brune, D. E. and J. A. Doolittle. 1990. Locating lagoon seepage with radar and electromagnetic survey. Environ. Geol. Water Sci. 16:195-207.

Drommerhausen, D. J., D. E. Radcliffe, D. E. Brune, and H. D. Gunter. 1995. Electromagnetic conductivity survey of dairies for groundwater nitrate. J. Environmental Quality, 24: 1083-1091.

Edet, A. E. 1990. Application of photogeologic and electromagnetic techniques to groundwater interpretations in northwestern Nigeria. Journal of African Earth Sciences 11:321-328.

Eigenberg, R. A., R. L. Korthals, and J. A. Nienaber. 1998. Geophysical electromagnetic survey methods applied to agricultural waste sites. J. Environmental Quality, 27:215-219.

Greenhouse, J. P., and D. D. Slaine. 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2): 47-59.

Hazell, J., C. Cratchley, and A. Preston. 1988. The location of aquifers in crystalline rock and alluvium in northern Nigeria using combined electromagnetic and resistivity techniques. Quarterly Journal of Engineering Geology, London 21:159-175.

Kachanoski, R. G., E. G. Gregorich, and I. J. van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

McNeill, J. D. 1980. Electromagnetic terrain conductivity measurements at low induction numbers. Technical Note TN-6. Geonics Ltd., Mississauga, Ontario. 15 p.

McNeill, J. D. 1991. Advance in electromagnetic methods for groundwater studies. Geoexplorations 27:65-80.

Olayinka, A. I. 1990. Electromagnetic profiling for groundwater in Precambrian basement complex areas of Nigeria. Nordic Hydrology 21:205-216.

Radcliffe, D. E., D. E. Brune, D. J. Drohmerhausen, and H. D. Gunther. 1994. Dairy loafing areas as sources of nitrate in wells. p. 307-313. IN: Environmentally Sound Agriculture: Proceedings of the Second Conference. 20-24 July 1994. American Society of Agricultural Engineers. St. Joseph, MI.

Ranjan, R. S., and T. Karthigesu. 1995. Evaluation of an electromagnetic method for detecting lateral seepage around manure storage lagoons. ASAE Paper 952440. ASAE, St. Joseph, MI.

Rhoades, J. D., P. A. Raats, and R. J. Prather. 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soc. Am. J. 40:651-655.

Siegrist, R. L. and D. L. Hargett. 1989. Application of surface geophysics for location of buried hazardous waste. Water Management and Research 7:325-335.

Stierman, D. L. and L. C. Ruedisili. 1988. Integrating geophysical and hydrogeological data: An efficient approach to remedial investigations of contaminated ground water. p. 43-57. IN: Collins, A. G. and A. J. Johnson (eds.) Ground water contamination field methods. ASTM STP 963. American Society for Testing Materials, Philadelphia.

Won, I. J., Dean A. Keiswetter, George R. A. Fields, and Lynn C. Sutton. 1996. GEM-2: A new multifrequency electromagnetic sensor. Journal of Environmental & Engineering Geophysics 1:129-137.

EMI SURVEY
FAIRMONT FARM, WASHINGTON COUNTY, VERMONT
RELATIVE TOPOGRAPHY
(ft)

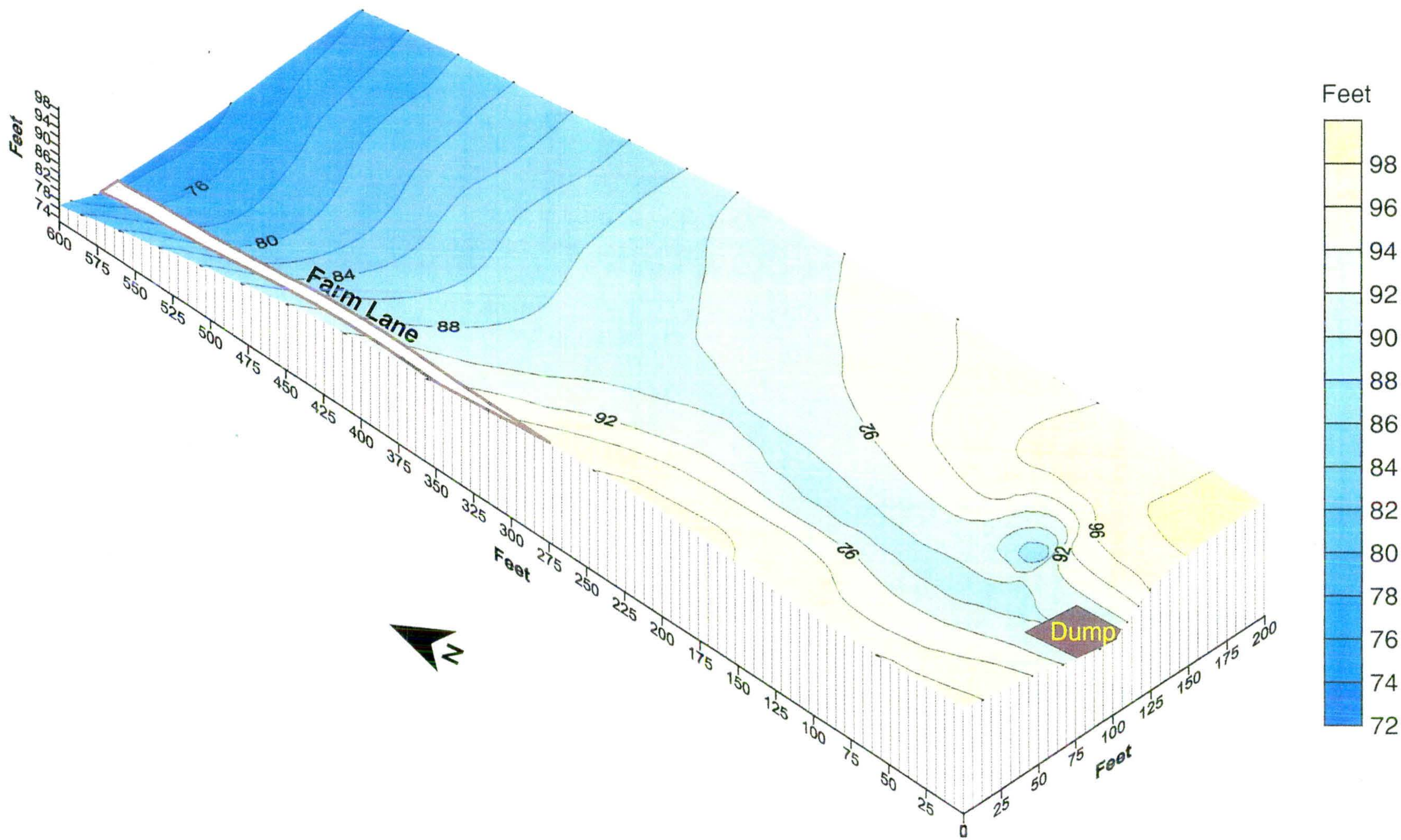


Figure 1

EMI SURVEY
FAIRMONT FARM, WASHINGTON COUNTY, VERMONT
GEM300 SENSOR

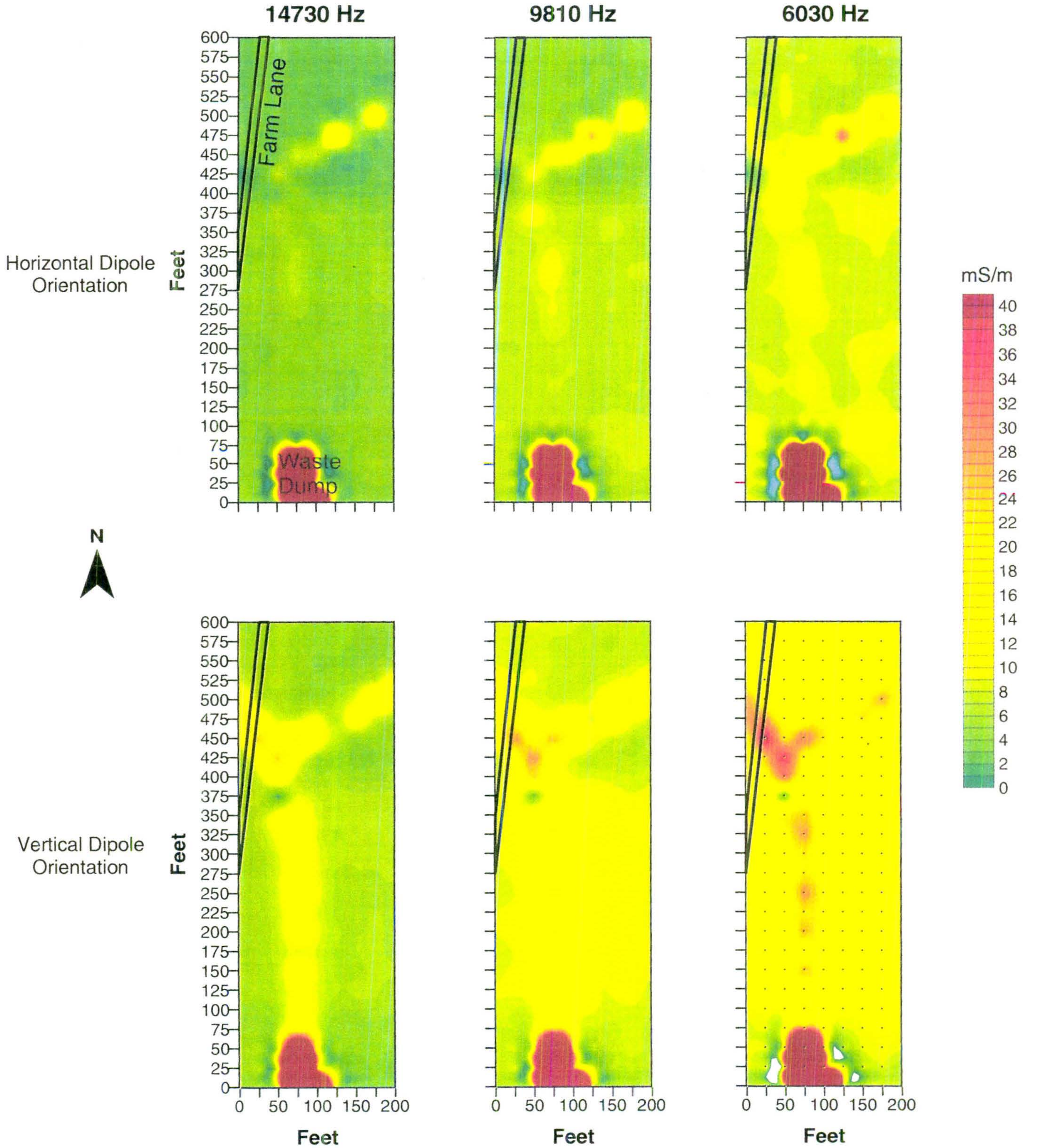
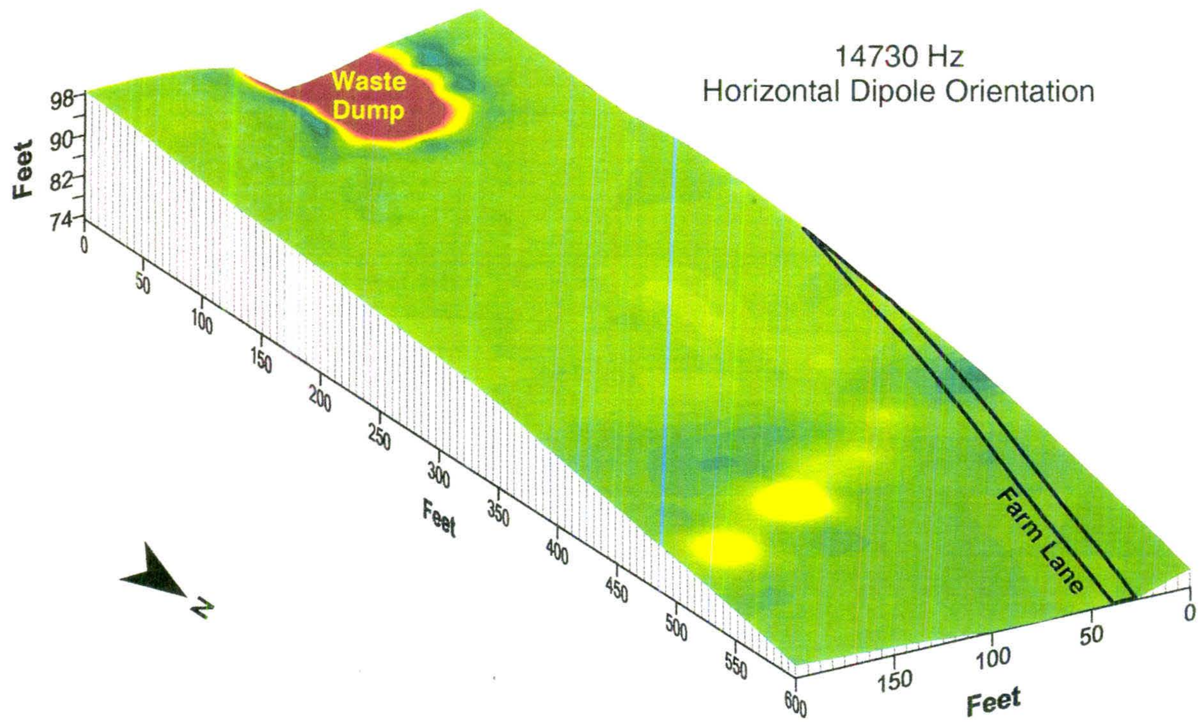


Figure 2

• Observation point

EMI SURVEY
FAIRMONT FARM, WASHINGTON COUNTY, VERMONT
GEM300 SENSOR



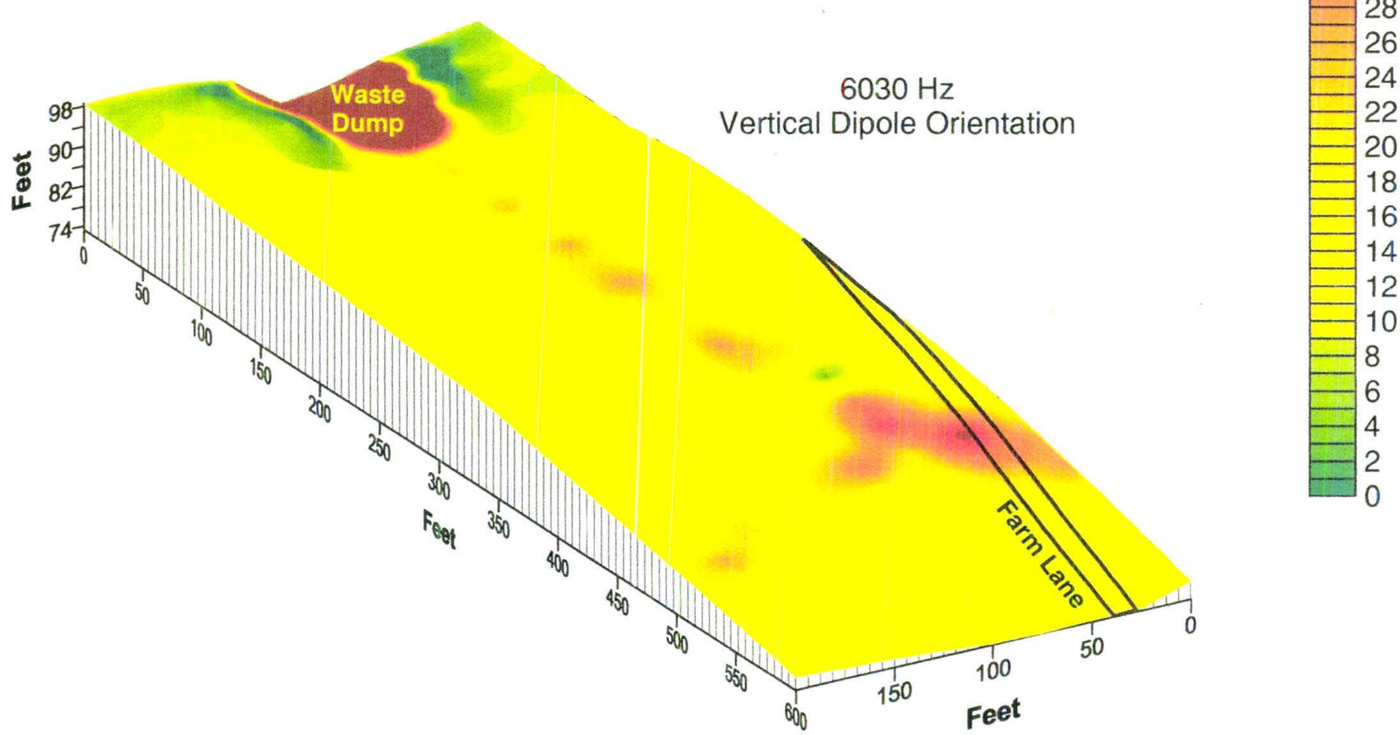
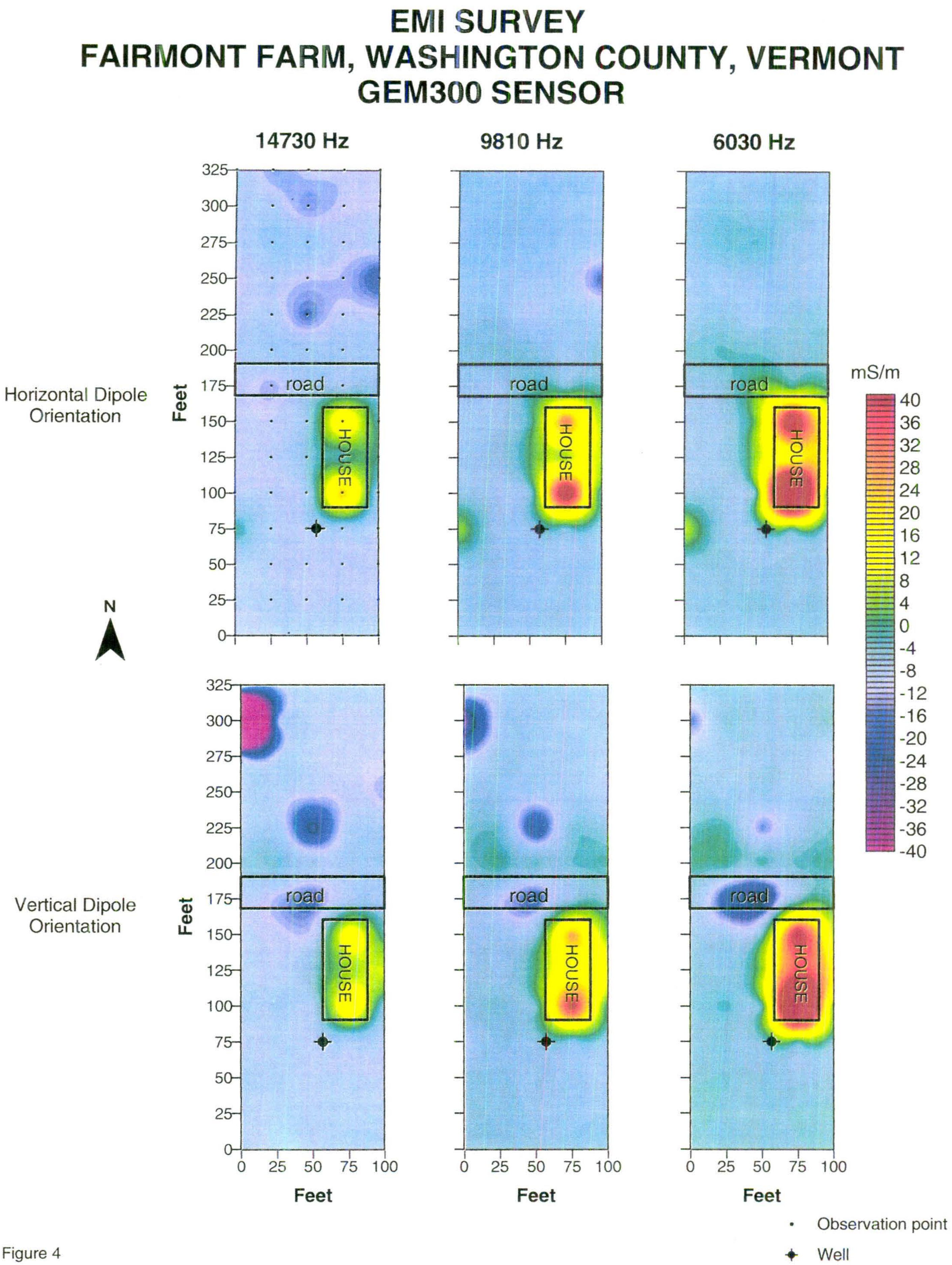


Figure 3



EMI SURVEY
FAIRMONT FARM, WASHINGTON COUNTY, VERMONT
GEM300 SENSOR
14730 Hz
9810 Hz
6030 Hz
Horizontal Dipole Orientation
Vertical Dipole Orientation
Feet
road
HOUSE
N
mS/m
40 36 32 28 24 20 16 12 8 4 0 -4 -8 -12 -16 -20 -24 -28 -32 -36 -40
0 25 50 75 100 125 150 175 200 225 250 275 300 325
Observation point
Well

Figure 4

TOPOGRAPHIC SURVEY OF FILTER FIELD
LAGGIS FARM, CALEDONIA COUNTY, VERMONT
(ft)

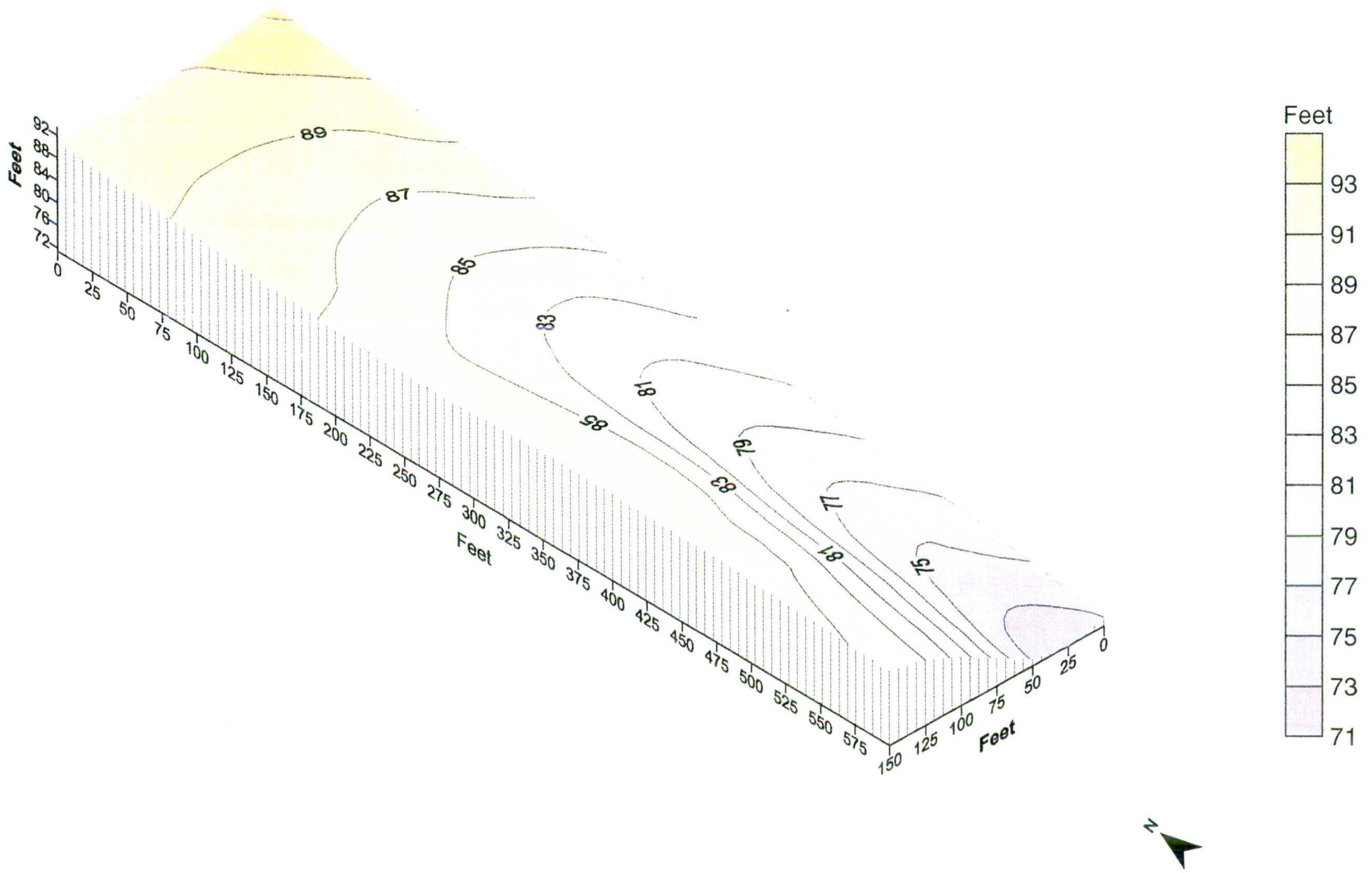


Figure 5

EMI SURVEY OF FILTER FIELD
LAGGIS FARM, CALEDONIA COUNTY, VERMONT
GEM300 SENSOR

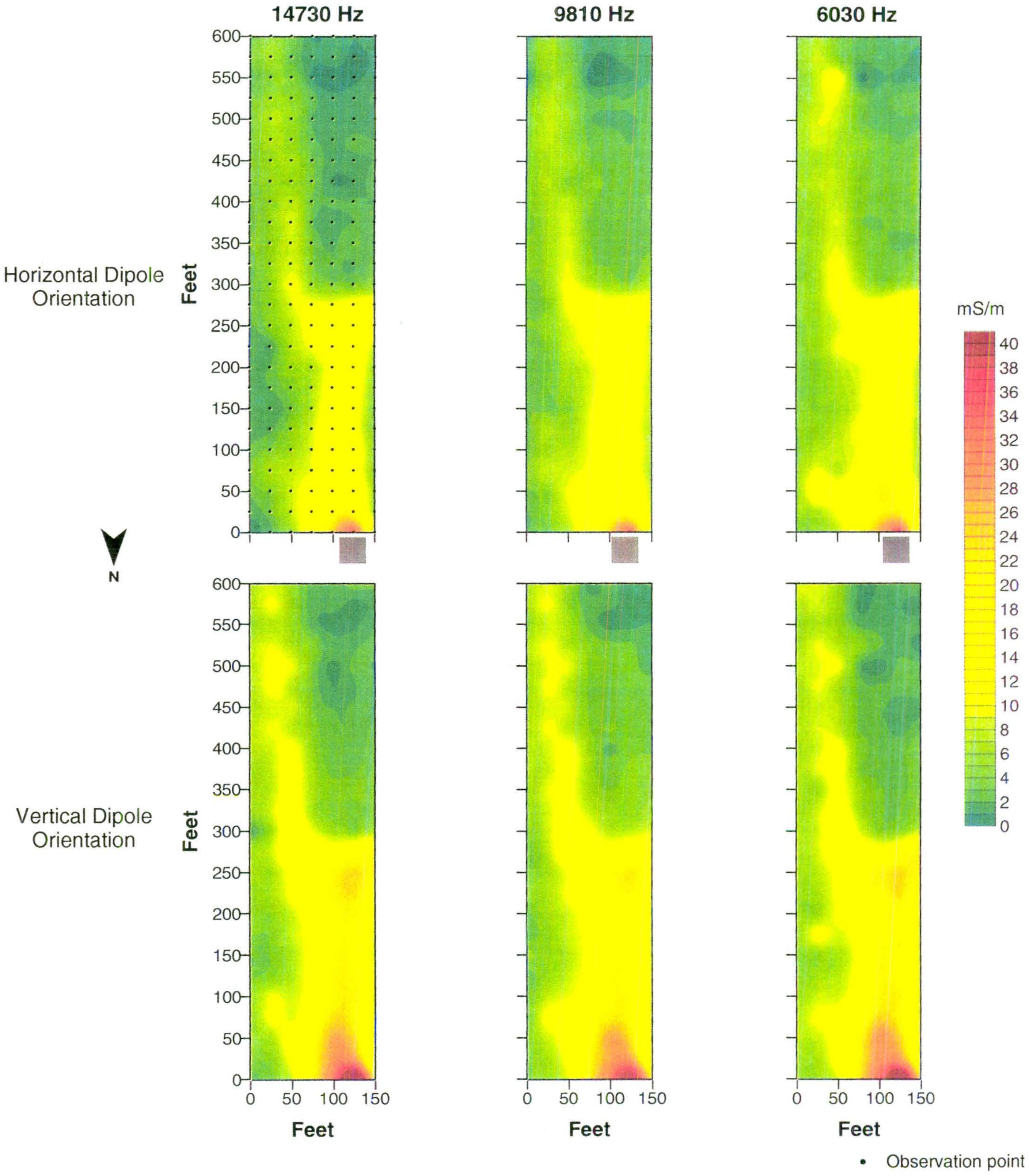


Figure 6

EMI SURVEY OF FILTER FIELD
LAGGIS FARM, CALEDONIA COUNTY, VERMONT
GEM300 SENSOR

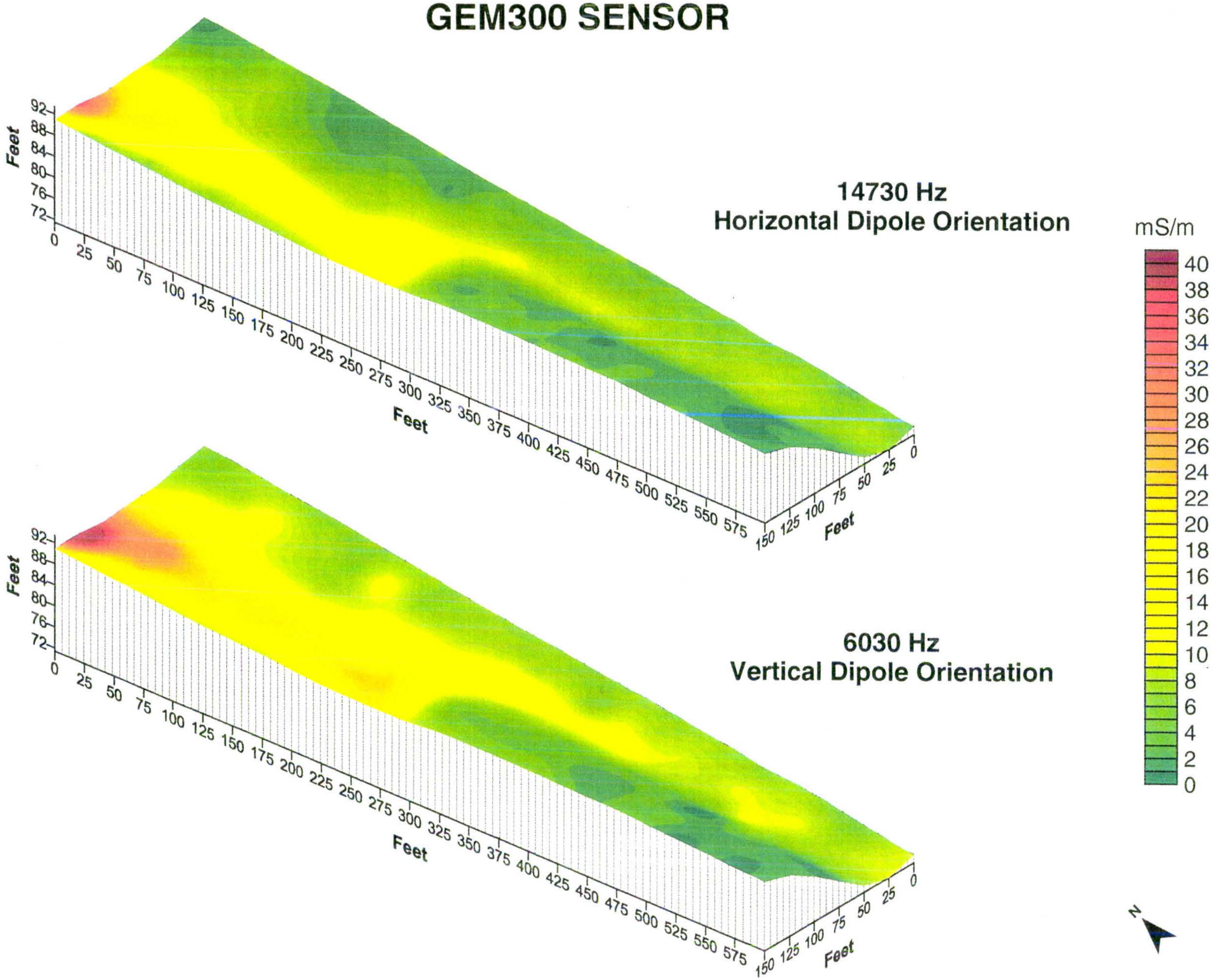


Figure 7

TOPOGRAPHIC SURVEY OF CULTIVATED FIELD
LAGGIS FARM, CALEDONIA COUNTY, VERMONT
(ft)

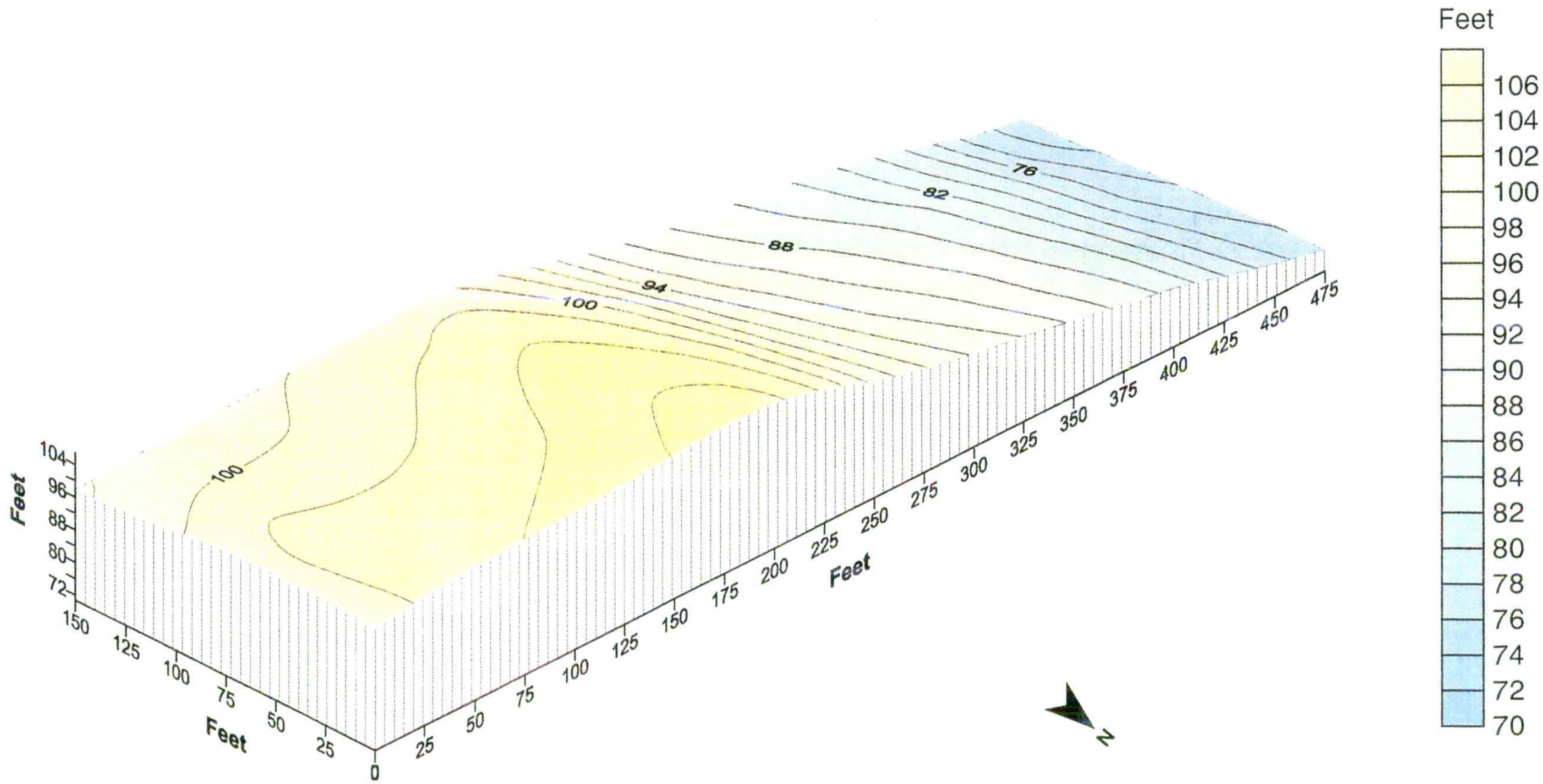


Figure 8

EMI SURVEY OF CULTIVATED FIELD
LAGGIS FARM, CALEDONIA COUNTY, VERMONT
GEM300 SENSOR

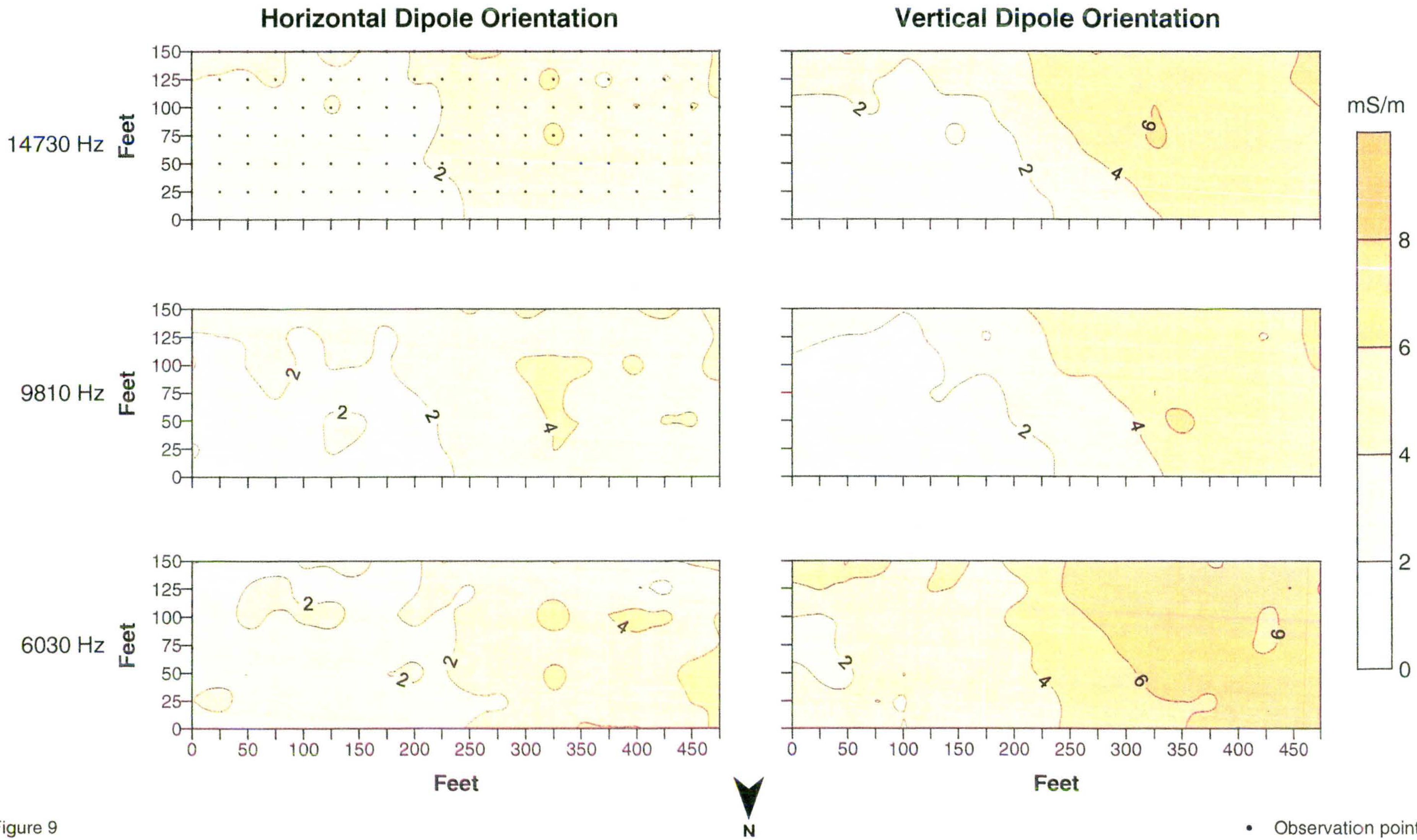


Figure 9

EMI SURVEY OF CULTIVATED FIELD
LAGGIS FARM, CALEDONIA COUNTY, VERMONT
GEM300 SENSOR

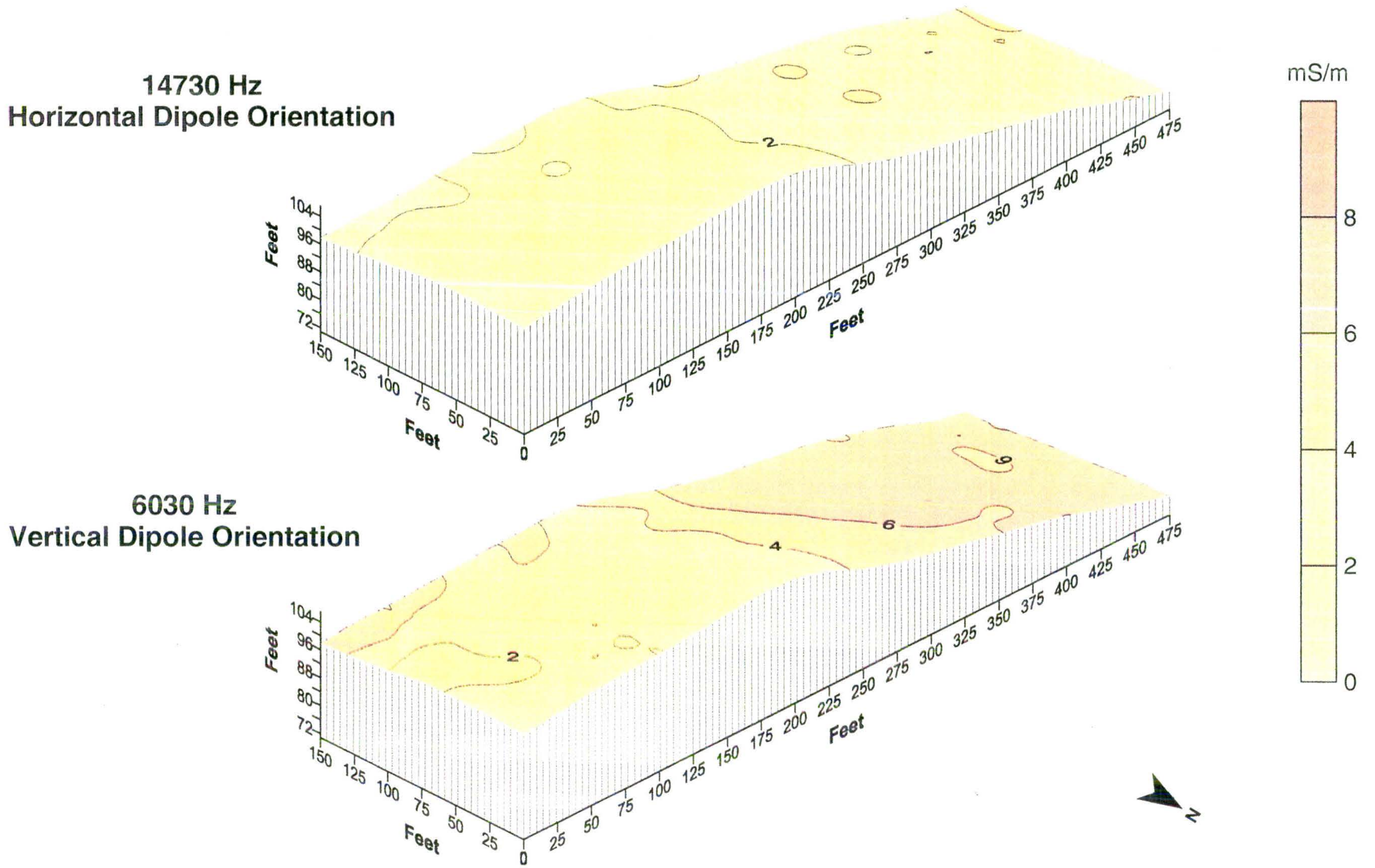


Figure 10

WASHINGTON COUNTY, VERMONT
SLOPE ABOVE SAND MOUNDS
RELATIVE TOPOGRAPHY
(ft)

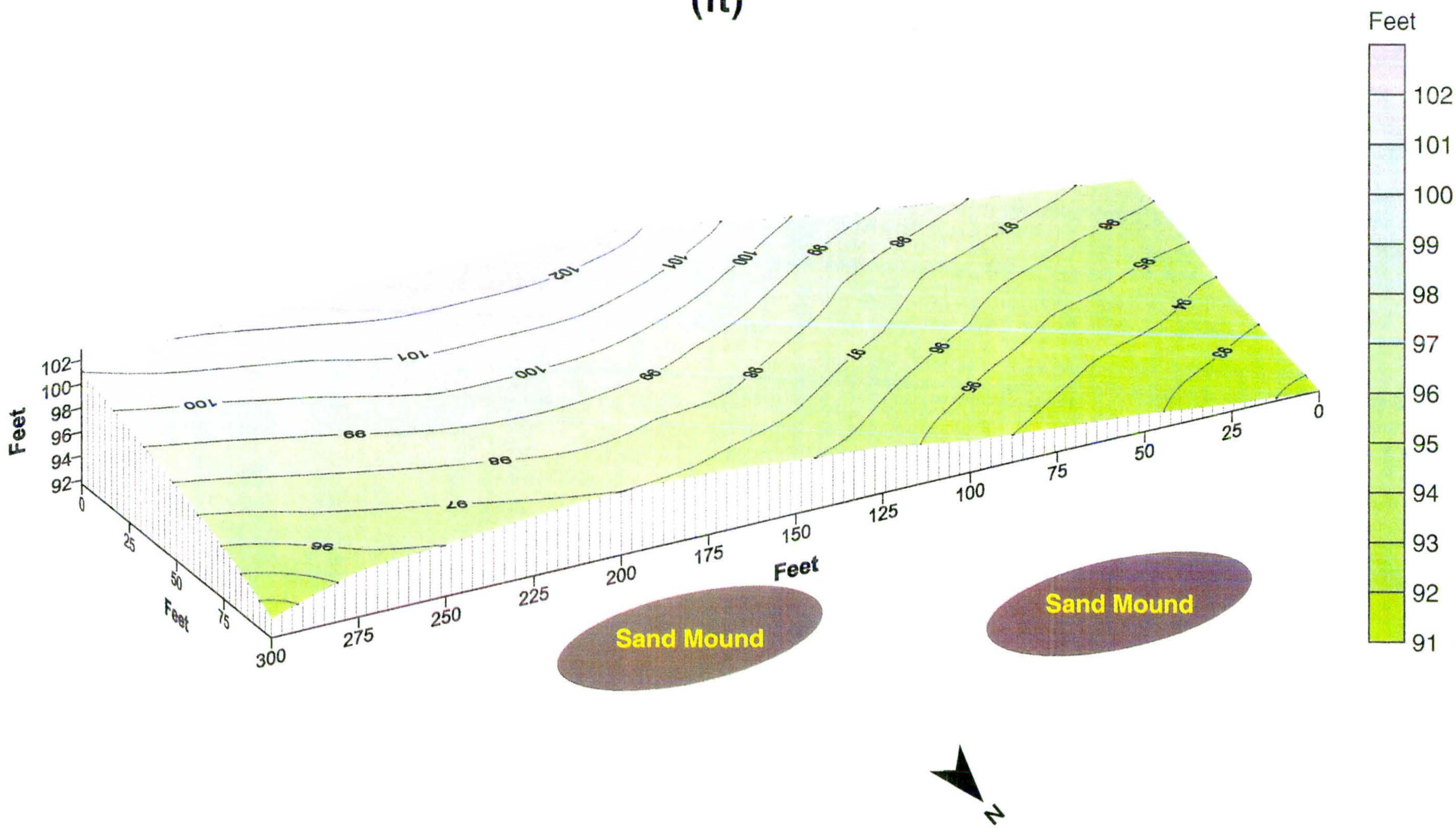


Figure 11

WASHINGTON COUNTY, VERMONT
SLOPE ABOVE SAND MOUNDS
GEM300 SENSOR

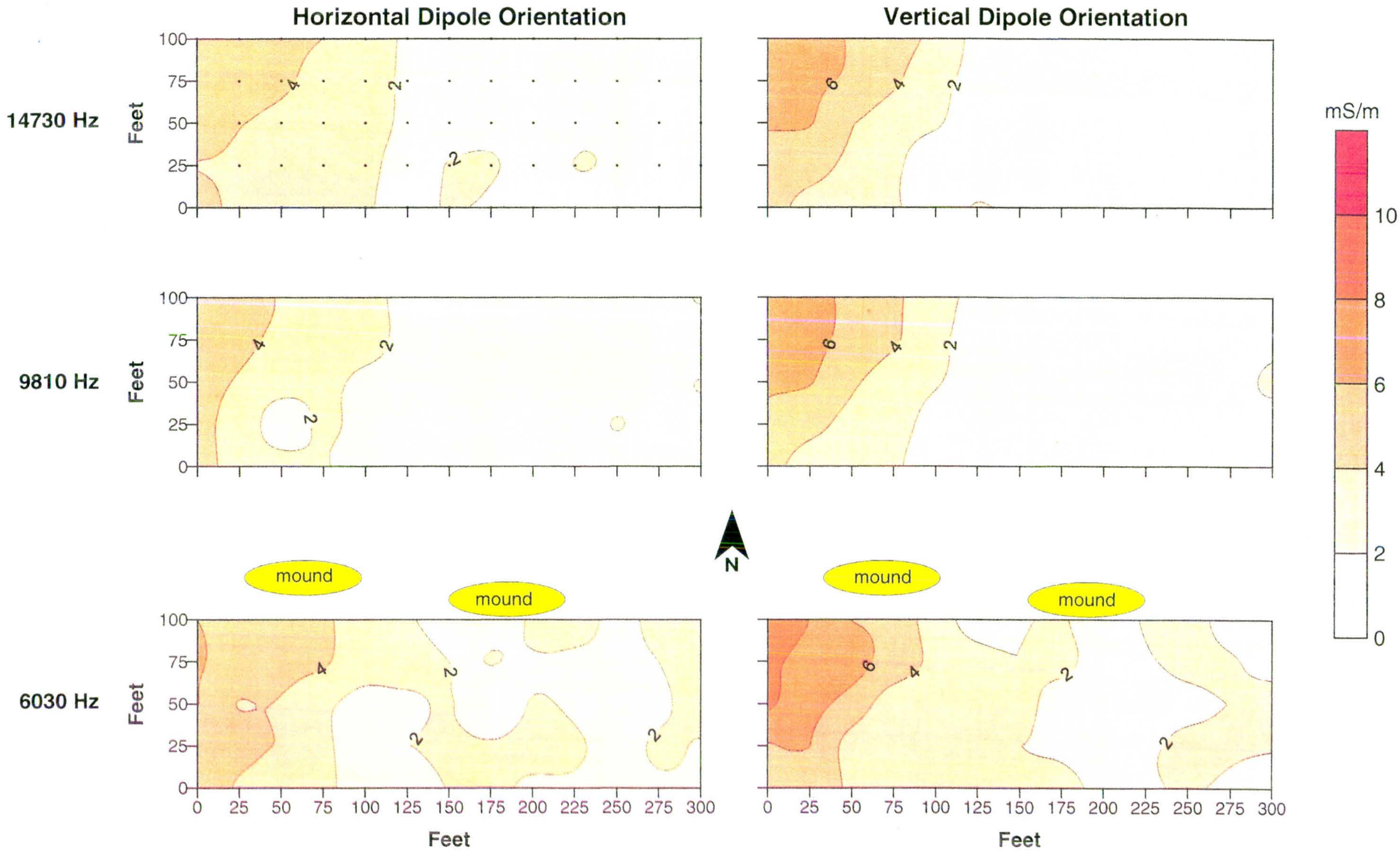


Figure 12

• Observation point

WASHINGTON COUNTY, VERMONT
SLOPE ABOVE SAND MOUNDS
GEM300 SENSOR

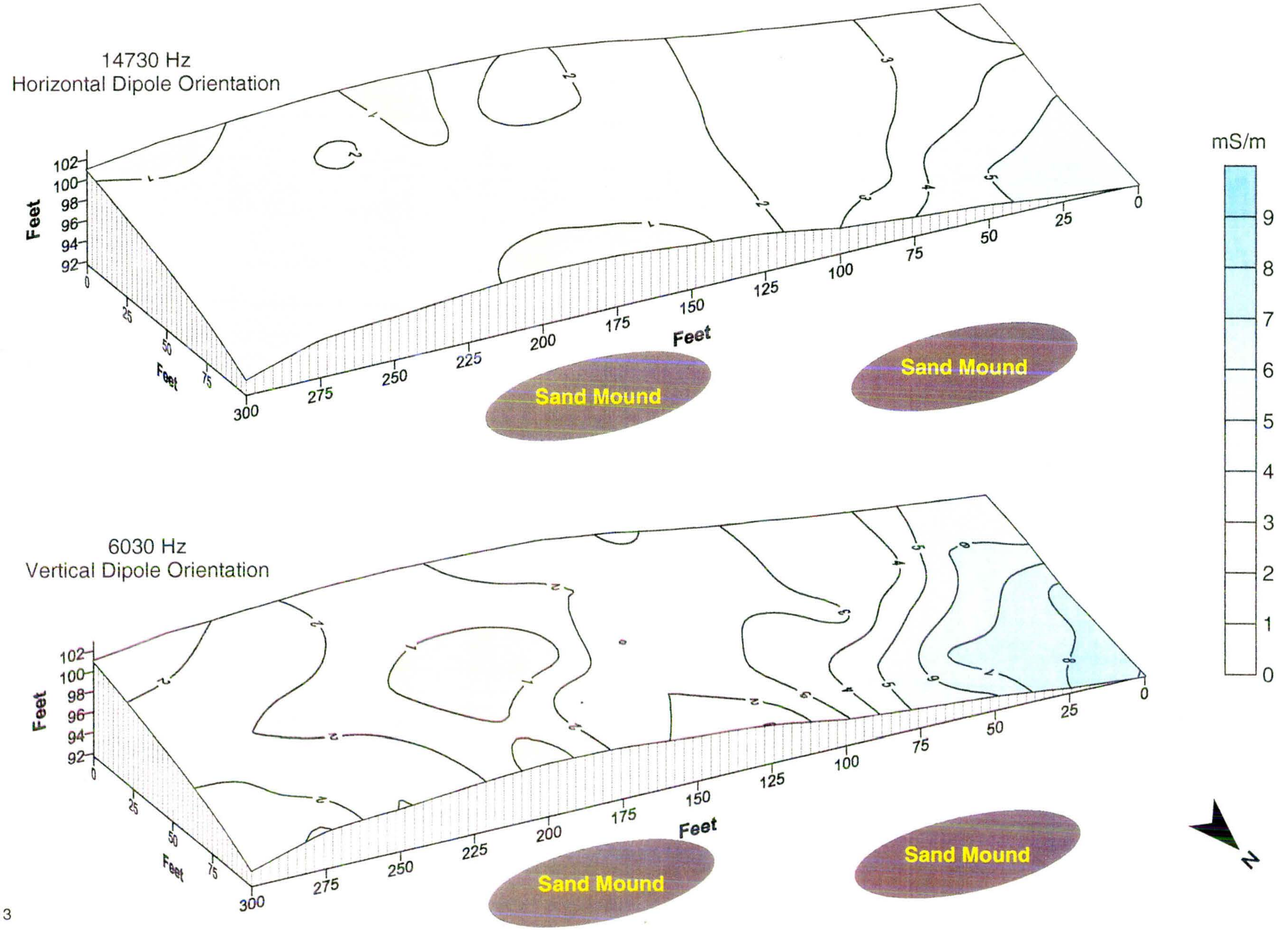


Figure 13

EMI SURVEY OF AREA BETWEEN HOUSE AND BARN
BROWN FARM, ESSEX COUNTY, VERMONT
RELATIVE TOPOGRAPHY
(ft)

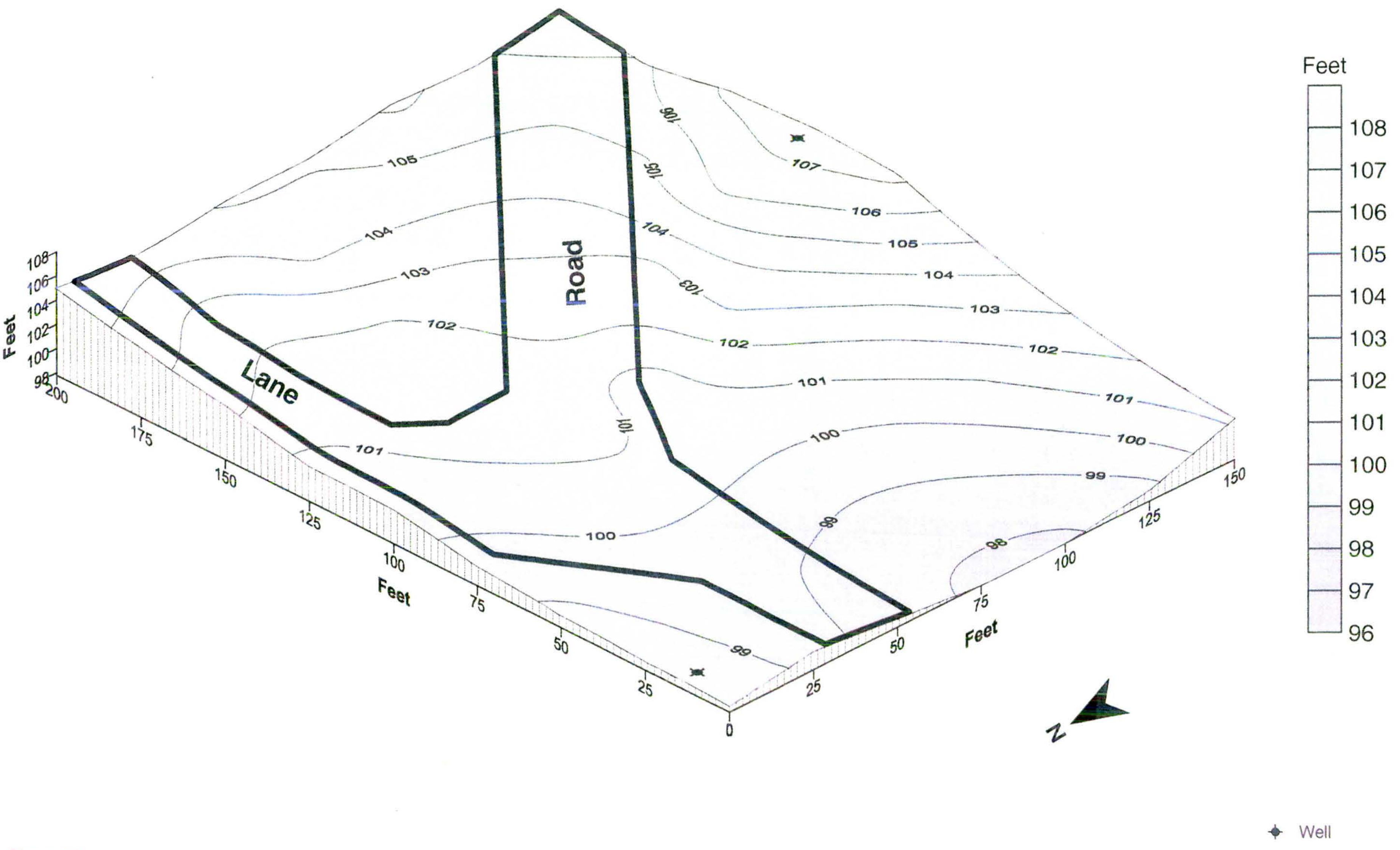


Figure 14

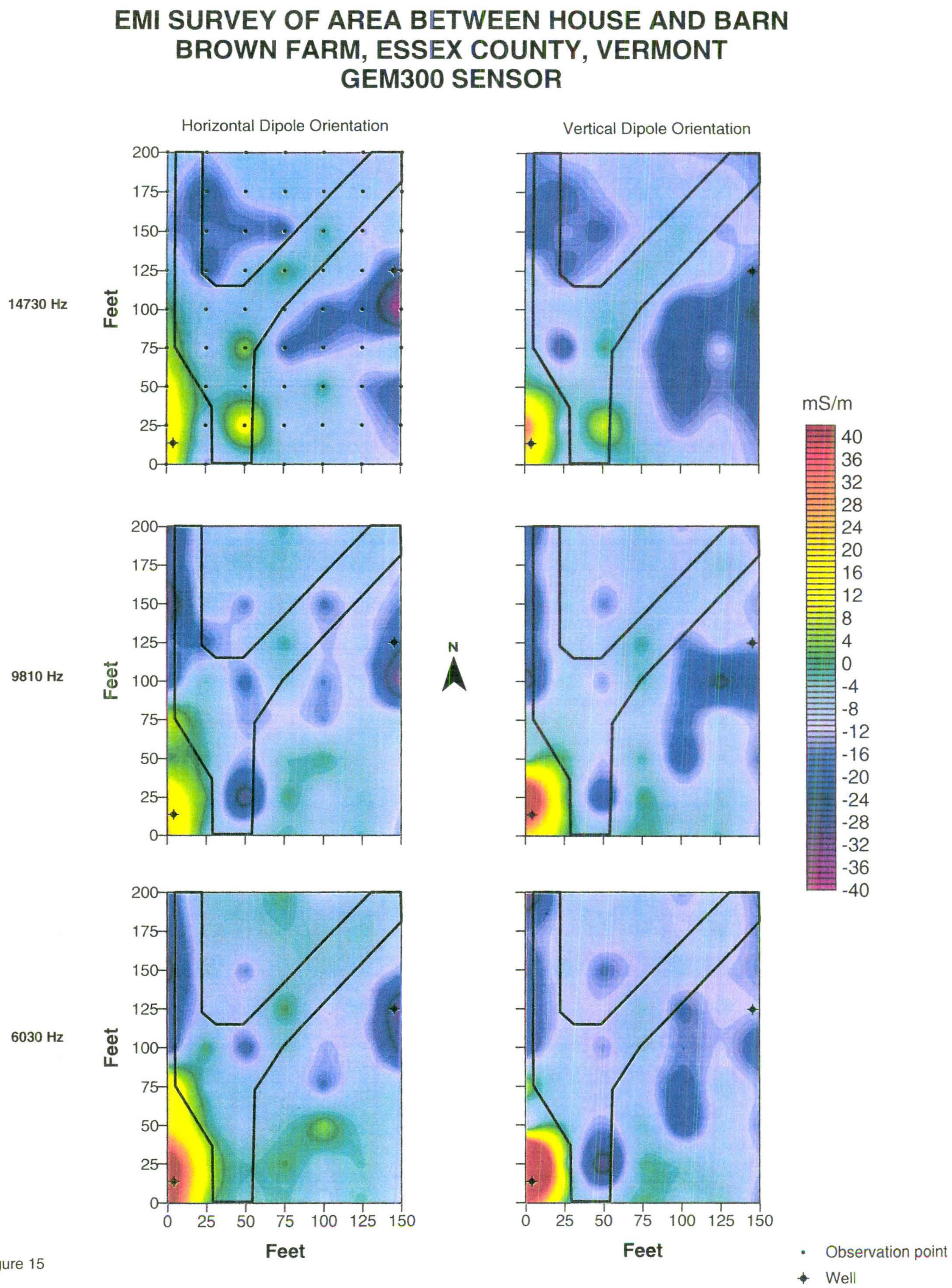

EMI SURVEY OF AREA BETWEEN HOUSE AND BARN
BROWN FARM, ESSEX COUNTY, VERMONT
GEM300 SENSOR
Horizontal Dipole Orientation
Vertical Dipole Orientation
14730 Hz
9810 Hz
6030 Hz
Feet
N
mS/m
40
36
32
28
24
20
16
12
8
4
0
-4
-8
-12
-16
-20
-24
-28
-32
-36
-40
Observation point
Well

Figure 15

EMI SURVEY OF FIELD DOWN SLOPE FROM LAGOON
BROWN FARM, ORLEANS COUNTY, VERMONT
RELATIVE TOPOGRAPHY
(ft)

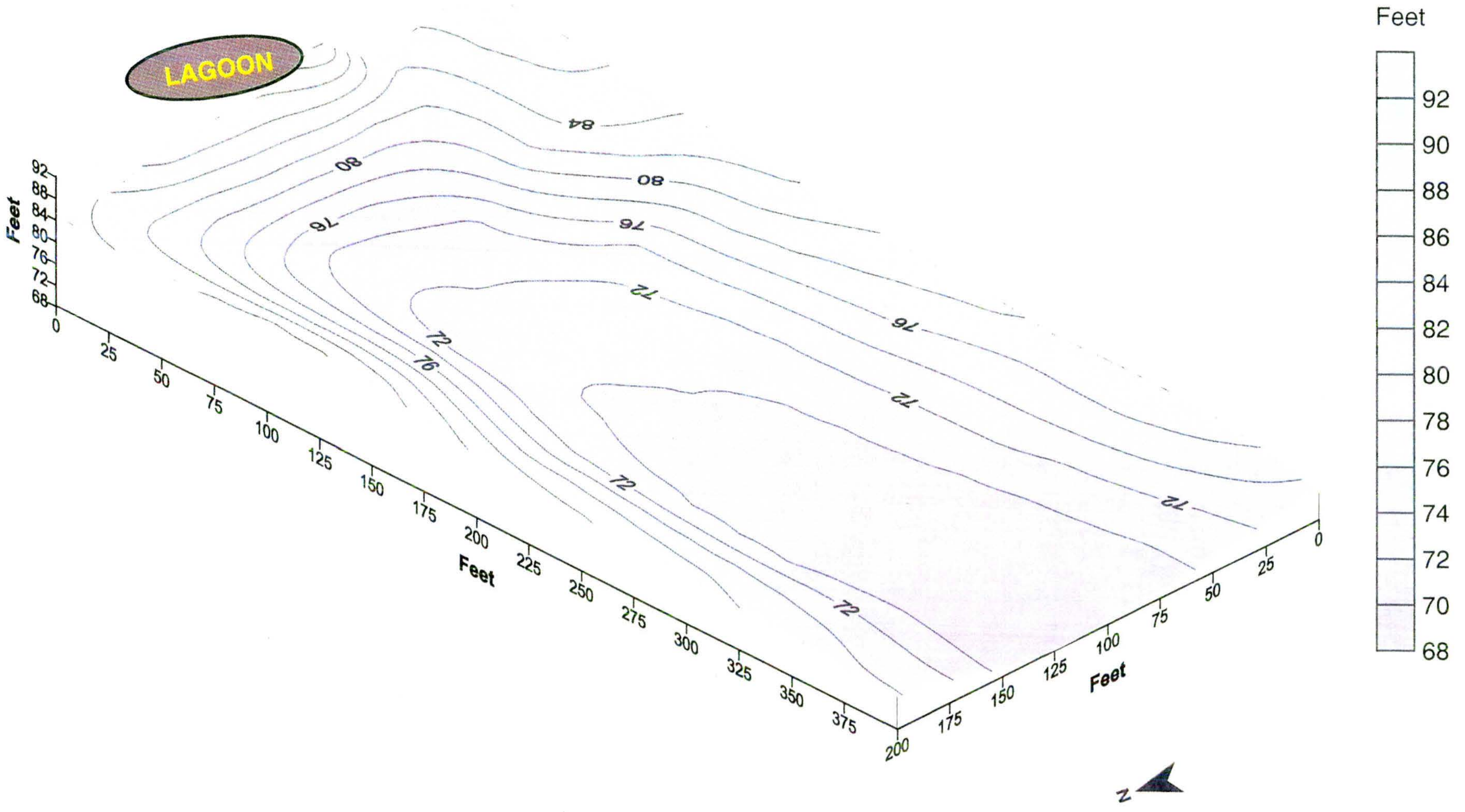


Figure 16

EMI SURVEY OF FIELD DOWN SLOPE FROM LAGOON
BROWN FARM, ORLEANS COUNTY, VERMONT
GEM300 SENSOR

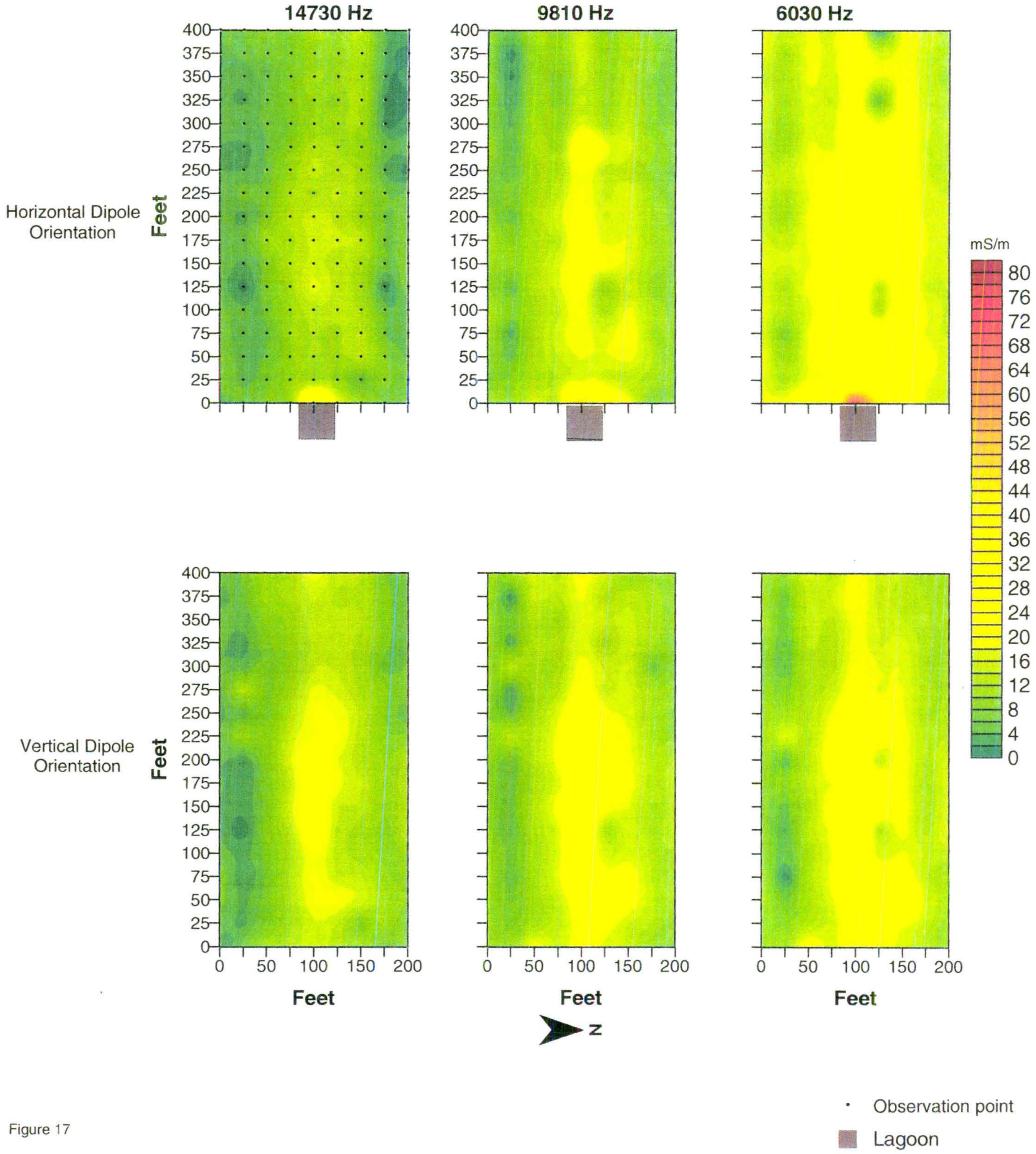


Figure 17