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

Subject: SOI -- Electromagnetic Induction (EMI) Assistance **Date:** 10 July 2000

To: Shirley Gammon
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Purpose:
Electromagnetic induction (EMI) was used to assess recharge, flow through, and discharge wetlands at the Bandy Ranch Research Site. Research supports the National Wet-Soil Monitoring Project.

Participants:
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Activities:
All field activities were completed during the period of 21 to 23 June 2000.

Results:

1. Apparent conductivity can be used to distinguish recharge, discharge, and flowthrough depressional wetlands in semi-arid environment. At a smaller scale, EMI can also be used to identify areas dominated by either recharge or discharge processes within these three types of depressional wetlands.

2. Recharge, discharge and flowthrough processes remove, translocate, and add soluble constituents to soils. Within the Brandy Ranch Research Site, EMI is sensitive to variations in the amount of soluble salts in soil profiles. In the two recharge wetlands, apparent conductivity averaged 28.2 mS/m with a standard deviation of 7.7 mS/m. In these wetlands, small, discontinuous areas of higher apparent conductivity occur in evaporative discharge areas. In the two flowthrough wetlands, apparent conductivity averaged 48.9 mS/m with a standard deviation of 13.2 mS/m. In these wetlands, zones of higher apparent conductivity forms either along the rim ("edge-effect" evaporative discharge) or in the central cores of depressions. In the one discharge wetland, apparent conductivity averaged 51.8 mS/m with a standard deviation of 15.0 mS/m. In this wetland, apparent conductivity increases towards the central core areas of the depression.

3. Observations obtained within the upland boundary of the low prairie vegetation were extracted from the data set and grouped according to wetland type: recharge, flowthrough, or discharge. An analysis of variance was performed on the data. A significant difference was found to exist between the apparent conductivity of the three wetland types. This difference suggests that the subdivision of the wetlands into three types is acceptable and that greater variations in apparent conductivity exist among than within the wetland types. Flowthrough wetlands have properties intermediate between recharge and discharge wetlands. Therefore,

depending on the dominance of processes, flowthrough wetlands may have apparent conductivity and soil properties that more closely resemble either recharge or discharge wetlands.

4. This study demonstrated the use of EMI to identify and map the three types of prairie wetlands (recharge, flowthrough, and discharge) described by Richardson and others (1992). Electromagnetic surveys are relatively quick and easy to complete and provided more inclusive coverage of sites. It appears to be an effective mapping tool useful in discriminating recharge, flowthrough, and discharge processes at different scales both among and within wetlands. Spatial patterns of apparent conductivity appear to mirror vegetative, soil, and hydrologic patterns. Additional studies in both arid and humid areas of the United States are needed to confirm this application.

5. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil borings). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report will be verified by analysis of soil samples.

With kind regards,

James A. Doolittle
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cc:
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Background:
Recent interest in soils and hydrologic modeling has increased the need for data on the depth and movement of groundwater across landscapes. Hydrology plays an important role in the development of soils and is a critical factor in the classification of wetlands. The depth and movement of water through the subsurface has a direct effect on the physical and chemical properties and the morphology of soils (Richardson et al., 1992). Recharge processes remove soluble chemical constituents and translocate suspend colloids, while discharge processes add materials to soils (Richardson et al., 1992). As a consequence, in many arid and semi-arid areas, discharge areas often have higher soluble salt concentrations than recharge areas.

Richardson and others (1992) discussed relationships between the hydrological regimes of wetlands and soil properties. These authors noted three types of prairie wetlands: recharge, discharge, and flowthrough. In North Dakota, recharge wetlands are typified by very deep, nonsaline and noncalcareous soils with argillic horizons. These soils have low electrical conductivity. Discharge wetlands are typified by very deep, saline and calcareous soils that lack well developed soil profiles. These soils have high electrical conductivity. Flowthrough wetlands have intermediate levels of soluble salt and carbonate concentrations, soil profile development, and electrical conductivity.

The objective of this study was to ascertain whether EMI could be used to identify and map the three types of wetlands described by Richardson and others (1992).

Brandy Ranch Study Site:
The study site was located on Bandy Ranch, near the town of Ovando, Powell County, Montana. The site was located on a hummocky moraine that was pitted with depressions. The study site had a high wetland density and consisted of relatively homogeneous glacial materials. These depressional wetlands have a shallow groundwater connection and are underlain by a compacted till layer with relatively low permeability (B. Cook, personal communication). This aquitard controls the movement of the shallow groundwater. This shallow movement of groundwater is short lived and has limited horizontal extent or distance (B. Cook, personal communication). All depressions were covered with wetland vegetation and had areas of ponded water. Areas of saline soils and sodium-affected soils were observed around some depressions.

Three areas of study were selected within Brandy Ranch (see Figure 1). Study area A is the highest lying and contains two recharge wetlands (sites # 1 and 3) and one flowthrough wetland (Site #2). Study area B has an intermediate elevation and consist of one flowthrough wetland (Site #7). Study area C is the lowest lying and consist of one discharge wetland (Site #27).

Equipment:
A GEM300 multifrequency sensor, developed by Geophysical Survey systems, Inc., [1] was used in this study. The GEM300 sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation (1.3 m). Won and others (1996) have described the use and operation of this sensor.

The location of observation points and the upland boundary of the low prairie vegetation around each wetland were obtained with Rockwell Precision Lightweight GPS Receivers (PLGR).[1] The receiver was operated in the continuous and the mixed satellite modes. The Universal Transverse Mercator (UTM) coordinate system was used. Horizontal datum is the North American 1983. Horizontal units are expressed in meters. For the detailed grid of wetlands #1, #2, and #3, the coordinates of all observations collected with the GEM300 sensor along measured grid lines were processed and adjusted by the MAGMAP96 software program. [1]

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

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

After reviewing the computer simulations of the detailed grid site, soil samples were collected at six observation points. At each of these observation points, the soil was described to a depth of 90 cm. In addition, samples were collected in 30 cm intervals to a depth of 90 cm and shipped to the National Soil Survey Center for analysis. Additional measurements were made with the GEM300 sensor over the each of the sampled points.

EMI:

Background:

Electromagnetic induction is a noninvasive geophysical tool that is used for high intensity soil surveys and detailed site assessments. 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 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). 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.

Variations in apparent conductivity are caused by changes in the electrical conductivity of earthen materials. Electrical conductivity is influenced by the volumetric water content, temperature and phase of the soil water, type and concentration of ions in solution, and amount and type of clays in the soil matrix (McNeill, 1980).

Apparent conductivity is a measure of the combined interaction of the soil's soluble salt content, clay content and mineralogy, and water content. The apparent conductivity of soils increases with increases in soluble salts, clay, and water contents (Kachanoski et al., 1988; Rhoades et al., 1976). In any soil-landscape, variations in one or more of these factors may dominate the EMI response. In areas of saline soils, 65 to 70 percent of the variance in apparent conductivity can be explained by changes in the concentration of soluble salts alone (Williams and Baker, 1982). Moderate to high correlations have been found between apparent conductivity and soil salinity (de Jong et al., 1979; Williams and Baker, 1982; and Wollenhaupt et al., 1986).

The presence of exchangeable cations on the surface of clay particles contributes to the total electrical conductivity of the soil. Depending on the type and amount of clays present, the number of exchangeable cations available to contribute to conduction when an electrical field is applied will vary. If the soil water conductivity is low, the high conductivity near some clay surfaces can dominate the overall conductance (Greenhouse et al., 1998). Clays also contribute to the water-holding capacity of soils.

Apparent conductivity is affected by changes in the electrolyte concentration of the soil water and the soil water content (Johnston, 1997). For soils with low concentrations of dissolved electrolytes, apparent conductivity is highly correlated to soil water content (Kachanoski et al., 1988, 1990; Sheets and Hendrickx, 1995). The strength of this association increases with increases in soil water content and the degree of water saturation. At low soil moisture contents, EMI is relatively insensitive to changes in soil-water content. However, at high soil moisture contents, EMI is more sensitive to changes in soil-water content (Hanson, 1997).

Depth of Observation:
The theoretical observation depth of the GEM300 is dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequency of the sensor. Observation depths are governed by the "skin-depth" effect (Won, 1980 and 1983). Skin-depth is the maximum depth of observation for an EMI sensor operating at a particular frequency and sounding a medium with a known conductivity. Observation depth or "skin-depth" is inversely proportional to frequency (Won et al., 1996). Low frequency signals travel farther through conductive mediums than high frequency signal. Decreasing the frequency will extend the observation depth. At a given frequency, the depth of observation is greater in low conductivity soil than in high conductivity soils. Mutifrequency sounding with the GEM300 allows multiple depths to be profiled with one pass of the sensor.

With the GEM300 sensor, the depth of observation or the "skin depth" is estimated using the following formula (McNeill, 1996):

$$D = 500/(s*f)^{-2} \qquad [1]$$

Where s is the ground conductivity (mS/m) and f is the frequency (kHz). Four frequencies were used in this study: 9810, 11790, 14790, and 19950 Hz. At Brandy ranch, with the GEM300 sensor held at hip height in the vertical dipole orientation, apparent conductivity averaged 19.9, 22.8, 24.9, and 27.4 mS/m at frequencies of 9810, 11790, 14790, and 19950 Hz, respectively. Based on equation [1], the selected frequencies and these averaged conductivities, the estimated skin depths (observation depths) were 35.8 m at 9810 Hz, 30.5 m at 11790 Hz, 26.9 m at 14790 Hz, and 21.4 m at 19950 Hz. Within these defined skin depth, earthen materials from all depths contribute, in varying degrees, to the measured response. With increasing depth, the relative contribution from various depth layers passes through a maximum and then decreases with increasing depth. While the induced magnetic fields may achieve these estimated skin depths, the strengths of the response diminish with increasing depth and are presumed to be too weak to be sensed by the GEM300 sensor.

The depth of observation may be defined as the depth that contributes the most to the total EMI response measured on the ground surface. Although contributions to the measured response come from all depths, the contribution from the *depth of observation* is the largest (Roy and Apparao, 1971). As noted by Roy and Apparao (1971), for any system, the depth of observation is a good deal shallower than is generally assumed or reported. As no depth-weighting functions are presently available for the GEM300 sensor, it is unclear what depth is providing the maximum response.

Field Procedures:
Depressions had been previously grouped into recharge, flowthrough, or discharge wetlands based on elevation and plant species composition. Measurements were taken with the GEM300 sensor held at hip-height in the vertical dipole orientation. In-phase, quadrature phase, and conductivity data were recorded at four different frequencies (9810, 11790, 14790, and 19950 Hz) at each observation point. Although data were recorded at four different frequencies, only the data recorded at 19950 Hz are discussed in this report. Data recorded at 19950 Hz represents the shallowest depth of observation. While inphase and quadrature data were recorded and stored on disc, these values are neither shown nor discussed in this report.

The GEM300 sensor was operated in the continuous mode for the survey of Study Area A. A 120 by 225 m grid was established across the site. Sixteen survey lines were established across the study area at intervals of 15 m. The length of each survey line was 120 m. The GEM300 sensor was configured to record an observation every 1.5 seconds. Walking at a uniform pace along each of the sixteen parallel survey lines resulted in 972 observations. The locations of these observation points were processed and adjusted by the MAGMAP96 software program. The locations of these observation points are shown in Figure 1. In Figure 1, the observation points are so closely spaced that they appear as straight lines. Seventy-six additional observations were recorded with the GEM300 (sensor operated in the station mode) in depressional areas (see Figure 1). The coordinates of each of these observation points were obtained with a Rockwell PLGR.

Random traverses were made across study areas B and C. Figure 1 shows the location of these traverse lines and observation points. Depressional areas were sampled at a greater intensity than upland areas. In general, traverse lines were orientated perpendicular to and extended from the upland boundary of the low prairie vegetation into areas of open water in the center of depressions. This process provided a total of 249 and 179 observation points for study areas B and C, respectively. The coordinates of each observation point were obtained with a Rockwell PLGR.

In most EMI studies, negative conductivity values are removed by electronic nulling of the data set. The negative offset was not taken out of the EMI data recorded at Brandy Ranch. As a consequence, negative apparent conductivity values appear in the data set and simulated plots.

Results:

Study Area A:

Tables 1 to 3 summarize the results of this survey. Site #1 is a recharge wetland (see Table 1). Values of apparent conductivity were variable across the site. The averaged apparent conductivity decreased and became less variable with increasing observation depth (lower frequency). At a frequency of 19950 Hz (shallowest observation depth), apparent conductivity averaged 29.7 mS/m and ranged from 0.7 to 40.1 mS/m. One half the observations had values of apparent conductivity between 23.8 and 36.5 mS/m.

Table 1
Site #1 - Recharge Wetland
Basic Statistics for theGEM300
Apparent Conductivity
(All values are in mS/m)

			Quartiles			
Frequency	**Minimum**	**Maximum**	**1st**	**Median**	**3rd**	**Average**
9,810 Hz	17.3	28.8	20.1	23.9	25.6	23.3
11,790 Hz	19.5	35.4	22.6	28.4	31.6	27.9
14,790 Hz	12.8	35.6	24.4	29.2	31.8	28.3
19,950 Hz	0.7	40.1	23.8	32.1	36.5	29.7

Site #2 is a flowthrough wetland (see Table 2). Values of apparent conductivity were variable across the site. The averaged apparent conductivity decreased and became less variable with increasing observation depth (lower frequency). Negative values are attributed to system error or buried metallic artifacts. At a frequency of 19950 Hz (shallowest observation depth), apparent conductivity averaged 46.0 mS/m and ranged from 13.3 to 68.0 mS/m. One half the observations had values of apparent conductivity between 38.3 and 52.2 mS/m. These values are conspicuous higher than similar values obtained in the recharge wetland (Site #1). This flowthrough wetland consists of a deep and a shallow part (B. Cook, personal communication). The deep part has higher salt contents and may act as a discharge area. Flowthrough wetlands often have brackish waters and are rimmed by areas of saline soils.

Table 2
Site #2 - Flowthrough Wetland
Basic Statistics for theGEM300
Apparent Conductivity
(All values are in mS/m)

			Quartiles			
Frequency	**Minimum**	**Maximum**	**1st**	**Median**	**3rd**	**Average**
9,810 Hz	11.5	56.8	31.1	39.7	44.4	38.6
11,790 Hz	5.4	60.8	33.0	41.6	47.3	40.7
14,790 Hz	-34.9	62.0	34.8	42.9	49.5	41.0
19,950 Hz	13.3	68.0	38.3	46.6	52.2	46.0

Site #3 is a recharge wetland (see Table 3). Values of apparent conductivity were variable across the site. The averaged apparent conductivity decreased and became less variable with increasing observation depth (lower frequency). At a frequency of 19950 Hz (shallowest observation depth), apparent conductivity averaged 27.4 mS/m and ranged from 3.3 to 37.0 mS/m. One half the observations had values of apparent conductivity between 22.3 and 32.9 mS/m. For this recharge wetland, apparent conductivity values were similar to those obtained in recharge wetland #1, but were significantly lower than those obtained in flowthrough wetland #2.

Table 3
Site #3 - Recharge Wetland
Basic Statistics for theGEM300
Apparent Conductivity
(All values are in mS/m)

			Quartiles			
Frequency	**Minimum**	**Maximum**	**1st**	**Median**	**3rd**	**Average**
9,810 Hz	6.9	28.8	15.9	19.6	23.6	19.7
11,790 Hz	13.0	32.2	18.8	23.6	28.0	23.3
14,790 Hz	15.2	32.6	21.6	25.3	28.5	24.7
19,950 Hz	3.3	37.0	22.3	28.4	32.9	27.4

Spatial distributions of apparent conductivity collected at 19950 Hz with the GEM300 sensor across Study Area A are shown in Figure 2. In Figure 2, the upland boundary of the low prairie vegetation that surrounds each wetland has been defined with a dark blue line. Besides the three investigated depressions, the locations of two smaller, shallower, ephemeral wetlands have been identified. The locations of the soil sampling sites are also shown in Figure 2. In general, drier, higher-lying upland areas have values of apparent conductivity less than 20 mS/m. However, along the lower eastern boundary of Study Area A, a conspicuous area of relatively high (>35 mS/m) apparent conductivity occurs on a steeply sloping upland area. In this area, soil borings revealed soils with over-thicken A horizon (pachic). Such morphological properties are anomalous on these slope positions and are believed to represent a localized and intermittent area of groundwater discharge.

Recharge and discharge processes occur at different scales within each depression shown in Figure 2. Evaporative discharge, resulting from evapotranspiration losses from shallow groundwater (Seelig et al., 1990), occurs within and around each wetland. Leaching removes large quantities of soluble salts from recharge wetlands. However localized areas of evaporative discharge occurs near the sides of recharge wetlands that border more steeply sloping upland areas. In addition, because of evaporative concentration of the chemical constituents, high values of apparent conductivity are associated with areas of the recharge wetlands where water moves into and evaporates. It is assumed that soluble salt levels are higher in these areas.

Site #7 is a flowthrough wetland (see Table 4). Within this wetland, values of apparent conductivity were variable and reflect the co-dominance of recharge and discharge processes within the wetland. The averaged apparent conductivity decreased and became less variable with increasing observation depth (lower frequency). At a frequency of 19950 Hz (shallowest observation depth), apparent conductivity averaged 31.5 mS/m and ranged from 12.0 to 58.0 mS/m. One half the observations had values of apparent conductivity between 25.1 and 36.5 mS/m. These values are lower than those obtained in the flowthrough wetland #2, but slightly higher than values obtained in the recharge wetlands (Site #1 and #3).

Table 4
Site #7 - Flowthrough Wetland
Basic Statistics for theGEM300
Apparent Conductivity
(All values are in mS/m)

			Quartiles			
Frequency	**Minimum**	**Maximum**	**1st**	**Median**	**3rd**	**Average**
9,810 Hz	5.2	47.5	17.4	22.9	29.0	23.6
11,790 Hz	9.0	49.9	20.1	25.2	31.3	26.3
14,790 Hz	10.8	54.1	22.3	26.9	32.9	28.5
19,950 Hz	12.0	58.0	25.1	30.9	36.5	31.5

Spatial distributions of apparent conductivity collected at 19950 Hz with the GEM300 sensor across Study Area B (Flowthrough Wetland #7) are shown in Figure 3. In Figure 3, the upland boundary of the low prairie vegetation that surrounds the wetland has been defined with a dark blue line. In general, drier, higher-lying upland areas have apparent conductivity less than 20 mS/m. A pronounced "edge-effect" zone of higher apparent conductivity almost completely surrounds this flowthrough wetland. As explained by Richardson and others (1992), this zone has a shallow water table that is near the surface during most of the year. As the water evaporates, soluble salts are added to the surface along the edges of the depression. It is assumed that the added salts are the source of the noticeably higher apparent conductivity near the rim of this depression. Lower apparent conductivity in the central portion of this depression suggests a net downward flow of groundwater and the removal of chemical constituents.

Site #27 is a discharge wetland (see Table 5). Values of apparent conductivity were noticeably higher across this wetland. As with the other wetlands, the averaged apparent conductivity decreased and became less variable with increasing observation depth (lower frequency). At a frequency of 19950 Hz (shallowest observation depth), apparent conductivity averaged 51.8 mS/m and ranged from 12.1 to 90.9 mS/m. One half the observations had values of apparent conductivity between 40.3 and 62.8 mS/m. These values are higher than values obtained in either the recharge (sites #1and #3) or flowthrough (sites #2 and #7) wetlands. The higher apparent conductivity values are believed to reflect the greater concentration of soluble salts in the discharge wetland.

Table 5
Site #27 - Discharge Wetland
Basic Statistics for theGEM300
Apparent Conductivity
(All values are in mS/m)

			Quartiles			
Frequency	**Minimum**	**Maximum**	**1st**	**Median**	**3rd**	**Average**
9,810 Hz	12.1	80.0	31.9	40.9	52.7	42.7
11,790 Hz	14.0	82.3	34.9	43.8	56.2	45.9
14,790 Hz	13.7	86.0	37.6	46.7	59.2	48.5
19,950 Hz	12.1	90.9	40.3	49.1	62.8	51.8

Spatial distributions of apparent conductivity collected at 19950 Hz with the GEM300 sensor across Study Area C are shown in Figure 4. In Figure 4, the upland boundary of the low prairie vegetation that surrounds the wetland has been defined with a dark blue line. As at the other sites, drier, higher-lying upland areas have values of apparent conductivity less than 20 mS/m. The movement of groundwater enriched in soluble salts into discharge wetland alters the soil morphology and chemistry (Richardson and others, 1992). Values of apparent conductivity increase towards the central core areas of this wetland. The spatial patterns evidenced in Figure 3 suggest that a net upward and/or inward flow of groundwater and the evaporative concentration of chemical constituents in the central core areas of this depression. The "edge-effect," so conspicuous in the recharge and flowthrough wetlands, is not apparent in this plot of apparent conductivity from the discharge wetland.

Several observations were made during the course of the survey. Consistently, zonal plant communities corresponded to unique ranges of apparent conductivity. Differences in hydrology and soil salinity determine the vegetative communities. Areas with apparent conductivity values greater than 35 mS/m are in depression or at the base of slopes. These areas are assumed to have high moisture and salt contents. Areas with apparent conductivity values of 20 to 35 mS/m are common in recharge wetlands and represent saturated areas dominated by dissolution and the removal of soluble salts. Areas with apparent conductivity values of less than 20 mS/m are on higher lying, better-drained knolls. The lower soluble salt and moisture contents of these better-drained soils produce lower values of apparent conductivity.

As evident in Figure 2 to 4, apparent conductivity appears to provide a satisfactory measure to distinguish recharge, discharge, and flowthrough depressional wetlands. Recharge processes remove soluble chemical constituents and translocates suspend colloids. Within the study site, based on landscape, soil, and vegetation criteria, two depressional wetlands were designated as being recharge areas. For these wetlands, apparent conductivity averaged 28.2 mS/m with a standard deviation of 7.7 mS/m. In these wetlands, small, discontinuous areas of higher apparent conductivity occur in evaporative discharge areas.

According to Richardson and others (1992), flowthrough wetlands have intermediate levels of soluble salt and carbonates, soil profile development, and electrical conductivity. Within the study site, based on landscape, soil, and vegetation criteria, two depressions were characterized as being flowthrough wetlands. For these wetlands, apparent conductivity averaged 48.9 mS/m with a standard deviation of 13.2 mS/m. The large standard deviation reflects the intermediate characteristics of the flowthrough wetlands. In these wetlands, zones of higher apparent conductivity forms either along the rim ("edge-effect") or in the central cores of depressions.

Discharge processes adds materials to soils. Within the study site, one depressional wetland was characterized as being a discharge area. For this wetland, apparent conductivity averaged 51.8 mS/m with a standard deviation of 15.0 mS/m. In this wetland, apparent conductivity increases towards the central core areas of the depression.

Table 6
Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-value	Probability
Between	2	26804.023	13402.012	79.181	0.0001
Within	397	67194.992	169.257		
Total	399	93999.015			

Observations obtained within the upland boundary of the low prairie vegetation for each depression were extracted from the data set and grouped according to wetland type: recharge (N = 67), flowthrough (N = 222), or discharge (N = 111). An analysis of variance was performed to test whether the three populations were equally variable and that no significant differences existed among the wetland types. Table 6 shows the results of the analysis. A significant difference was found to exist between the apparent conductivity of the three wetland types. This difference suggests that the subdivision of the wetlands into three types is acceptable and that greater variations in apparent conductivity exist among than within the wetland types.

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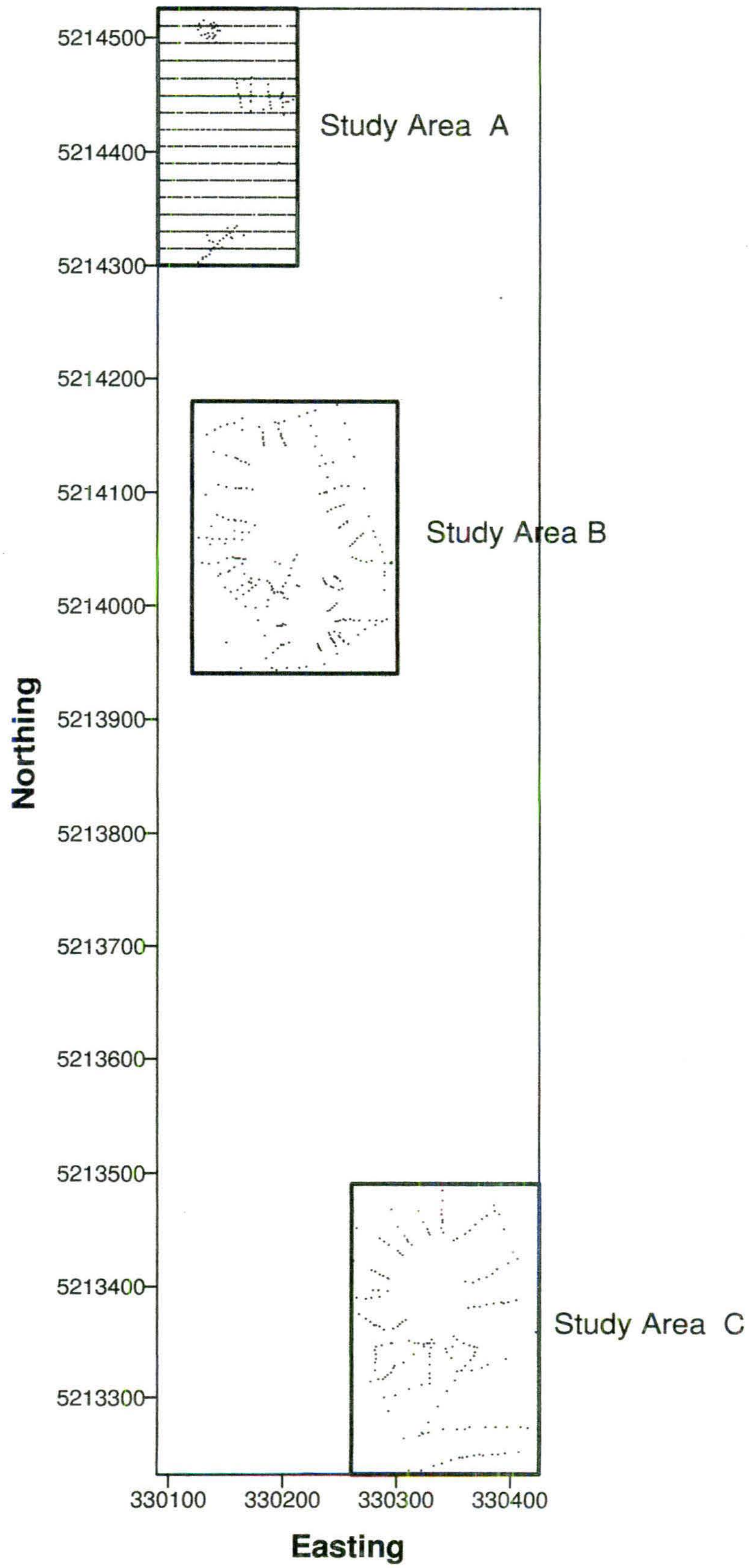
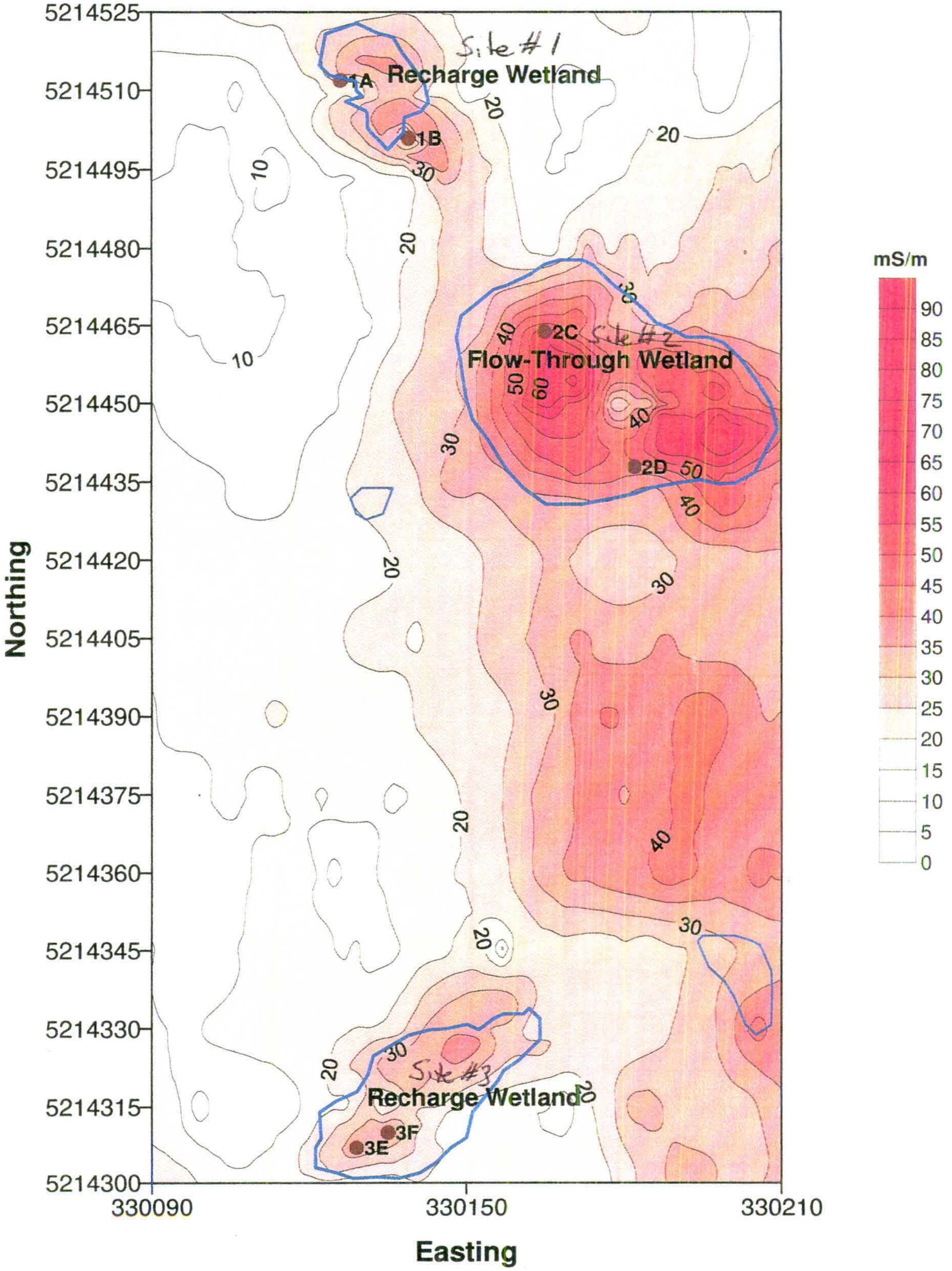
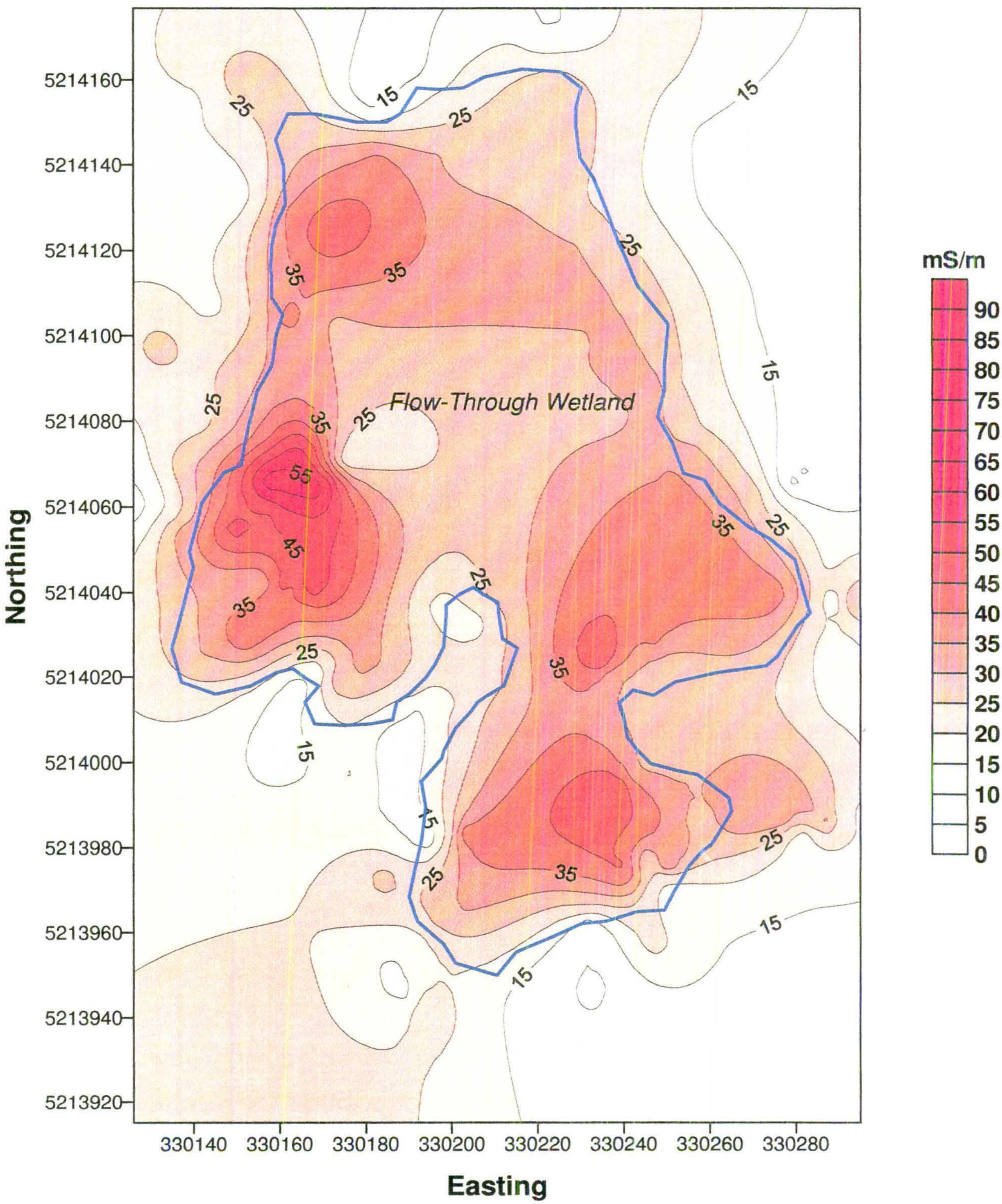
EMI SURVEY
BRANDY RANCH, MONTANA
LOCATION OF OBSERVATION POINTS



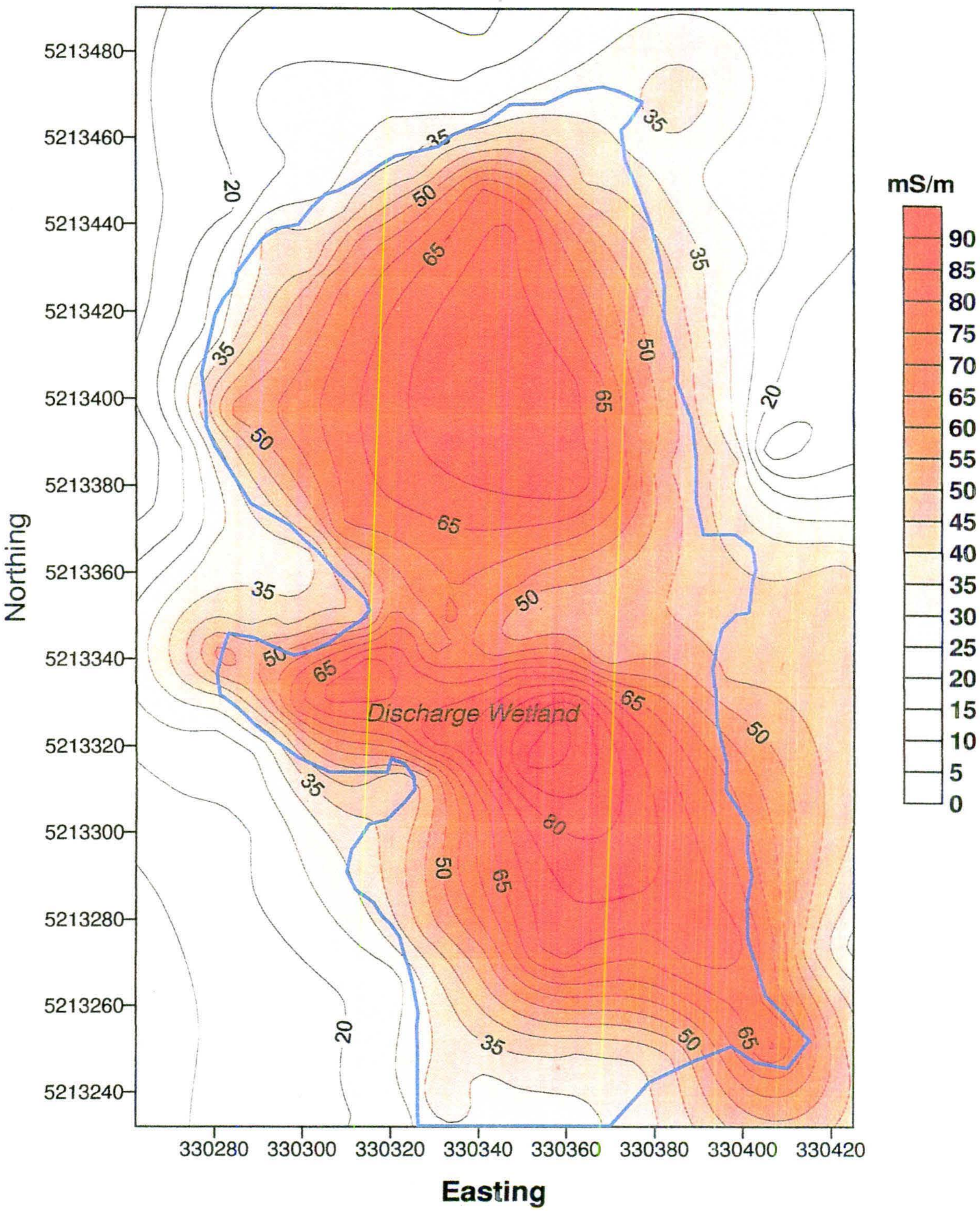
EMI SURVEY OF WETLANDS #1, 2, & 3
BRANDY RANCH, MONTANA
GEM300 SENSOR
19950 Hz



EMI SURVEY OF WETLAND #7
BRANDY RANCH, MONTANA
GEM300 SENSOR
19950 Hz



EMI SURVEY OF WETLAND #27
BRANDY RANCH, MONTANA
GEM300 SENSOR
19950 Hz



EMI SURVEY OF WETLAND #7
BRANDY RANCH, MONTANA
GEM300 SENSOR
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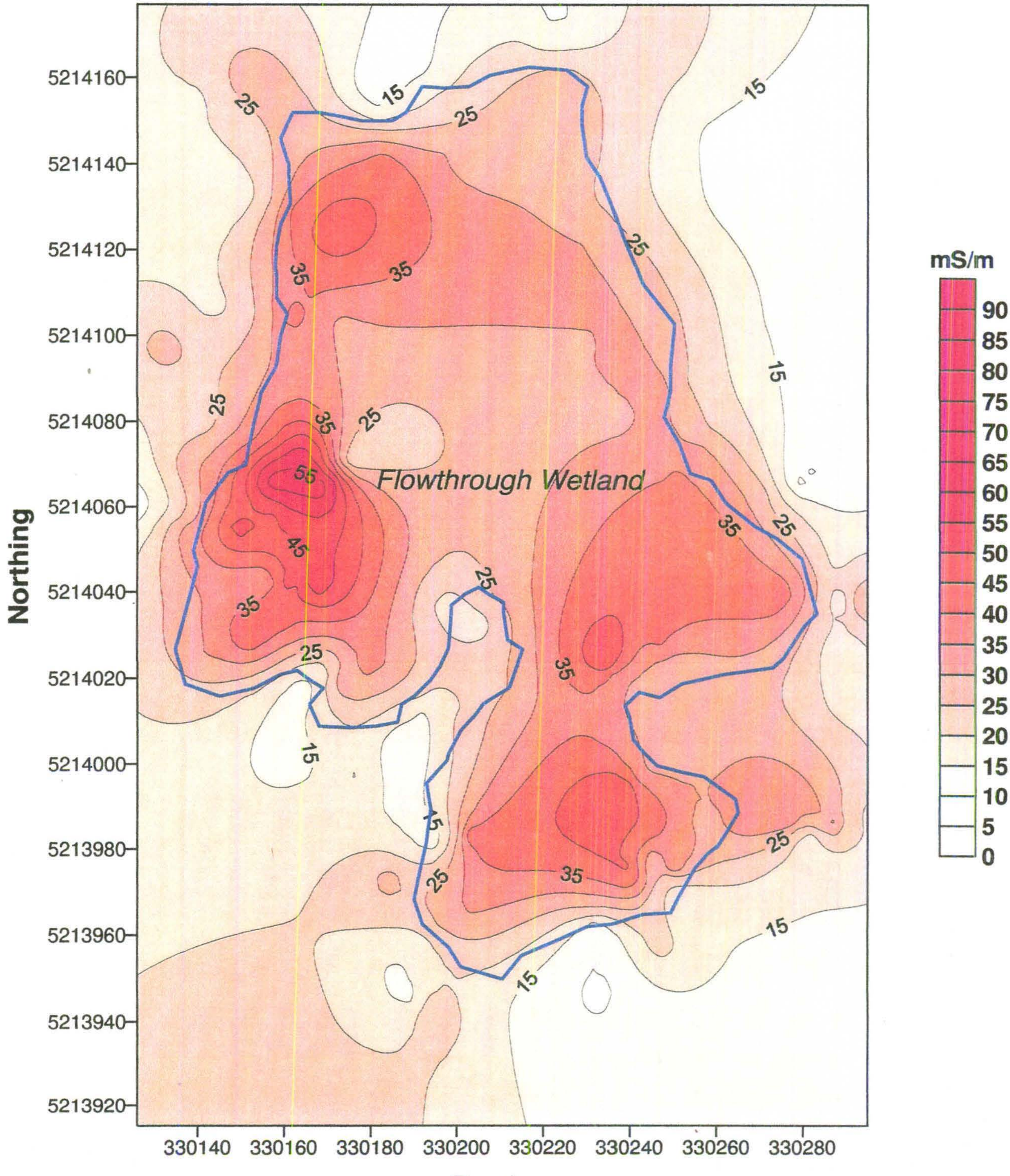
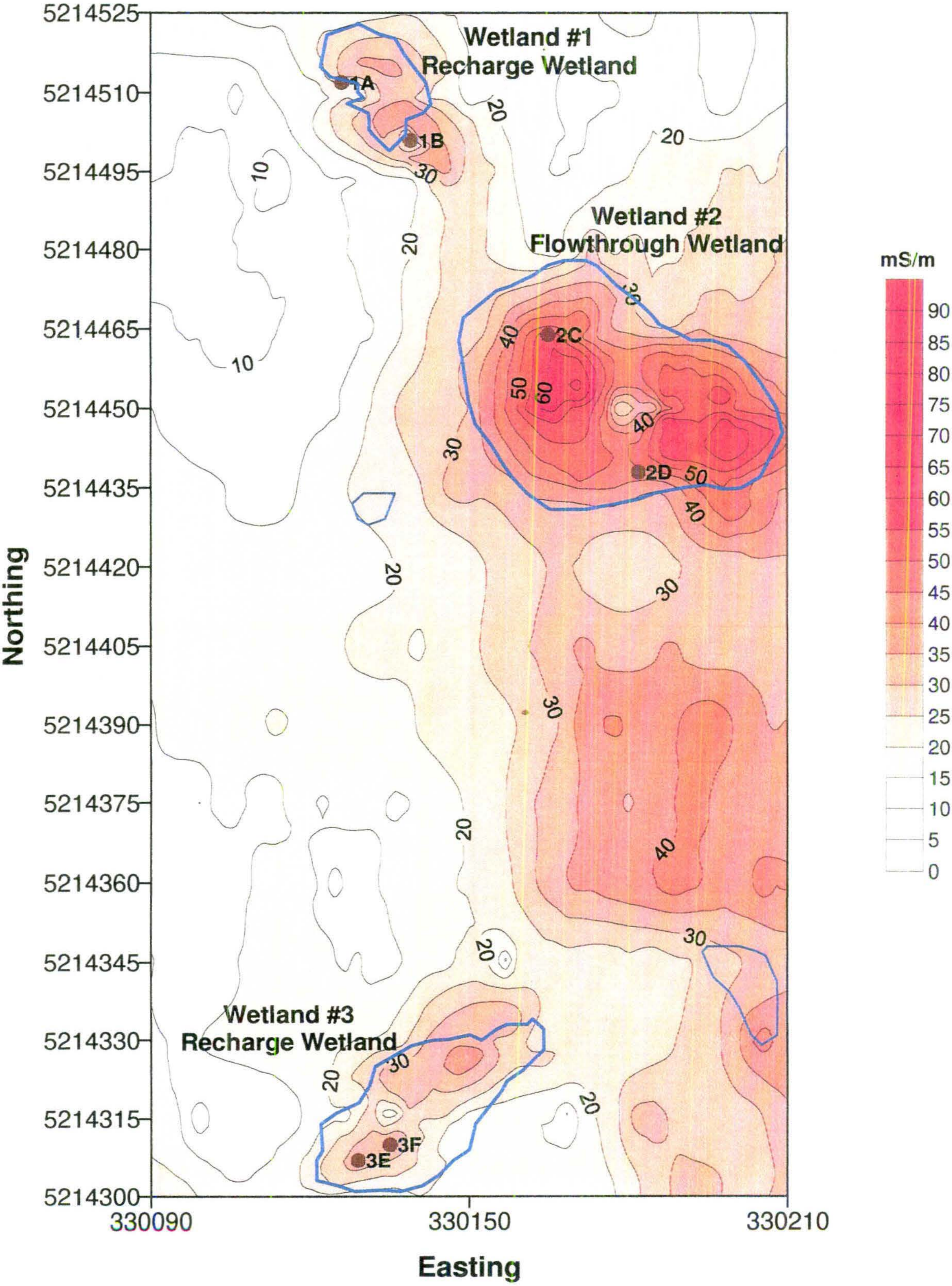


EMI SURVEY OF WETLANDS #1, 2, & 3
BRANDY RANCH, MONTANA
GEM300 SENSOR
19950 Hz



EMI SURVEY OF WETLANDS #1, 2, & 3
BRANDY RANCH, MONTANA
GEM300 SENSOR
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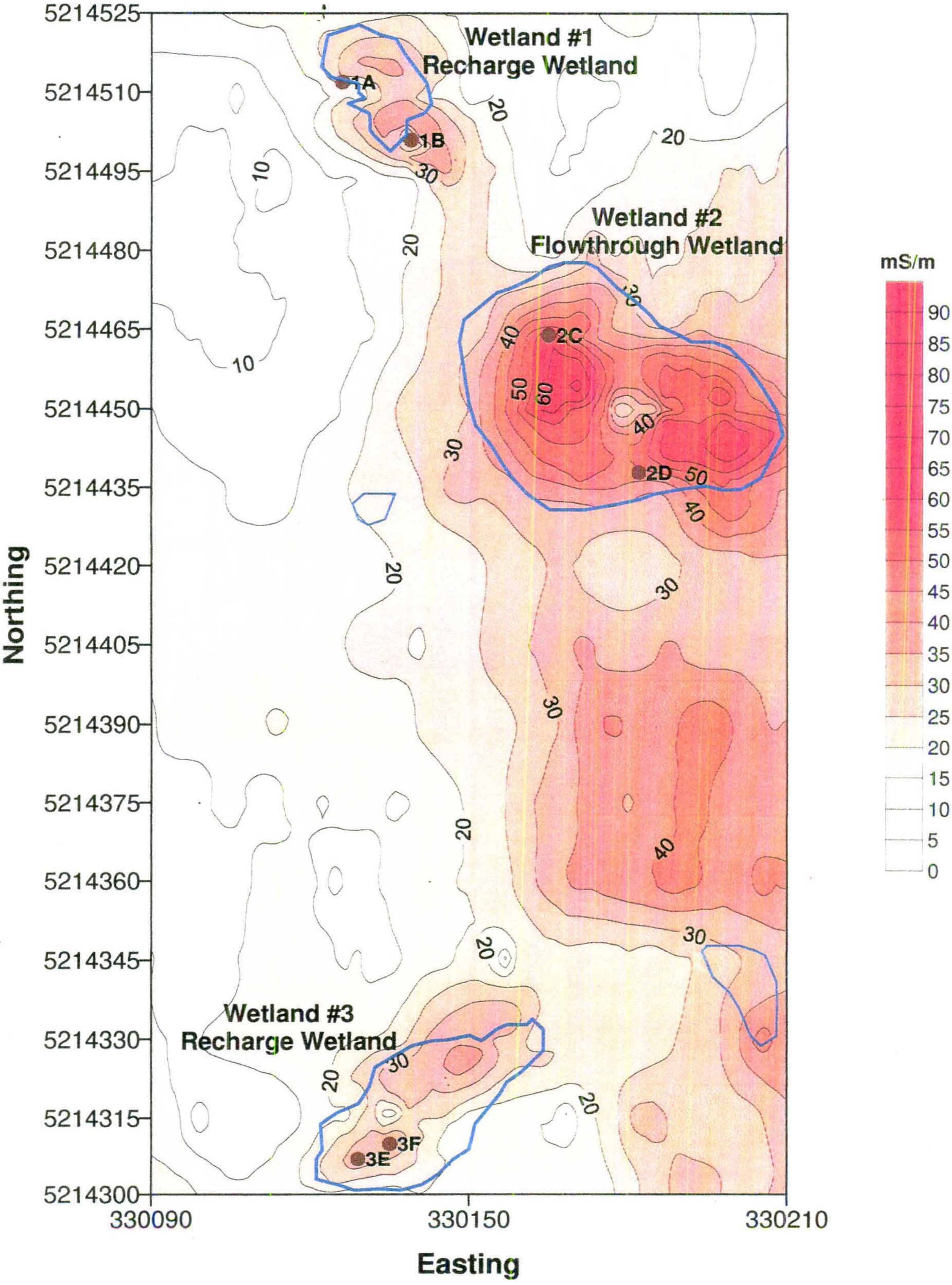

EMI SURVEY OF WETLAND #27
BRANDY RANCH, MONTANA
GEM300 SENSOR
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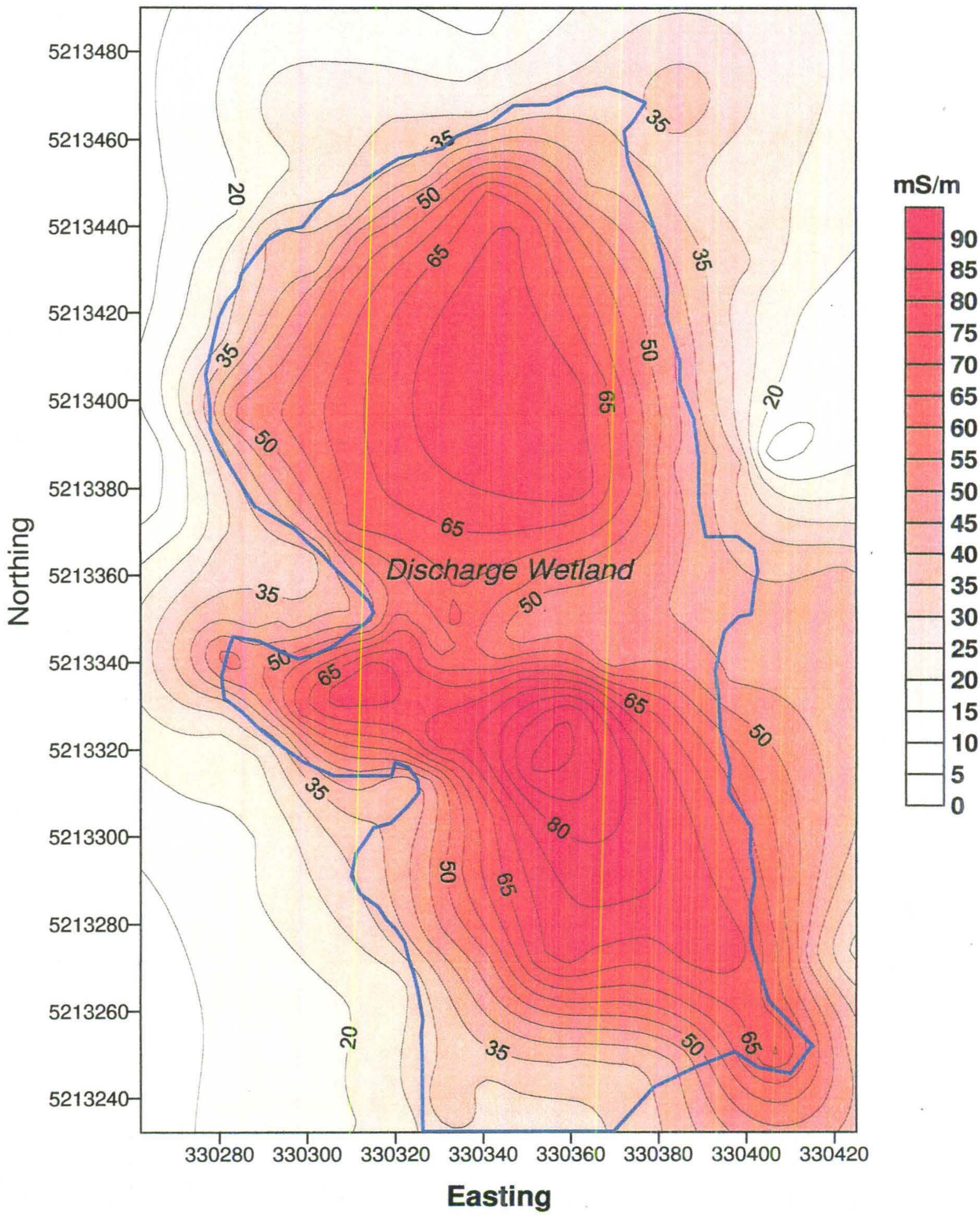
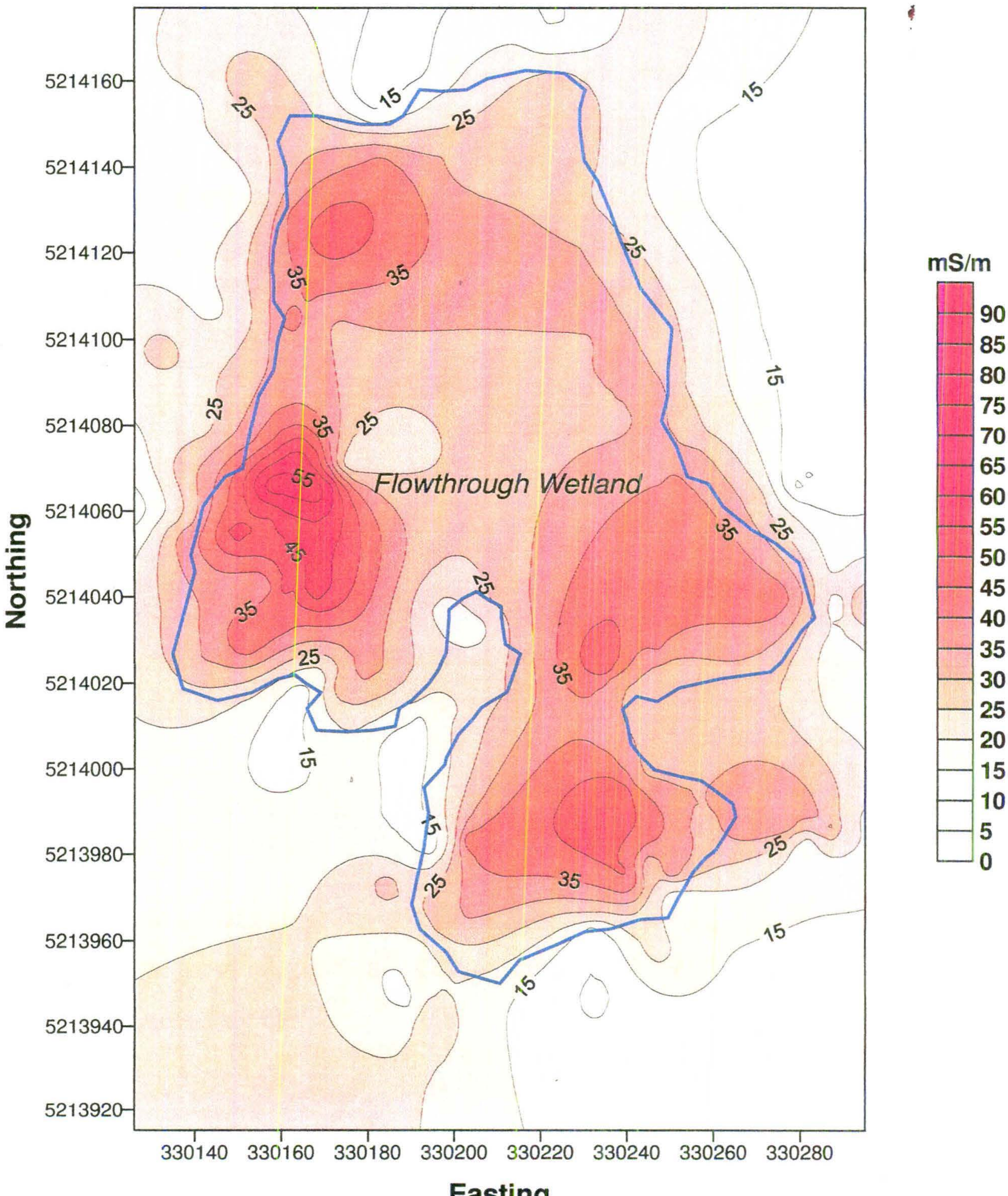


EMI SURVEY OF WETLAND #7
BRANDY RANCH, MONTANA
GEM300 SENSOR
19950 Hz



EMI SURVEY OF WETLAND #7
BRANDY RANCH, MONTANA
GEM300 SENSOR
19950 Hz