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

Subject: -- Geophysical Assistance --

Date: 10 March 1999

To: M. Denise Doetzer
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Purpose:
The purpose of this investigation was to locate and recovery six temperature (*hobos*) units and to prepare a detailed map of apparent conductivity at a suitable scale for use with precision farming. The potential of using global positioning systems (GPS) and electromagnetic induction techniques (EMI) to map soil variability across comparatively large units of management was also evaluated. This study demonstrated the value of integrating contemporary geophysical, geo-referencing, and computer technologies with traditional soil survey techniques to characterize soils over large areas.

Participants:
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Activities:
All field activities were completed on 3 to 4 March 1999.

Equipment:
To locate the six *Hobo* temperature units, the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.was used.[1] The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. A model 5103 (400 mHz) antenna was used.

The electromagnetic induction meter used in this study was the EM38 manufactured by Geonics Limited.[1] This meter is portable and requires only one person to operate. McNeill (1986) has described principles of operation. No ground contact is required with this meter. The EM38 meter operates at a frequency of 14,600 Hz. This meter provides limited vertical resolution and depth information. Lateral resolution is approximately equal to the intercoil spacing. It has theoretical observation depths of about 0.75 and 1.5 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

The position of each observation points was obtained with Rockwell Precision Lightweight GPS Receivers (PLGR). The receiver was operated in the continuous mode using an external power source (portable 9-volt battery). The mixed satellite mode was used. The coordinate system was Latitude/Longitude (geodetic). Horizontal datum was the North American 1983 (same as datum on 7.5 minute topographic quadrangles).

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[1] Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.

To help summarize the results of this study, SURFER for Windows software program developed by Golden Software Inc. [2] was used to construct two-dimensional simulations. Grids were created using kriging methods. In each of the enclosed plots, shading and filled contour lines have been used. These options were selected to help emphasize spatial patterns. Other than showing trends and patterns in values of apparent conductivity (i.e., zones of higher or lower electrical conductivity), no significance should be attached to the shades themselves.

Study Site
This study was conducted at the Virginia Tech Cropping Systems Experiment Camden Farm in Caroline County, Virginia. The site is near the Rappahannock River south of the town of Port Royal. The study site covered an area of about 57.8 acres. The site consists of twenty-one, 2000-feet by 60-feet wide experimental strips.

Soil scientists of the USDA-NRCS are completing a detailed, digitized soil survey of the site. Soil delineations mapped within the site include phases of Bojac, State, and Wickham soils. Bojac soils are members of the coarse-loamy, mixed, thermic Typic Hapludalfs family. These very deep, well-drained soils formed in loamy and sandy fluvial sediments on terraces and flood plains in the Piedmont and Coastal Plain. State and Wickham soils are members of the fine-loamy, mixed, semiactive, thermic Typic Hapludults family. These very deep, well drained soils formed in fluvial and marine sediments on terraces in the Piedmont and Coastal Plain.

Field Procedures:
The centerline of each 2000-feet by 60-feet wide experimental strips was walked. At intervals of about 30 paces a measurement was obtained with the EM38 meter placed on the ground surface in the vertical dipole orientation. This procedure produced 524 observation points. The coordinates of each observation point were obtained with a Rockwell Precision Lightweight GPS receiver.

Apparent conductivity changes 2.2 percent per degree centigrade (McNeill, 1980). All measurements were standardized to an equivalent electrical conductivity at a reference temperature of 25° C.

Introduction:
The last decade has witnessed the rapid evolution of precision farming. The goal of precision farming is to produce optimal yields and to maximize efficiency by varying seeding and chemical application rates. Precision farming helps to reduce the off-site impact of chemicals, by adjusting and optimizing application rates. Precision farming uses yield mapping, grid sampling, and variable-rate chemical applications. A goal of precision farming is to tie seeding and application rates to the characteristics of each soil type within a field. As specific requirements become known, precision farming seeks to adjust the application and seeding rates to soil conditions.

Precision farming attempts to divide farmlands into management zones that have different seeding and chemical requirements (Mulla, 1993). To accomplish this, precision farming relies on maps showing the location, size, shape and distribution of soils and soil properties within fields. Unfortunately, soil maps prepared by the USDA do not show in sufficient detail the variations in soils and soil properties needed for precision farming (Jaynes et al., 1995a). In general, poor correlations have been obtained between chemical requirements or yield potentials and map units defined by soil surveys (Carr et al., 1991). Conventional soil maps were not prepared nor intended for site specific farming.

Conventional soil maps are inappropriate for precision farming. Precision farming requires a new generation of soil maps. Mapping must be at a level of resolution that is comparable to the scale of chemical applications (Jaynes, 1995a). A new generation of soil maps will be prepared at more appropriate scales (1:6000 or larger) and will show in greater detail the variability of soils, soil properties, or capabilities across fields. The preparation of these maps will be a formidable and expensive task. Unless alternative field methods are developed, a more comprehensive mapping of soils will be prohibitively expensive, time-consuming, and labor-intensive. Alternative methods are needed to complement traditional survey techniques, provide more comprehensive coverage, and improve site assessments. To be effective, these methods must be relatively inexpensive, fast, and provide precise maps of soils or soil properties.

Alternative methods for mapping soils and soil properties are available. Electromagnetic induction (EMI) is a noninvasive geophysical tool that has been used in high intensity surveys and for detailed site assessments. Electromagnetic induction has been used to assess and map soil salinity (Cook and Walker, 1992; Corwin and Rhoades, 1982, 1984, and 1990; Slavich and Petterson, 1990), sodium-affected soils (Ammons et al., 1989; Nettleton et al., 1994), depths to claypans (Doolittle et al., 1994; Stroh et al., 1993; Sudduth and Kitchen, 1993; and Sudduth et al., 1995), and edaphic properties important to

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forest site productivity (McBride et al., 1990). In addition, electromagnetic induction has been used to measure soil water contents (Kachanoski et al., 1988), cation exchange capacity (McBride et al., 1990), and leaching rates of solutes (Jaynes et al., 1995b). Recently, EMI has been used as a mapping tool for precision farming (Jaynes, 1995; Jaynes et al., 1995b; Sudduth et al., 1995).

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 type and concentration of ions in solution, the amount and type of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic induction is not suitable for use in all soil investigations. Generally, the use of EMI has been most successful in areas where subsurface properties are reasonably homogeneous. This technique has been most effective in areas where the effects of one property (e.g., clay, water, or salt content) dominate over the other properties. In these areas, variations in apparent conductivity can be directly related to changes in the dominant property (Cook et al., 1989). In studies conducted in Iowa (Jaynes et al., 1995, 1995b), variations in more than one property weakened and obscured relationships. In these studies, collective changes in the moisture, clay, and carbonates weakened relationships between apparent conductivity and moisture stress or drainage classes.

An EMI meter must be sensitive to the differences existing between soil horizons or layers. In other words, to be effective, a meter must be able to detect differences in electromagnetic properties between the layers. Many soils have subsurface layers with varying thickness and chemical and physical properties, but closely similar conductivity values. Where dissimilar layers produce the same measured EMI response, *equivalence* is said to occur. Equivalent solutions obscure interpretations and limit the effectiveness of EMI.

Discussion:
Interpretations of the EMI data are based on the identification of spatial patterns within data sets. Though seldom diagnostic in themselves, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. Electromagnetic induction integrates the bulk physical and chemical properties for a defined observation depth into a single value. As a consequence, measurements can be associated with changes in soils and soil map units (Hoekstra et al., 1992; Jaynes et al., 1993; Doolittle et al., 1996). For each soil, inherent physical and chemical properties, as well as temporal variations in soil water and temperature, establish a unique or characteristic range of apparent conductivity values. The patterns appearing in accompanying figures are believed to principally reflect variations in clay content. Areas of high apparent conductivity are presumed to have greater average clay contents than areas of low conductivity. Areas of higher clay contents also retain more soil moisture and have higher cations exchange capacities than areas of low clay content.

Figure 1 and 2 are two-dimensional plots of data collected with the EM38 meter in the vertical dipole orientation. Each figure contains the same information, only the isoline intervals have been varied. The isoline intervals are 2 mS/m and 3 mS/m in figure 1 and 2, respectively. The spatial patterns appearing in these figures are closely similar. Values of apparent conductivity appear to conform to predictable spatial relationship and pattern.

While surveying, visual correlations were made between landscape positions and EM measurements. Higher values (> 6 mS/m) of apparent conductivity were recorded on slightly lower-lying and very gently sloping areas. These areas were presumed to have higher clay and moisture contents. State and Wickham are believed to be the dominant soils in these areas. Lower values (< 6 mS/m) of apparent conductivity were recorded on higher-lying, more convex and sloping areas. These areas appear as low dunes and are composed of coarser textured soil materials. Bojac is believed to be the dominant soil in these areas.

Results:

1. The six hobo temperature units were found with ground-penetrating radar.

2. EMI can be used as a surrogate for soil mapping. Maps were prepared of the site showing the spatial variability of apparent conductivity. Variations in apparent conductivity were associated with changes in soils and soil properties across fields. Areas with apparent conductivity greater than 6 mS/m were presumed to be dominated by State and

Wickham soils. Areas with apparent conductivity less than 6 mS/m are presumed to be dominated by Bojac soil.

3. Electromagnetic induction helped to identify locations in the field requiring additional soil sampling. The use of correctly interpreted EMI data can reduce the total number of required soil observations.

4. Interpretations contained in this report are considered preliminary estimates of site conditions. These interpretations do not substitute for direct observations, but rather reduce their number, direct their placement, and supplement their interpretations. Interpretations should be verified by ground-truth observations.

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

With kind regards,

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			Apparent Conductivity	
Waypoint	**Longitude**	**Latitude**	**Measured**	**Temp. Corrected**
WP001	-77.1554	38.1536	4.8	7.37
WP002	-77.1554	38.1536	4.3	6.60
WP003	-77.1551	38.1536	5.2	7.98
WP004	-77.1548	38.1537	4.9	7.52
WP005	-77.1545	38.1538	5.0	7.67
WP006	-77.1541	38.1538	5.2	7.98
WP007	-77.1538	38.1539	5.4	8.29
WP008	-77.1535	38.1540	4.4	6.75
WP009	-77.1532	38.1540	3.1	4.76
WP010	-77.1528	38.1541	1.3	2.00
WP011	-77.1525	38.1542	3.9	5.99
WP012	-77.1522	38.1542	3.9	5.99
WP013	-77.1519	38.1543	3.2	4.91
WP014	-77.1516	38.1544	2.1	3.22
WP015	-77.1513	38.1544	3.0	4.60
WP016	-77.1510	38.1545	3.1	4.76
WP017	-77.1506	38.1546	1.8	2.76
WP018	-77.1503	38.1546	3.5	5.37
WP019	-77.1500	38.1547	3.0	4.60
WP020	-77.1497	38.1547	2.4	3.68
WP021	-77.1494	38.1548	3.1	4.76
WP022	-77.1491	38.1549	2.7	4.14
WP023	-77.1488	38.1549	3.0	4.60
WP024	-77.1486	38.1550	2.3	3.53
WP025	-77.1486	38.1551	2.1	3.22
WP026	-77.1485	38.1548	3.3	5.07
WP027	-77.1488	38.1547	2.4	3.68
WP028	-77.1491	38.1547	2.2	3.38
WP029	-77.1494	38.1546	2.8	4.30
WP030	-77.1497	38.1546	1.8	2.76
WP031	-77.1500	38.1545	2.3	3.53
WP032	-77.1503	38.1544	1.8	2.76
WP033	-77.1506	38.1544	0.9	1.38
WP034	-77.1510	38.1543	2.5	3.84
WP035	-77.1512	38.1542	2.7	4.14

Apparent Conductivity

Waypoint	Longitude	Latitude	Measured	Temp. Corrected
WP036	-77.1515	38.1542	1.5	2.30
WP037	-77.1518	38.1541	2.4	3.68
WP038	-77.1522	38.1541	2.8	4.30
WP039	-77.1525	38.1540	2.5	3.84
WP040	-77.1528	38.1539	2.4	3.68
WP041	-77.1530	38.1539	1.6	2.46
WP042	-77.1533	38.1538	2.8	4.30
WP043	-77.1536	38.1538	3.7	5.68
WP044	-77.1539	38.1537	4.4	6.75
WP045	-77.1543	38.1536	4.5	6.91
WP046	-77.1546	38.1536	4.7	7.21
WP047	-77.1549	38.1535	3.7	5.68
WP048	-77.1552	38.1534	4.2	6.45
WP049	-77.1553	38.1532	2.6	3.99
WP050	-77.1550	38.1533	4.7	7.21
WP051	-77.1547	38.1534	3.5	5.37
WP052	-77.1544	38.1534	3.9	5.99
WP053	-77.1541	38.1535	6.8	10.44
WP054	-77.1538	38.1536	3.4	5.22
WP055	-77.1535	38.1536	3.0	4.60
WP056	-77.1531	38.1537	2.4	3.68
WP057	-77.1528	38.1537	1.6	2.46
WP058	-77.1525	38.1538	3.1	4.76
WP059	-77.1522	38.1539	2.2	3.38
WP060	-77.1519	38.1539	2.7	4.14
WP061	-77.1516	38.1540	1.8	2.76
WP062	-77.1513	38.1541	1.1	1.69
WP063	-77.1510	38.1541	1.8	2.76
WP064	-77.1507	38.1542	0.7	1.07
WP065	-77.1504	38.1542	1.1	1.69
WP066	-77.1501	38.1543	2.3	3.53
WP067	-77.1498	38.1544	1.9	2.92
WP068	-77.1495	38.1544	2.1	3.22
WP069	-77.1492	38.1545	2.1	3.22
WP070	-77.1489	38.1545	2.0	3.07
WP071	-77.1486	38.1546	2.0	3.07
WP072	-77.1484	38.1545	3.1	4.76
WP073	-77.1487	38.1544	1.8	2.76
WP074	-77.1490	38.1544	2.0	3.07
WP075	-77.1493	38.1543	1.8	2.76
WP076	-77.1497	38.1542	1.7	2.61
WP077	-77.1500	38.1542	1.7	2.61
WP078	-77.1502	38.1541	1.5	2.30
WP079	-77.1506	38.1540	1.4	2.15
WP080	-77.1509	38.1540	1.3	2.00
WP081	-77.1512	38.1539	0.7	1.07
WP082	-77.1515	38.1539	0.8	1.23
WP083	-77.1518	38.1538	1.8	2.76
WP084	-77.1521	38.1537	3.4	5.22
WP085	-77.1524	38.1537	3.7	5.68
WP086	-77.1527	38.1536	0.7	1.07
WP087	-77.1530	38.1535	1.5	2.30
WP088	-77.1533	38.1535	3.4	5.22
WP089	-77.1536	38.1534	4.0	6.14
WP090	-77.1540	38.1533	3.1	4.76
WP091	-77.1543	38.1533	4.4	6.75
WP092	-77.1546	38.1532	3.5	5.37
WP093	-77.1549	38.1532	3.9	5.99
WP094	-77.1552	38.1531	3.7	5.68
WP095	-77.1552	38.1529	4.2	6.45
WP096	-77.1549	38.1530	4.7	7.21
WP097	-77.1546	38.1531	5.8	8.90
WP098	-77.1543	38.1531	5.5	8.44

Apparent Conductivity

Waypoint	Longitude	Latitude	Measured	Temp. Corrected
WP099	-77.1540	38.1532	5.2	7.98
WP100	-77.1537	38.1532	5.7	8.75
WP101	-77.1534	38.1533	5.0	7.67
WP102	-77.1531	38.1534	5.0	7.67
WP103	-77.1528	38.1534	2.4	3.68
WP104	-77.1524	38.1535	5.6	8.60
WP105	-77.1521	38.1536	5.0	7.67
WP106	-77.1518	38.1536	4.4	6.75
WP107	-77.1515	38.1537	3.2	4.91
WP108	-77.1512	38.1538	4.0	6.14
WP109	-77.1509	38.1538	3.5	5.37
WP110	-77.1506	38.1539	4.0	6.14
WP111	-77.1502	38.1539	5.3	8.14
WP112	-77.1499	38.1540	3.8	5.83
WP113	-77.1496	38.1541	3.5	5.37
WP114	-77.1493	38.1542	3.5	5.37
WP115	-77.1490	38.1542	3.6	5.53
WP116	-77.1487	38.1543	3.2	4.91
WP117	-77.1484	38.1543	3.7	5.68
WP118	-77.1483	38.1542	3.8	5.83
WP119	-77.1486	38.1541	2.9	4.45
WP120	-77.1490	38.1540	3.2	4.91
WP121	-77.1493	38.1540	2.5	3.84
WP122	-77.1496	38.1539	3.2	4.91
WP123	-77.1499	38.1539	3.5	5.37
WP124	-77.1502	38.1538	4.8	7.37
WP125	-77.1505	38.1537	4.0	6.14
WP126	-77.1508	38.1537	4.5	6.91
WP127	-77.1511	38.1536	1.5	2.30
WP128	-77.1514	38.1535	4.1	6.29
WP129	-77.1517	38.1535	5.3	8.14
WP130	-77.1520	38.1534	4.1	6.29
WP131	-77.1523	38.1534	5.4	8.29
WP132	-77.1526	38.1533	2.2	3.38
WP133	-77.1529	38.1532	3.1	4.76
WP134	-77.1532	38.1532	3.4	5.22
WP135	-77.1535	38.1531	5.3	8.14
WP136	-77.1538	38.1530	4.3	6.60
WP137	-77.1542	38.1530	4.9	7.52
WP138	-77.1545	38.1529	4.3	6.60
WP139	-77.1548	38.1529	5.1	7.83
WP140	-77.1551	38.1528	4.6	7.06
WP141	-77.1551	38.1526	1.1	1.69
WP142	-77.1548	38.1526	4.3	6.60
WP143	-77.1545	38.1527	5.5	8.44
WP144	-77.1542	38.1528	4.2	6.45
WP145	-77.1539	38.1528	4.0	6.14
WP146	-77.1536	38.1529	4.3	6.60
WP147	-77.1532	38.1529	4.8	7.37
WP148	-77.1529	38.1530	3.5	5.37
WP149	-77.1526	38.1531	2.2	3.38
WP150	-77.1523	38.1531	4.0	6.14
WP151	-77.1520	38.1532	3.7	5.68
WP152	-77.1517	38.1533	3.2	4.91
WP153	-77.1514	38.1533	3.7	5.68
WP154	-77.1511	38.1534	2.9	4.45
WP155	-77.1508	38.1534	3.4	5.22
WP156	-77.1506	38.1535	2.5	3.84
WP157	-77.1503	38.1536	3.7	5.68
WP158	-77.1499	38.1536	3.6	5.53
WP159	-77.1497	38.1537	2.9	4.45
WP160	-77.1494	38.1538	2.1	3.22
WP161	-77.1491	38.1538	2.2	3.38

Apparent Conductivity

Waypoint	Longitude	Latitude	Measured	Temp. Corrected
WP162	-77.1488	38.1539	2.7	4.14
WP163	-77.1485	38.1539	3.2	4.91
WP164	-77.1482	38.1538	3.5	5.37
WP165	-77.1485	38.1537	3.8	5.83
WP166	-77.1488	38.1536	5.4	8.29
WP167	-77.1491	38.1536	3.4	5.22
WP168	-77.1494	38.1535	4.8	7.37
WP169	-77.1497	38.1535	3.5	5.37
WP170	-77.1500	38.1534	4.6	7.06
WP171	-77.1503	38.1533	4.8	7.37
WP172	-77.1507	38.1533	3.3	5.07
WP173	-77.1509	38.1532	3.6	5.53
WP174	-77.1513	38.1532	3.8	5.83
WP175	-77.1516	38.1531	3.6	5.53
WP176	-77.1518	38.1530	4.5	6.91
WP177	-77.1522	38.1530	4.8	7.37
WP178	-77.1525	38.1529	2.4	3.68
WP179	-77.1528	38.1529	2.9	4.45
WP180	-77.1531	38.1528	4.1	6.29
WP181	-77.1534	38.1527	4.4	6.75
WP182	-77.1537	38.1527	4.5	6.91
WP183	-77.1540	38.1526	5.3	8.14
WP184	-77.1543	38.1525	3.9	5.99
WP185	-77.1546	38.1525	1.2	1.84
WP186	-77.1549	38.1524	1.0	1.53
WP187	-77.1552	38.1524	0.7	1.07
WP188	-77.1552	38.1522	1.2	1.84
WP189	-77.1549	38.1522	1.2	1.84
WP190	-77.1546	38.1523	0.7	1.07
WP191	-77.1543	38.1524	1.1	1.69
WP192	-77.1540	38.1524	1.9	2.92
WP193	-77.1537	38.1525	5.6	8.60
WP194	-77.1534	38.1525	4.2	6.45
WP195	-77.1531	38.1526	3.4	5.22
WP196	-77.1528	38.1527	2.4	3.68
WP197	-77.1525	38.1527	1.7	2.61
WP198	-77.1522	38.1528	5.5	8.44
WP199	-77.1519	38.1529	4.2	6.45
WP200	-77.1515	38.1529	4.4	6.75
WP201	-77.1512	38.1530	4.1	6.29
WP202	-77.1509	38.1530	4.2	6.45
WP203	-77.1506	38.1531	3.1	4.76
WP204	-77.1503	38.1532	4.6	7.06
WP205	-77.1500	38.1532	3.9	5.99
WP206	-77.1497	38.1533	3.4	5.22
WP207	-77.1494	38.1533	3.8	5.83
WP208	-77.1491	38.1534	4.9	7.52
WP209	-77.1488	38.1535	4.5	6.91
WP210	-77.1485	38.1535	4.1	6.29
WP211	-77.1482	38.1536	4.4	6.75
WP212	-77.1482	38.1535	5.0	7.67
WP213	-77.1484	38.1534	3.4	5.22
WP214	-77.1487	38.1533	3.1	4.76
WP215	-77.1490	38.1533	3.5	5.37
WP216	-77.1493	38.1532	4.4	6.75
WP217	-77.1496	38.1532	3.7	5.68
WP218	-77.1499	38.1531	3.5	5.37
WP219	-77.1502	38.1530	3.6	5.53
WP220	-77.1505	38.1530	3.5	5.37
WP221	-77.1508	38.1529	2.9	4.45
WP222	-77.1510	38.1529	2.4	3.68
WP223	-77.1513	38.1528	3.6	5.53
WP224	-77.1516	38.1528	3.1	4.76

Apparent Conductivity

Waypoint	Longitude	Latitude	Measured	Temp. Corrected
WP225	-77.1519	38.1527	4.6	7.06
WP226	-77.1522	38.1526	4.0	6.14
WP227	-77.1524	38.1526	1.3	2.00
WP228	-77.1527	38.1525	2.0	3.07
WP229	-77.1530	38.1525	3.1	4.76
WP230	-77.1533	38.1524	5.0	7.67
WP231	-77.1536	38.1524	1.8	2.76
WP232	-77.1539	38.1523	0.5	0.77
WP233	-77.1542	38.1522	0.4	0.61
WP234	-77.1545	38.1522	0.7	1.07
WP235	-77.1548	38.1521	0.5	0.77
WP236	-77.1551	38.1519	1.1	1.69
WP237	-77.1548	38.1520	1.1	1.69
WP238	-77.1545	38.1520	1.1	1.69
WP239	-77.1542	38.1521	1.0	1.53
WP240	-77.1539	38.1521	1.3	2.00
WP241	-77.1536	38.1522	1.3	2.00
WP242	-77.1533	38.1523	2.3	3.53
WP243	-77.1529	38.1524	3.6	5.53
WP244	-77.1526	38.1524	2.5	3.84
WP245	-77.1523	38.1525	3.1	4.76
WP246	-77.1520	38.1525	6.9	10.59
WP247	-77.1517	38.1526	5.9	9.06
WP248	-77.1514	38.1527	5.2	7.98
WP249	-77.1511	38.1527	5.1	7.83
WP250	-77.1508	38.1528	4.0	6.14
WP251	-77.1505	38.1528	5.2	7.98
WP252	-77.1503	38.1529	5.0	7.67
WP253	-77.1500	38.1529	4.6	7.06
WP254	-77.1497	38.1530	5.5	8.44
WP255	-77.1495	38.1530	5.8	8.90
WP256	-77.1492	38.1531	5.3	8.14
WP257	-77.1489	38.1532	5.2	7.98
WP258	-77.1486	38.1532	4.8	7.37
WP259	-77.1483	38.1533	4.5	6.91
WP260	-77.1480	38.1532	4.2	6.45
WP261	-77.1483	38.1531	4.2	6.45
WP262	-77.1486	38.1531	5.3	8.14
WP263	-77.1489	38.1530	4.6	7.06
WP264	-77.1492	38.1529	3.7	5.68
WP265	-77.1495	38.1529	5.1	7.83
WP266	-77.1498	38.1528	5.1	7.83
WP267	-77.1501	38.1528	5.1	7.83
WP268	-77.1504	38.1527	4.9	7.52
WP269	-77.1507	38.1526	4.8	7.37
WP270	-77.1510	38.1526	5.1	7.83
WP271	-77.1513	38.1525	5.7	8.75
WP272	-77.1516	38.1525	5.8	8.90
WP273	-77.1519	38.1524	6.4	9.82
WP274	-77.1522	38.1523	6.2	9.52
WP275	-77.1525	38.1523	2.4	3.68
WP276	-77.1528	38.1522	2.1	3.22
WP277	-77.1531	38.1521	2.6	3.99
WP278	-77.1535	38.1521	2.0	3.07
WP279	-77.1538	38.1520	2.0	3.07
WP280	-77.1541	38.1520	3.5	5.37
WP281	-77.1543	38.1519	3.0	4.60
WP282	-77.1546	38.1518	3.4	5.22
WP283	-77.1549	38.1518	3.2	4.91
WP284	-77.1550	38.1516	2.4	3.68
WP285	-77.1547	38.1516	1.4	2.15
WP286	-77.1544	38.1517	2.4	3.68
WP287	-77.1541	38.1518	2.7	4.14

Apparent Conductivity

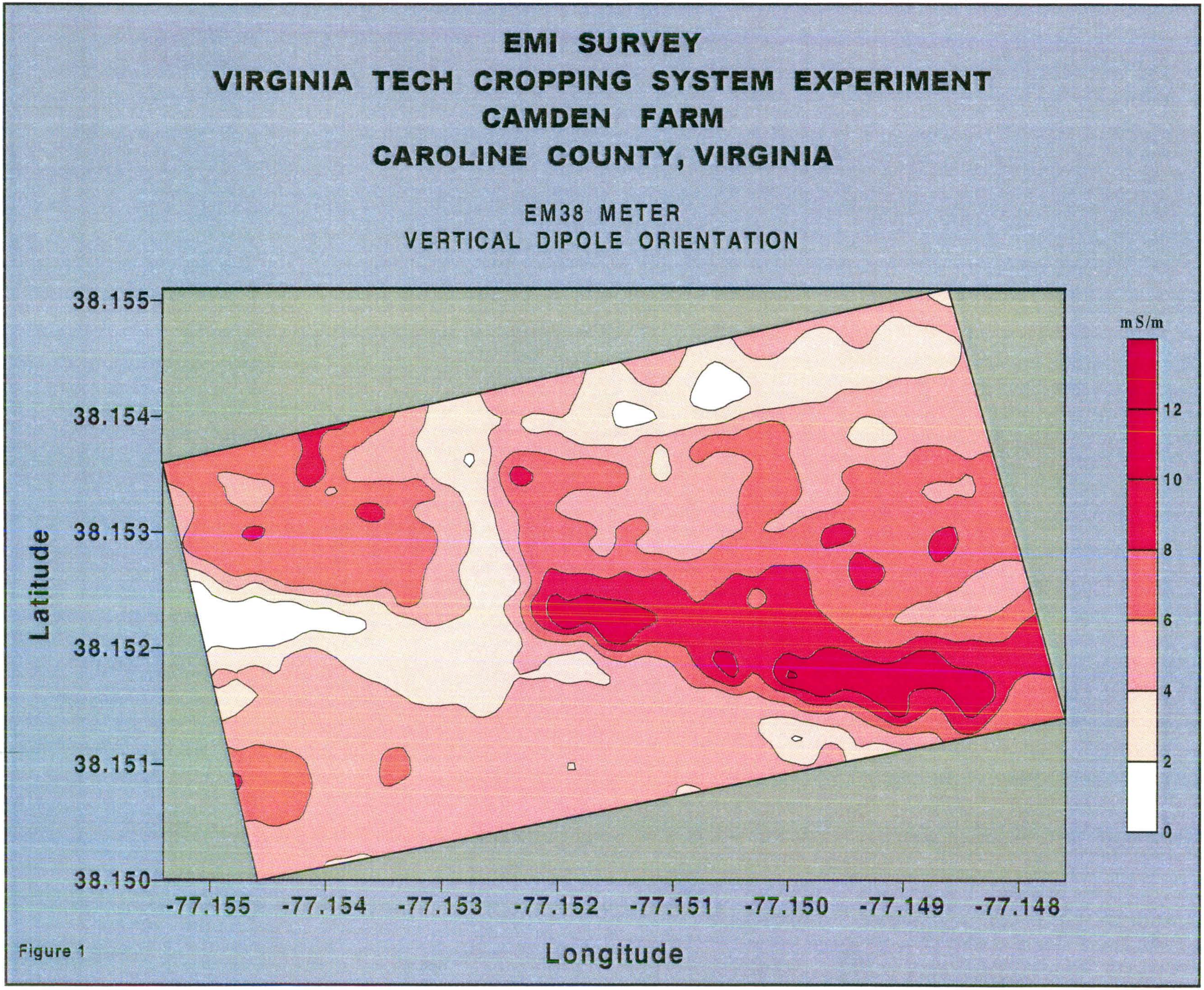
Waypoint	Longitude	Latitude	Measured	Temp. Corrected
WP288	-77.1539	38.1518	2.9	4.45
WP289	-77.1536	38.1519	1.6	2.46
WP290	-77.1533	38.1519	1.2	1.84
WP291	-77.1530	38.1520	1.1	1.69
WP292	-77.1527	38.1520	1.6	2.46
WP293	-77.1524	38.1521	1.6	2.46
WP294	-77.1522	38.1522	4.6	7.06
WP295	-77.1519	38.1522	8.0	12.28
WP296	-77.1516	38.1523	7.3	11.20
WP297	-77.1513	38.1523	6.6	10.13
WP298	-77.1510	38.1524	5.8	8.90
WP299	-77.1507	38.1524	4.9	7.52
WP300	-77.1504	38.1525	5.6	8.60
WP301	-77.1501	38.1526	5.3	8.14
WP302	-77.1498	38.1526	5.3	8.14
WP303	-77.1496	38.1527	4.6	7.06
WP304	-77.1493	38.1527	6.1	9.36
WP305	-77.1490	38.1528	4.8	7.37
WP306	-77.1487	38.1528	5.5	8.44
WP307	-77.1484	38.1529	4.9	7.52
WP308	-77.1480	38.1528	5.5	8.44
WP309	-77.1483	38.1528	4.7	7.21
WP310	-77.1486	38.1527	5.0	7.67
WP311	-77.1489	38.1527	4.7	7.21
WP312	-77.1491	38.1526	5.0	7.67
WP313	-77.1494	38.1525	5.2	7.98
WP314	-77.1497	38.1525	4.9	7.52
WP315	-77.1500	38.1524	5.5	8.44
WP316	-77.1503	38.1524	5.0	7.67
WP317	-77.1506	38.1523	6.6	10.13
WP318	-77.1509	38.1522	6.2	9.52
WP319	-77.1512	38.1522	7.0	10.74
WP320	-77.1515	38.1521	8.5	13.05
WP321	-77.1518	38.1521	3.8	5.83
WP322	-77.1520	38.1520	2.8	4.30
WP323	-77.1523	38.1519	3.3	5.07
WP324	-77.1526	38.1519	1.3	2.00
WP325	-77.1529	38.1518	2.1	3.22
WP326	-77.1532	38.1518	1.8	2.76
WP327	-77.1535	38.1517	2.7	4.14
WP328	-77.1537	38.1517	2.9	4.45
WP329	-77.1540	38.1516	3.4	5.22
WP330	-77.1543	38.1515	3.3	5.07
WP331	-77.1546	38.1515	3.3	5.07
WP332	-77.1549	38.1512	3.1	4.76
WP333	-77.1546	38.1513	3.6	5.53
WP334	-77.1543	38.1514	3.6	5.53
WP335	-77.1540	38.1514	3.2	4.91
WP336	-77.1537	38.1515	3.1	4.76
WP337	-77.1534	38.1516	2.7	4.14
WP338	-77.1531	38.1516	1.8	2.76
WP339	-77.1528	38.1517	1.3	2.00
WP340	-77.1525	38.1517	2.0	3.07
WP341	-77.1522	38.1518	2.4	3.68
WP342	-77.1519	38.1518	2.1	3.22
WP343	-77.1517	38.1519	2.2	3.38
WP344	-77.1513	38.1520	4.5	6.91
WP345	-77.1510	38.1520	4.8	7.37
WP346	-77.1507	38.1521	5.5	8.44
WP347	-77.1504	38.1521	6.0	9.21
WP348	-77.1501	38.1522	5.7	8.75
WP349	-77.1498	38.1523	5.4	8.29
WP350	-77.1495	38.1523	4.7	7.21

Apparent Conductivity

Waypoint	Longitude	Latitude	Measured	Temp. Corrected
WP351	-77.1492	38.1524	4.6	7.06
WP352	-77.1489	38.1525	4.3	6.60
WP353	-77.1486	38.1525	4.4	6.75
WP354	-77.1483	38.1526	3.3	5.07
WP355	-77.1480	38.1527	2.4	3.68
WP356	-77.1479	38.1525	4.2	6.45
WP357	-77.1482	38.1524	3.2	4.91
WP358	-77.1485	38.1524	2.8	4.30
WP359	-77.1488	38.1523	3.6	5.53
WP360	-77.1491	38.1522	3.8	5.83
WP361	-77.1494	38.1522	4.4	6.75
WP362	-77.1498	38.1521	5.8	8.90
WP363	-77.1501	38.1520	7.1	10.90
WP364	-77.1504	38.1520	5.4	8.29
WP365	-77.1507	38.1519	6.4	9.82
WP366	-77.1510	38.1519	4.0	6.14
WP367	-77.1513	38.1518	2.9	4.45
WP368	-77.1516	38.1517	2.2	3.38
WP369	-77.1520	38.1517	2.8	4.30
WP370	-77.1523	38.1516	3.2	4.91
WP371	-77.1526	38.1515	2.1	3.22
WP372	-77.1529	38.1515	3.0	4.60
WP373	-77.1532	38.1514	3.3	5.07
WP374	-77.1535	38.1513	3.4	5.22
WP375	-77.1538	38.1513	3.6	5.53
WP376	-77.1541	38.1512	3.8	5.83
WP377	-77.1544	38.1512	3.5	5.37
WP378	-77.1547	38.1511	3.8	5.83
WP379	-77.1549	38.1511	4.7	7.21
WP380	-77.1549	38.1509	5.6	8.60
WP381	-77.1546	38.1510	5.1	7.83
WP382	-77.1543	38.1510	4.2	6.45
WP383	-77.1540	38.1511	3.5	5.37
WP384	-77.1537	38.1511	3.5	5.37
WP385	-77.1534	38.1512	3.9	5.99
WP386	-77.1531	38.1513	3.3	5.07
WP387	-77.1528	38.1513	3.2	4.91
WP388	-77.1525	38.1514	2.9	4.45
WP389	-77.1522	38.1514	3.3	5.07
WP390	-77.1519	38.1515	3.4	5.22
WP391	-77.1517	38.1516	3.6	5.53
WP392	-77.1513	38.1516	4.1	6.29
WP393	-77.1511	38.1517	3.1	4.76
WP394	-77.1508	38.1517	4.0	6.14
WP395	-77.1505	38.1518	7.9	12.13
WP396	-77.1502	38.1519	5.7	8.75
WP397	-77.1499	38.1519	6.1	9.36
WP398	-77.1496	38.1520	6.7	10.28
WP399	-77.1493	38.1520	5.0	7.67
WP400	-77.1490	38.1521	4.3	6.60
WP401	-77.1487	38.1522	3.8	5.83
WP402	-77.1484	38.1522	4.4	6.75
WP403	-77.1481	38.1523	4.4	6.75
WP404	-77.1478	38.1521	6.3	9.67
WP405	-77.1481	38.1521	5.1	7.83
WP406	-77.1484	38.1520	5.7	8.75
WP407	-77.1488	38.1520	7.0	10.74
WP408	-77.1491	38.1519	6.6	10.13
WP409	-77.1494	38.1518	8.1	12.43
WP410	-77.1497	38.1518	7.7	11.82
WP411	-77.1500	38.1517	8.5	13.05
WP412	-77.1503	38.1517	4.2	6.45
WP413	-77.1506	38.1516	2.8	4.30

			Apparent Conductivity	
Waypoint	**Longitude**	**Latitude**	**Measured**	**Temp. Corrected**
WP414	-77.1509	38.1515	3.7	5.68
WP415	-77.1512	38.1514	2.6	3.99
WP416	-77.1515	38.1514	3.0	4.60
WP417	-77.1518	38.1513	2.8	4.30
WP418	-77.1522	38.1513	2.8	4.30
WP419	-77.1525	38.1512	3.1	4.76
WP420	-77.1528	38.1512	2.8	4.30
WP421	-77.1531	38.1511	3.4	5.22
WP422	-77.1534	38.1510	4.2	6.45
WP423	-77.1537	38.1510	3.5	5.37
WP424	-77.1540	38.1509	4.0	6.14
WP425	-77.1542	38.1509	3.9	5.99
WP426	-77.1545	38.1508	4.4	6.75
WP427	-77.1548	38.1507	5.3	8.14
WP428	-77.1547	38.1506	3.8	5.83
WP429	-77.1544	38.1507	4.6	7.06
WP430	-77.1541	38.1507	3.8	5.83
WP431	-77.1538	38.1508	3.7	5.68
WP432	-77.1535	38.1508	3.9	5.99
WP433	-77.1533	38.1509	3.9	5.99
WP434	-77.1529	38.1510	3.9	5.99
WP435	-77.1526	38.1510	2.3	3.53
WP436	-77.1524	38.1511	3.6	5.53
WP437	-77.1521	38.1511	3.2	4.91
WP438	-77.1518	38.1512	3.1	4.76
WP439	-77.1515	38.1513	3.3	5.07
WP440	-77.1512	38.1513	3.7	5.68
WP441	-77.1509	38.1514	3.6	5.53
WP442	-77.1505	38.1515	3.4	5.22
WP443	-77.1503	38.1515	3.0	4.60
WP444	-77.1500	38.1516	4.8	7.37
WP445	-77.1497	38.1516	7.0	10.74
WP446	-77.1494	38.1517	7.5	11.51
WP447	-77.1491	38.1518	6.7	10.28
WP448	-77.1488	38.1518	7.5	11.51
WP449	-77.1485	38.1519	5.8	8.90
WP450	-77.1482	38.1520	5.4	8.29
WP451	-77.1479	38.1520	6.0	9.21
WP452	-77.1477	38.1519	6.3	9.67
WP453	-77.1480	38.1518	5.4	8.29
WP454	-77.1483	38.1517	7.1	10.90
WP455	-77.1486	38.1517	7.1	10.90
WP456	-77.1489	38.1516	6.2	9.52
WP457	-77.1492	38.1516	7.2	11.05
WP458	-77.1495	38.1515	4.1	6.29
WP459	-77.1498	38.1514	3.4	5.22
WP460	-77.1501	38.1514	2.5	3.84
WP461	-77.1504	38.1513	2.8	4.30
WP462	-77.1507	38.1513	3.0	4.60
WP463	-77.1510	38.1512	2.8	4.30
WP464	-77.1513	38.1511	3.0	4.60
WP465	-77.1516	38.1511	2.6	3.99
WP466	-77.1519	38.1510	2.4	3.68
WP467	-77.1522	38.1510	2.5	3.84
WP468	-77.1525	38.1509	3.4	5.22
WP469	-77.1528	38.1508	2.7	4.14
WP470	-77.1531	38.1508	3.6	5.53
WP471	-77.1534	38.1507	3.6	5.53
WP472	-77.1537	38.1507	3.4	5.22
WP473	-77.1540	38.1506	3.6	5.53
WP474	-77.1543	38.1505	3.9	5.99
WP475	-77.1546	38.1504	3.8	5.83
WP476	-77.1547	38.1503	3.3	5.07

			Apparent Conductivity	
Waypoint	**Longitude**	**Latitude**	**Measured**	**Temp. Corrected**
WP477	-77.1543	38.1503	3.5	5.37
WP478	-77.1540	38.1504	3.8	5.83
WP479	-77.1537	38.1504	3.2	4.91
WP480	-77.1534	38.1505	3.5	5.37
WP481	-77.1531	38.1505	3.5	5.37
WP482	-77.1528	38.1506	3.8	5.83
WP483	-77.1525	38.1507	3.6	5.53
WP484	-77.1522	38.1507	3.5	5.37
WP485	-77.1520	38.1508	3.5	5.37
WP486	-77.1517	38.1508	3.0	4.60
WP487	-77.1514	38.1509	3.0	4.60
WP488	-77.1511	38.1510	3.3	5.07
WP489	-77.1508	38.1510	2.9	4.45
WP490	-77.1505	38.1511	3.5	5.37
WP491	-77.1502	38.1511	3.2	4.91
WP492	-77.1499	38.1512	0.1	0.15
WP493	-77.1496	38.1513	2.1	3.22
WP494	-77.1493	38.1513	3.3	5.07
WP495	-77.1490	38.1514	7.1	10.90
WP496	-77.1487	38.1515	5.0	7.67
WP497	-77.1483	38.1515	8.0	12.28
WP498	-77.1480	38.1516	4.4	6.75
WP499	-77.1477	38.1516	3.8	5.83
WP500	-77.1476	38.1514	5.0	7.67
WP501	-77.1476	38.1515	4.9	7.52
WP502	-77.1479	38.1514	4.4	6.75
WP503	-77.1482	38.1514	4.2	6.45
WP504	-77.1485	38.1513	5.6	8.60
WP505	-77.1488	38.1513	3.6	5.53
WP506	-77.1491	38.1512	2.3	3.53
WP507	-77.1494	38.1511	2.6	3.99
WP508	-77.1497	38.1511	3.1	4.76
WP509	-77.1500	38.1510	3.1	4.76
WP510	-77.1503	38.1510	2.9	4.45
WP511	-77.1506	38.1509	2.8	4.30
WP512	-77.1509	38.1508	2.5	3.84
WP513	-77.1513	38.1508	3.0	4.60
WP514	-77.1516	38.1507	3.1	4.76
WP515	-77.1519	38.1506	3.3	5.07
WP516	-77.1522	38.1506	2.9	4.45
WP517	-77.1525	38.1505	3.5	5.37
WP518	-77.1528	38.1505	3.5	5.37
WP519	-77.1531	38.1504	2.5	3.84
WP520	-77.1534	38.1503	3.0	4.60
WP521	-77.1537	38.1503	2.6	3.99
WP522	-77.1540	38.1502	2.6	3.99
WP523	-77.1544	38.1501	3.5	5.37
WP524	-77.1546	38.1500	2.8	4.30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VIRGINIA TECH CROPPING SYSTEM EXPERIMENT
CAMDEN FARM
CAROLINE COUNTY, VIRGINIA
EM38 METER
VERTICAL DIPOLE ORIENTATION
Latitude
38.155
38.154
38.153
38.152
38.151
38.150
Longitude
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-77.154
-77.153
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-77.148
mS/m
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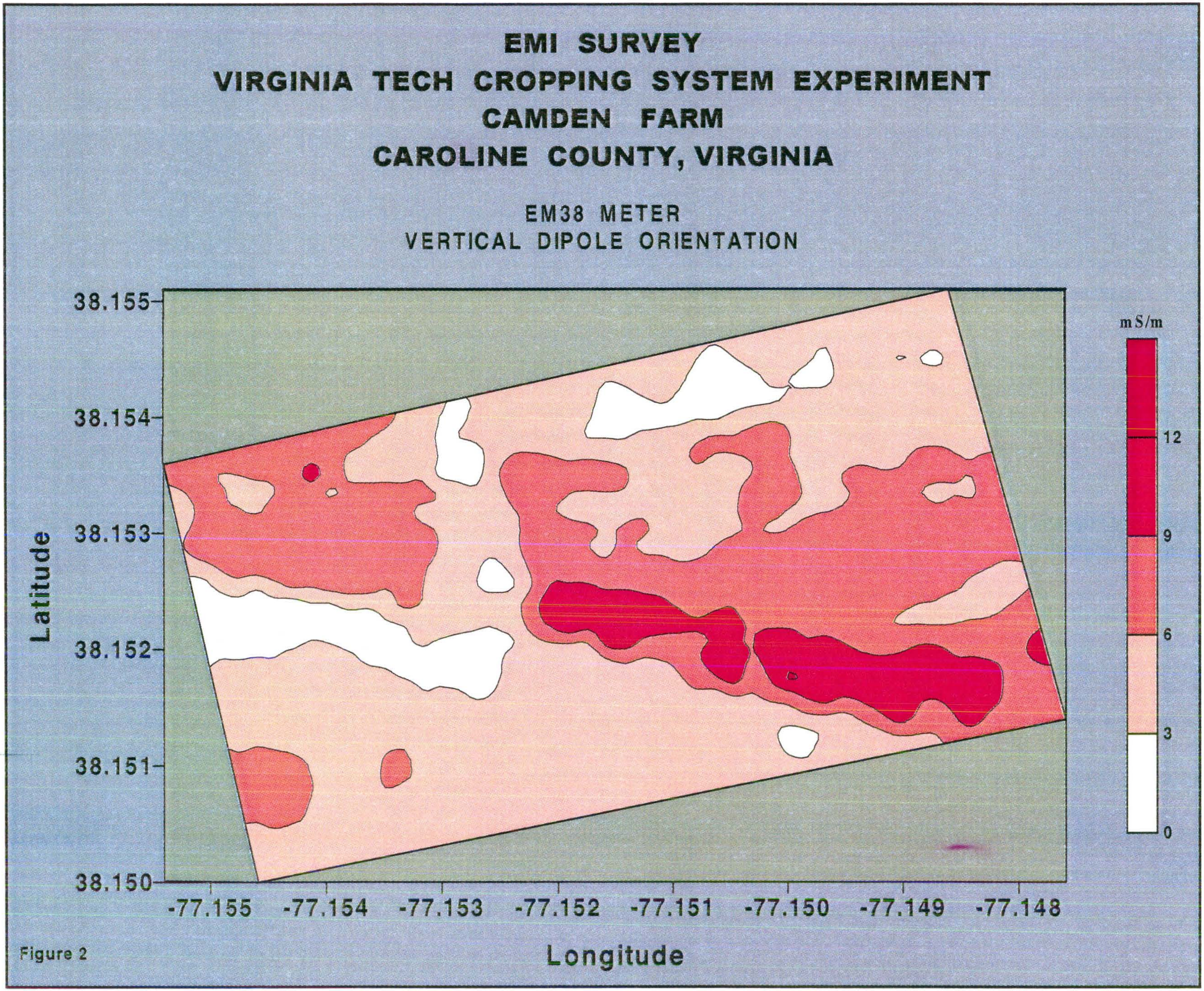
10
8
6
4
2
0
Figure 1


EMI SURVEY
VIRGINIA TECH CROPPING SYSTEM EXPERIMENT
CAMDEN FARM
CAROLINE COUNTY, VIRGINIA
EM38 METER
VERTICAL DIPOLE ORIENTATION
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38.154
38.153
38.152
38.151
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Latitude
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-77.153
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-77.151
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-77.149
-77.148
Longitude
mS/m
12
9
6
3
0

Figure 2