United States Department of Agriculture | **Natural Resources Conservation Service** | **11 Campus Boulevard, Suite 200 Newtown Square, PA 19073**

Subject: Soil - Geophysical Assistance **Date:** 29 October 2009

To: Serapio Flores Jr.
State Conservationist
USDA-NRCS,
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Purpose:
The purpose of this study was to further explore the use of electromagnetic induction (EMI) as a tool to assess sodium-affected soils (SAS) in North Dakota and the Northern Great Plains.

Participants:
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Mike Ulmer, Senior MO Soil Scientists, MO7, USDA-NRCS, Bismarck, ND

Activities:
All EMI activities were completed during the period of 1 to 4 October 2009.

Summary:

1. This study resulted in the refinement of survey protocol needed to efficiently conduct mobile EMI surveys in the Northern Great Plains. Experience and increased awareness to the various programs in the *ESAP Software Suite* were achieved. Collected EMI and, when processed, sampled soil profile data will be compared. The comparison of EMI and soil profile data at this and other sites in North Dakota will be used to evaluate the suitability of EMI for mapping and assessing sodium-affected (SAS) and saline soils. The comparison of data will also facilitate an evaluation of the *ESAP-Calibrate* program and the effectiveness and suitability of both its deterministic and stochastic models.

2. In general, at all study sites, EC_a increased with increasing soil depth (measurements for the shallower-sensing, 50-cm intercoil spacing were typically lower than measurements for the deeper-sensing, 100-cm intercoil spacing). This trend suggests that soluble salts increase with increasing soil depth. This vertical trend in soil salinity reflects the accepted hydropedologic processes and conceptual models for these landscapes.

3. The *Response Surface Sampling Design* (RSSD) of the *ESAP Software Suite* was used to statistically select a small set of sample locations from the EMI survey data. The use of RSSD has been accepted by soil scientists in North Dakota. The ESAP-RSSD attempts to economize the number of sample locations, while locating sampling sites that are far apart to minimize spatial autocorrelations and still be representative of the collected EMI data and spatial variabilities of soils and soil properties.

4. Based on the RSSD program, optimal soil sampling locations were identified within each study site. Samples will be collected at these locations for laboratory analysis. Results from these analyses will be used to calibrate a suitable regression equation for the prediction of soil sodicity and salinity. The sampled soil profile data will add to our inventory of soil data for North Dakota.

It was my pleasure to work in North Dakota and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

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Background:
Sodium-affected soils (SAS) extend to well over 10 million acres in the Northern Great Plains. Concerns have recently increased over the interpretation, classification, and mapping of these soils, especially after tillage and applications of modern management practices (e.g., no-till) (Mike Ulmer, personal communication). Electromagnetic induction (EMI) is a geophysical method that can quickly and non-invasively evaluate some soil properties. Presently, the effectiveness of this geophysical tool on SAS in the Northern Great Plains has not been fully established. The prime purpose of this study is to evaluate the effectiveness of EMI for the characterization of SAS.

Soil sodicity varies considerably across landscapes and within soil delineations. As a consequence, soil sodicity is difficult to measure, characterize, and manage. Soil sodicity is quantified by laboratory measurements of exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), and by field pH measurements and observations of the physical appearance of soils. Laboratory measurements are relatively time-consuming and costly, and are therefore limited in number. Surrogate field measures such as EMI have the potential to improve the mapping and management of SAS. In areas of SAS, the use of EMI is considered more expedient and economical than conventional laboratory determinations of ESP, SAR, pH, and electrical conductivity of the saturated paste (EC_e). Because of the larger number of measurements that can be quickly obtained with EMI, more comprehensive and detailed surveys of SAS delineations and management units can be conducted than with traditional sampling methods. However, in order to establish relationships between SAR and apparent conductivity (EC_a) and to develop predictive equations, the collection of a small number of soil samples for laboratory analysis is necessary with EMI.

Over the years, EMI has been limitedly used to study sodic soils (Amezketa, 2007; Corwin et al., 2003a; Nelson et al., 2002; Nettleton et al., 1994, Ammons et al., 1989). Ammons et al. (1989) used EMI to distinguish Natraqualfs in Tennessee. Nettleton et al. (1994) observed relatively strong relationships between EC_a, ESP, and EC_e. These researchers concluded that EMI provides a rapid and accurate method for describing the composition of SAS map units in south-central Illinois. Sodium-affected soils in Illinois are typically non-saline and lack significant concentrations of soluble salts. In California, Corwin et al. (2003a) used EMI on saline-sodic soils. Their study resulted in correlation coefficients that ranged from 0.70 to 0.82 between EC_a and EC_e, SAR, SO_4, Na, and Mg. However, correlation coefficients were noticeably lower (0.31 to 0.32) between EC_a and ESP. In a study conducted by Amezketa (2007) in Spain, a strong and significant correlation ($r = 0.91$) was observed between SAR and EC_a. However, the strength of this correlation was attributed to the significant auto-correlation between SAR and EC_e. The significant auto-correlation between EC_e and SAR was attributed to "evapo-concentration processes that occur in saline-sodic soils" (Amezketa, 2007). Significant auto-correlations between EC_e and SAR were also reported in studies conducted by Corwin et al. (2003a) and Nelson et al. (2002). In studies conducted by Nelson et al. (2002) on saline-sodic soils in Australia, EC_a measurements were reasonably correlated with ESP. However, on nonsaline-sodic soils, no relationships were observed between EC_a and ESP. Contrary to the findings of Nelson et al. (2002), Nettleton et al. (1994) observed significant correlations between EC_a and ESP on nonsaline-sodic soils.

Equipment:
An EM38-MK2-2 meter (Geonics Limited; Mississauga, Ontario), was used in this investigation.[1] The EM38-MK2-2 meter requires no ground contact and only one person to operate. The EM38-MK2-2 meter operates at a frequency of 14,500 Hz and weighs about 5.4 kg (11.9 lbs). The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter coil by distances of either 1.0 or 0.5 m. This configuration provides nominal depth of penetration ranges of about 1.5 and 0.75 m in the vertical dipole orientation and about 0.75 and 0.40 m in the horizontal dipole orientation. In either dipole orientation, the EM38-MK2-2 meter provides measurements of both the quadrature-phase (EC_a) and the in-phase (susceptibility) components within the two depth ranges. Apparent conductivity is typically expressed in milliSiemens/meter (mS/m). Susceptibility is expressed parts per thousand (ppt). Operating procedures for the EM38-MK2-2 meter are described by Geonics Limited (2007).

A Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced the EMI data.[1] Using the RTmap38 program (Geomar Software, Inc., Mississauga, Ontario), both GPS and EC_a data were simultaneously recorded and displayed on an Allegro CX field computer (Juniper Systems, North Logan, UT).[1]

The ESAP Software Suite for Windows (Version 2.35R) developed by the USDA-ARS, Salinity Laboratory (Riverside, CA) was used to create optimal soil sampling schemes based on EC_a data and to estimate soil salinity (EC_e) (Lesch et al., 2000).

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

The ESAP-RSSD (*Response Surface Sampling Design*) software was used to generate optimal sampling schemes and identify sampling locations. The *ESAP-Salt Mapper* software was used to prepare raster maps showing plots of EC_a data with the positions of the sampling locations. The *ESAP-Calibrate* software was used to estimate EC_e from the collected EC_a survey data.

To help summarize the results of the EMI surveys, the SURFER for Windows (version 9.0) software (Golden Software, Inc., Golden, CO) was used to construct the two-dimensional simulations shown in this report.[2] Grids were created using kriging methods with an octant search.

Study Site:
The two study sites are located in on adjoining areas of Billings and Stark Counties. The Billings County site is in cultivation (grain stubble) and the Stark County site is in rangeland. Figure 1 is the soil map of the study area from the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm). In Figure 1, rectangles have been used to identify the areas that were surveyed with EMI.

Figure 1. Soil map of the Billings (left) and Stark (right) County Sites.

The Billings County site is located in the NW ¼ of Section 12, T. 139 N., R. 100 W. Within the Billings County site, soils are mapped as Daglum-Rhoades complex, 0 to 6 % slopes (15B); Sen-Janesburg silt loams, 0 to 6 % slopes (31B); and Janesburg-Dogtooth silt loams, 3 to 6 % slopes (E0563B). The deep and very deep, moderately well drained and well drained Daglum

[2] Manufacturer's names are provided for specific information; use does not constitute endorsement.

soils formed in clayey alluvium or residuum on upland swales. The deep and very deep, well drained and moderately well drained Rhoades soils formed in stratified loamy and clayey materials derived from soft shale, siltstone or mudstone on uplands. The well drained Sen soils formed in calcareous siltstone or shale on upland plains. Sen soils are moderately deep to soft bedrock. The moderately deep, well drained Janesburg and Dogtooth soils formed in residuum weathered from alkaline, soft shale, siltstone and/or mudstone on uplands. The taxonomic classifications of these soils are listed in Table 1.

The Stark County site is located in the NE ¼ of Section 7, T. 139 N., R. 99 W. Within the Stark County site, soils are mapped as Janesburg-Dogtooth silt loams, 2 to 6 % slopes (E0563B); Lawther-Daglum complex, 2 to 6 % slopes (E0634B); Cabba-Chama-Sen silt loams, 9 to 15 % slopes (E2741D); and Lambert-Badlands outcrop-Cabba complex, 6 to 45 % slopes (E3185F). The very deep, well drained Lawther soils formed in calcareous clayey sediments on uplands. The shallow, well drained Cabba soils formed in residuum or colluvium derived from semi-consolidated, loamy sedimentary beds on sedimentary plains. The moderately deep, well drained Chama soils formed in materials weathered from soft siltstone, mudstone and shale on uplands. The very deep, well drained Lambert soils formed recent alluvium on uplands. The taxonomic classifications of these soils are also listed in Table 1.

Table 1. Taxonomic classifications of the soils recognized at the Billings County study sites.

Soil Series	Taxonomic Classification
Cabba	Loamy, mixed, superactive, calcareous, frigid, shallow Typic Ustorthents
Chama	Fine-silty, mixed, superactive, frigid Typic Calciustolls
Daglum	Fine, smectitic, frigid Vertic Natrustolls
Dogtooth	Fine, smectitic, frigid Leptic Natrustolls
Janesburg	Fine, smectitic, frigid Typic Natrustolls
Lambert	Fine-silty, mixed, superactive, calcareous, frigid Typic Ustorthents
Lawther	Fine, smectitic, frigid Typic Haplusterts
Rhoades	Fine, smectitic, frigid Leptic Vertic Natrustolls
Sen	Fine-silty, mixed, superactive, frigid Typic Haplustolls

Survey Procedures:

The EMI surveys were completed by towing the EM38-MK2-2 meter, which was mounted in a plastic sled, behind an ATV at speeds of 3 to 4 m/sec. Mobile surveys were completed by driving the ATV at a uniform speed in a back and forth manner across each site. It was raining during the EMI survey and the surface soil layers, where exposed, were wet and sticky. The EC_a data discussed in this report were temperature corrected to a standard temperature of 25^o C. In each field, the soil temperature was measured at a depth of 50 cm. In the stubble field (Billings County), the recorded temperature was 11^o C (52^o F); in the rangeland (Stark County), the recorded temperature was 13^o C (56^o F). The observed soil in the rangeland was more friable than the soil observed in the stubble field.

All collected EC_a data were entered into an Excel spreadsheet and processed thru the ESAP (version 2.35) software program (Lesch, 2000). The *Response Surface Sampling Design* software program of ESAP was used to generate an optimal sampling design for each field based on the EC_a data. Based on the results of the RSSD program, six optimal sampling locations were selected from the EC_a data collected in each site. The six optimal sampling locations that were generated for each study sites are shown in Figure 2.

For each EMI survey, plots of EC_a data were prepared using the SURFER for Windows program (version 9.0). Plots of EC_a data showing the locations of the optimal sampling locations for each study site were compiled and copies supplied to soil scientists involved in soil sampling. At a later time, these sampling locations will be cored with the soils described and sampled for laboratory characterization.

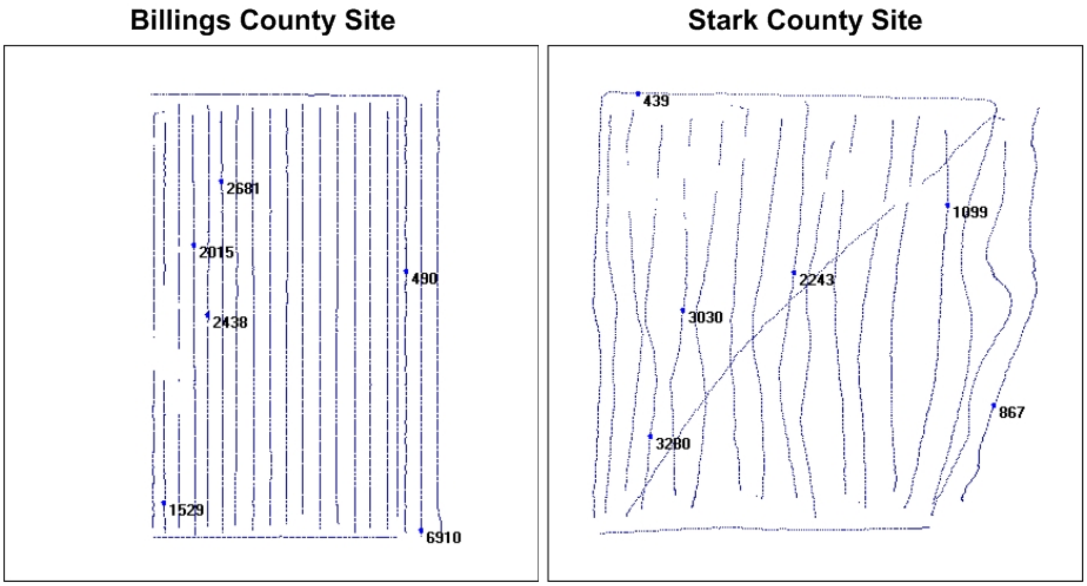

Figure 2. The six point, response surface sampling designs for the Billings (left) and Stark (right) Counties sites are displayed in these plots. Sample locations are identified by their observation numbers. Also shown in these plots are the locations of EMI measurement points and the tracks of the mobile EMI platform.

Results:
EMI Surveys:
At both SAS study sites, EC_a increased with increasing soil depth (measurements for the shallower-sensing, 50-cm intercoil spacing were lower than measurements for the deeper-sensing, 100-cm intercoil spacing). This trend suggests that the concentration of soluble salts increases with increasing soil depth. This vertical trend is considered a reflection of prevailing hydropedologic processes (e.g., depth to the water table, seepage, leaching, and evaporative discharge). Within each study site the range in EC_a for both effective penetration depths was relatively large with standard deviations of 38.60 and 50.41 for the shallow measurements and 53.15 and 68.80 for the deeper measurements at the Billings and Stark County sites, respectively. The variability in EC_a is inferred to largely reflect the presence, concentration, and distribution of sodium and soluble salts within soil profiles and across the landscape. As Daglum, Dogtooth, Janesburg, and Rhoades soils have an EC_e greater than 4 dS/m and SAR greater than 13 (http://soildatamart.nrcs.usda.gov) in some horizon within depths of 100 cm, they are all considered to be saline-alkaline soils (U.S. Salinity Laboratory Staff, 1954).

Table 2. Basic statistics for EMI surveys conducted in Billings and Stark Counties.

	Billings County 0 to 150 cm	**Billings County 0 to 75 cm**	**Stark County 0 to 150 cm2**	**Stark County 0 to 75 cm**
Observations	7120	7120	4171	4171
Minimum	48.82	-27.07	32.66	-0.30
25 % tile	129.22	65.26	71.79	24.64
75 % tile	182.94	102.96	180.36	106.82
Maximum	441.99	367.22	482.39	369.90
Average	160.36	87.40	132.74	69.31
Standard Deviation	53.15	38.60	68.80	50.41

Table 2 provides the basic statistics for the two EMI surveys. At the Billings County site, EC_a averaged about 160 mS/m and ranged from about 49 to 442 mS/m for measurements obtained with the deeper-sensing, 100-cm intercoil spacing. One-half the EC_a measurements acquired with the 100-cm intercoil spacing were between about 129 and 183 mS/m. At the Billings County site, for the shallower-sensing, 50-cm intercoil spacing, EC_a averaged about 87 mS/m and ranged from about -27 to 367 mS/m. Negative measurements are attributed to the presence of metallic artifacts scattered across the site and flawed meter calibration. At the Billings County site, one-half the measurements obtained with the 50-cm intercoil spacing were between about 65 and 103 mS/m.

At the Stark County site, EC_a averaged about 133 mS/m and ranged from about 33 to 482 mS/m for measurements obtained with the deeper-sensing, 100-cm intercoil spacing. One-half the EC_a measurements acquired with the 100-cm intercoil spacing were between about 72 and 180 mS/m. At the Stark County site, for the shallower-sensing, 50-cm intercoil spacing, EC_a averaged about 69 mS/m and ranged from about 0 to 370 mS/m. At the Stark County site, one-half the measurements obtained with the 50-cm intercoil spacing were between about 25 and 107 mS/m.

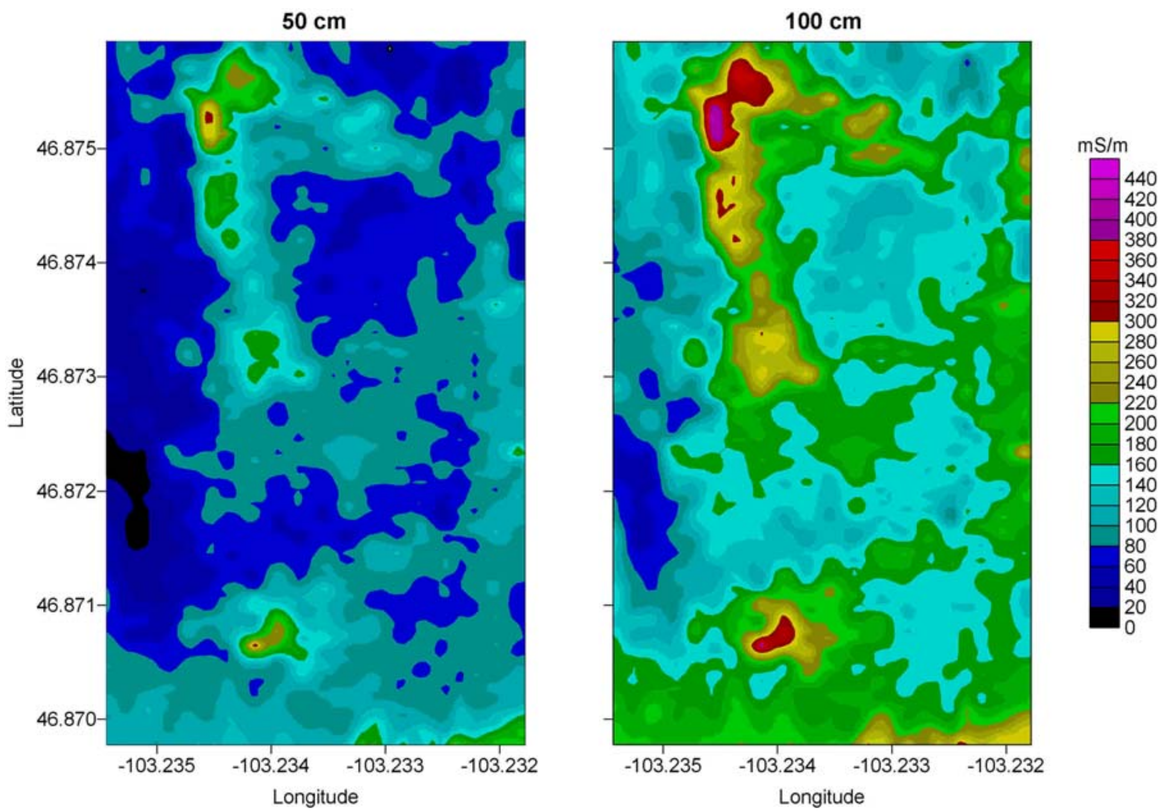

Figure 3. These plots of EC_a data were collected at the Billings County site. The left-hand and right-hand plots show the spatial distribution of EC_a recorded with the EM38-MK2-2 meter in the shallower-sensing 50-cm, and the deeper-sensing 100-cm intercoil spacings, respectively.

Figures 3 and 4 contain plots of the EC_a data collected with EM38-MK2-2 meter at the Billings and Stark County sites, respectively. In all plots, similar color scales and ramps have been used. At each site, similar spatial EC_a patterns were obtained from measurements obtained with the two intercoil spacings. While the spatial patterns are similar, the amplitudes of the recorded measurements were higher in the deeper-sensing, 100-cm intercoil spacing. At both sites, spatial EC_a patterns were visually correlated with landscape features. In general, EC_a appeared higher in exposed or shallow to soft bedrock areas, seepage areas, and swales.

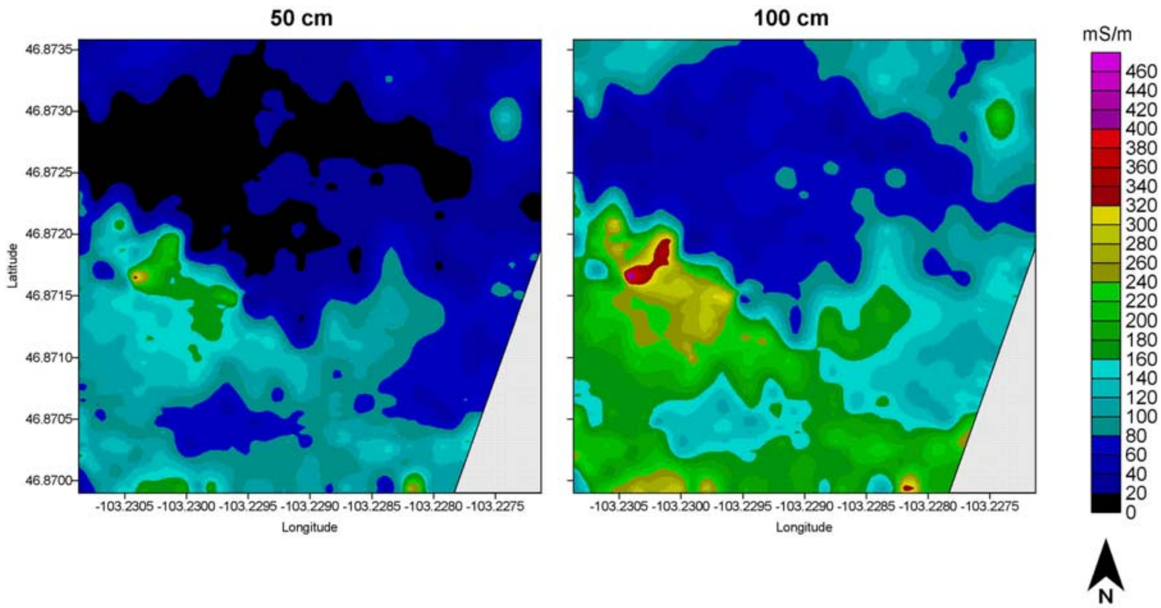

Figure 4. These plots of EC_a data were collected at the Stark County site. The left-hand and right-hand plots show the spatial distribution of EC_a recorded with the EM38-MK2-2 meter in the shallower-sensing, 50-cm, and the deeper-sensing, 100-cm intercoil spacings, respectively.

Directed-Sampling:

As a tool for precision agriculture and high intensity soil surveys, spatial EC_a data are often used to direct soil sampling, refine maps, and as ancillary measures for spatially varying soil properties that are not easily sensed or mapped (Jaynes, 1995; Stafford, 2000). In order to be effectively used, however, the spatially varying soil property must strongly correlate with EC_a. Recently, the USDA-ARS Salinity Laboratory (Riverside, California) has developed software to select optimal soil sampling locations based on EC_a data (Lesch, 2005; Lesch et al., 2000, 1995a, 1995b). The USDA-ARS's ESAP (*EC_e Sampling, Assessment, and Prediction*) software was originally designed to predict soil salinity (EC_e) from EC_a data. The ESAP program embraces prediction-based sampling and modeling approaches as a cost-effective alternative to geostatistical modeling techniques, which are often more sample-intensive (Eigenberg et al., 2008). The ESAP software is designed to combine high-intensity EC_a data with sparse, low-density soil sampling in order to calibrate a suitable predictive equation. A goal of this prediction-based sampling approach is to statistically select a small number of sample locations from the EC_a survey data. The ESAP software, however, has been used to predict soil properties other than soil salinity. Amezketa (2007) used ESAP to determine levels of sodicity in saline-sodic soils. Hunsaker et al. (2009) used ESAP to infer the spatial variability of basal crop coefficients and crop water use from normalized difference vegetation indices (NDVI) obtain from aerial images. Fitzgerald et al. (2006) used ESAP to predict crop height and width attributes from aerial imagery. Eigenberg et al. (2008) used ESAP to assess and manage the flow of liquid cattle wastes within vegetative treatment areas.

The ESAP-*Response Surface Sampling Design* (RSSD) program can generate three different directed-sampling plans (6, 12, and 20 sample locations). The selection of the most suitable sampling design will depend on site and soil conditions, availability of resources, and intensity or use of the survey. In this directed-sampling approach, a minimum number of calibration sample locations are selected based on the observed magnitudes and spatial distribution of EC_a data (Eigenberg et al., 2008). The sampling locations are selected to statistically optimize the estimation of a regression model and to simultaneously maximize the average separation distance among sample locations. Sample locations are representative of the total variation of EC_a and, expectantly, the targeted soil property (Corwin et al., 2006). This directed-sampling approach has been described as a hybrid blend of a response surface sampling design with a space-filling algorithm (Eigenberg et al., 2008; Lesch, 2005).

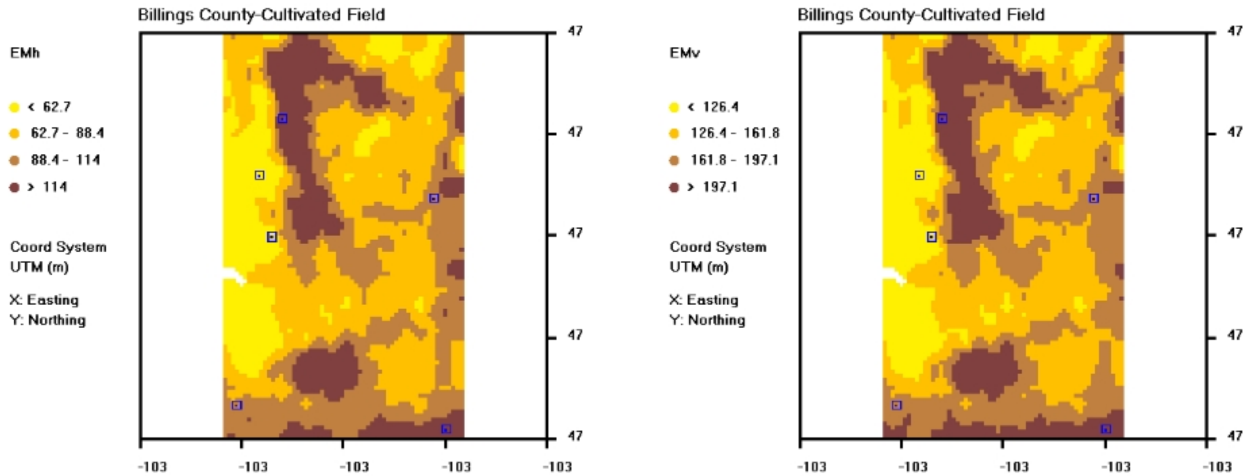

Figure 5. These raster maps of EC_a data collected at the Billings County site were prepared using ESAP-SaltMapper Program. The left and right-hand plots show the spatial distribution of EC_a in the shallower-sensing, 50-cm; and the deeper-sensing, 100 cm dipole spacings, respectively. The positions of the six optimal sampling locations, which were determined using ESAP-Response Surface Sampling Design, are shown in each map.

Raster maps (Figures 5 and 6) of depth-weighted EC_a data obtained with the EM38-MK2-2 meter were prepared using the ESAP-*SaltMapper* program, which employs an inverse distance-squared interpolation (Lesch et al., 2000). The raster maps shown in Figures 5 and 6 reveal spatial EC_a patterns (for the 50- (EMh) and 100- (EMv) cm intercoil spacings) and the positions of the six optimal sample locations for Billings and Stark Counties, respectively. Table 3 provides pertinent data for the six optimal sampling locations within the Billings and Stark Counties sites.

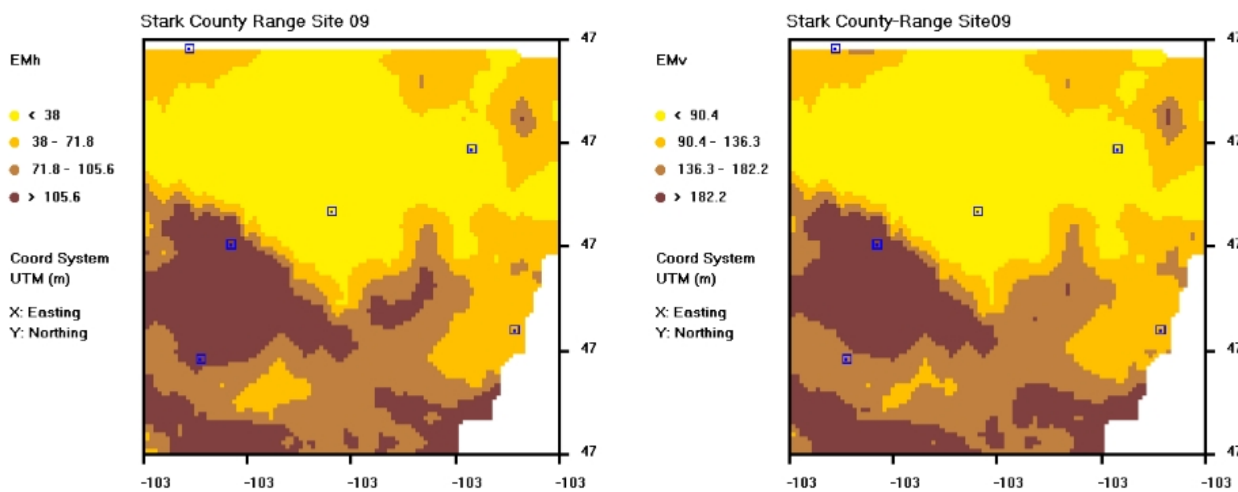

Figure 6. These raster maps of EC_a data collected at the Stark County site were prepared using the ESAP-SaltMapper Program. The left and right-hand plots show the spatial distribution of EC_a in the shallower-sensing, 50-cm; and the deeper-sensing, 100-cm dipole spacings, respectively. The positions of the six optimal sampling locations, which were determined using ESAP-Response Surface Sampling Design, are shown in each map.

Table 3. Critical data for the six sampling locations selected in Billings and Stark Counties. These optimal sampling locations were selected using the ESAP-RSSD Program.

Billings County

Observation #	Longitude	Latitude	EC_a 0 to 175 cm	EC_a 0 to 75 cm
490	-103.23223	46.87346	154.0	81.2
1529	-103.23528	46.87026	160.4	86.7
2015	-103.23491	46.87381	88.4	42.3
2438	-103.23473	46.87286	90.0	36.3
2681	-103.23456	46.87469	275.1	161.1
6910	-103.23203	46.86988	273.5	189.9

Stark County

Observation #	Longitude	Latitude	EC_a 0 to 175 cm	EC_a 0 to 75 cm
439	-103.23049	46.87357	110.3	45.6
867	-103.22751	46.87098	118.0	51.6
1099	-103.22790	46.87265	49.9	9.5
2243	-103.22918	46.87208	56.5	18.4
3030	-103.23011	46.87177	342.8	232.2
3280	-103.23039	46.87072	180.0	124.7

Deterministic Model:

Apparent soil electrical conductivity can be correlated with any soil property that significantly influences the EC_a measurements (Corwin and Lesch, 2005). The ESAP-Calibrate program is designed to estimate a calibration equation that can be used to predict values of a soil attribute from the EC_a survey data. Two models are available in ESAP-Calibrate: a *deterministic* and a *stochastic model*. The deterministic model does not require (as does the stochastic model) soil sample characterization data, but can only be used to estimate soil salinity (EC_e) from EC_a survey data. The deterministic model also requires the collection of EC_a data in two dipole orientations or intercoil spacings. The stochastic model requires the collection and analysis of soil sample data (from sample locations selected by RSSD program), but can be used to predict soil attributes other than EC_e alone. In addition, the stochastic model can use EC_a data collected in only one dipole orientation (an advantage for mobile EMI surveys conducted with an EM38 meter).

In the deterministic model, the *dual pathway parallel conductance* (DPPC) *model* (Rhoades et al., 1989a, 1989b, 1990; Corwin and Lesch, 2003b) is used to convert EC_a to EC_e based on knowledge of other soil properties. The DPPC model is based on the idea that soil electrical conductivity can be modeled by a multi-pathway parallel electrical conductance equation. In this model, soil electrical conductivity is reduced to a nonlinear function of five soil physiochemical properties: EC_e, saturation potential, volumetric soil water content, bulk density, and soil temperature (Corwin and Lesch, 2005). The deterministic approach is the preferred approach, when significant localized variations in soils exist in the survey area (Corwin and Lesch, 2005). This approach, however, requires knowledge of soil properties (e.g., soil water content, saturation potential or clay content, bulk density, and temperature) (Corwin and Lesch, 2005). Errors in the estimation of any one of these soil properties will produce inaccuracies in the predictive model. In this study, when using the deterministic model, unease was felt concerning the selection of the averaged soil's clay and soil water contents which varied both vertically and spatially across each site.

Figures 7 and 8 show the spatial and depth distributions of EC_e that were estimated using the deterministic model for the Billings and Stark County sites, respectively. At both sites, soil salinity has been estimated to increase with increasing soil depths. At both sites, soils are dominantly non-saline (<2 dS/m) and very slightly saline (2 to < 4 dS/m) in the upper 30 cm. For the 30 to 60 cm depth interval, soils were dominantly very slightly and slightly (4 to <8 dS/m) saline at the Billings County site (collectively, 62 %), but remained largely non-saline and very slightly saline at the Stark County site (collectively, 57 %). For the 60 to 90 cm depth interval, soils were mostly moderately (8 to <16 dS/m) and strongly (>16 dS/m) saline at both sites (92 % and 62 % at the Billings and Stark County sites, respectively). The estimated salinity class distributions for the three depth intervals at the Billings and Stark County sites are provided in Table 4.

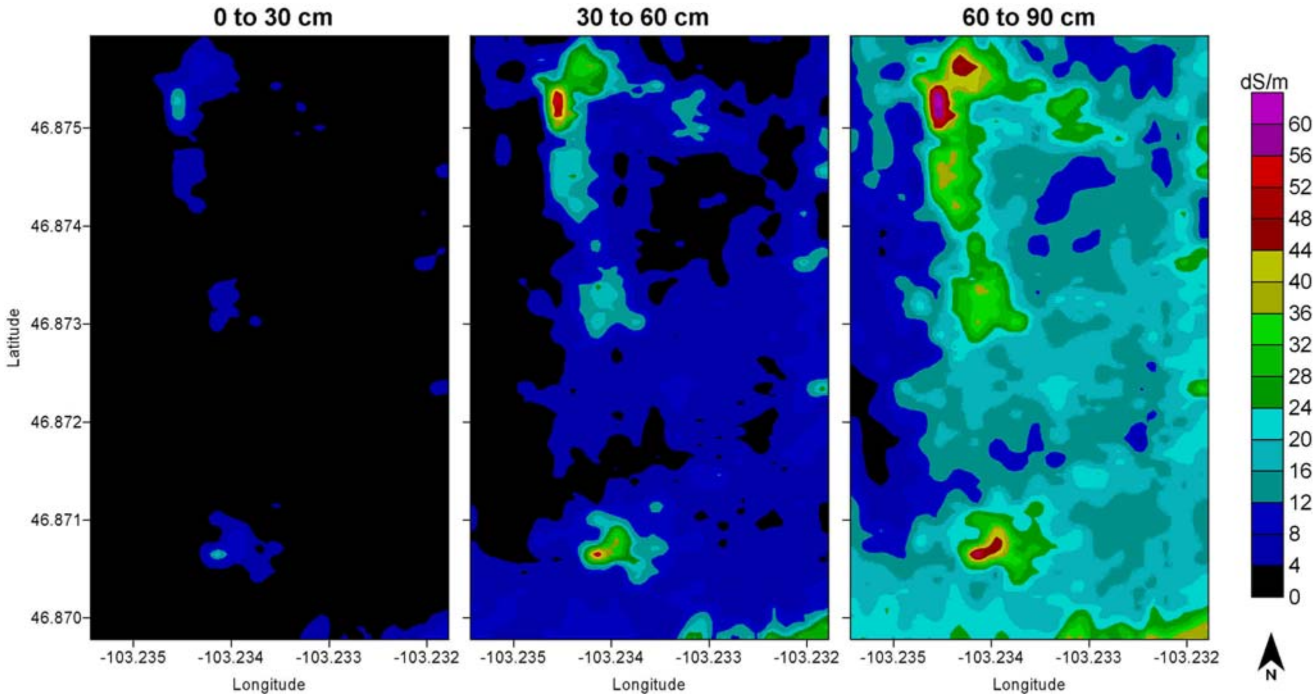

Figure 7. These plots of spatial EC_e data at the Billings County site were derived using the deterministic model in ESAP-Calibrate. The plots show (from left to right) the spatial distribution of EC_e within the 0 to 30, 30 to 60, and 60 to 90 cm depth intervals.

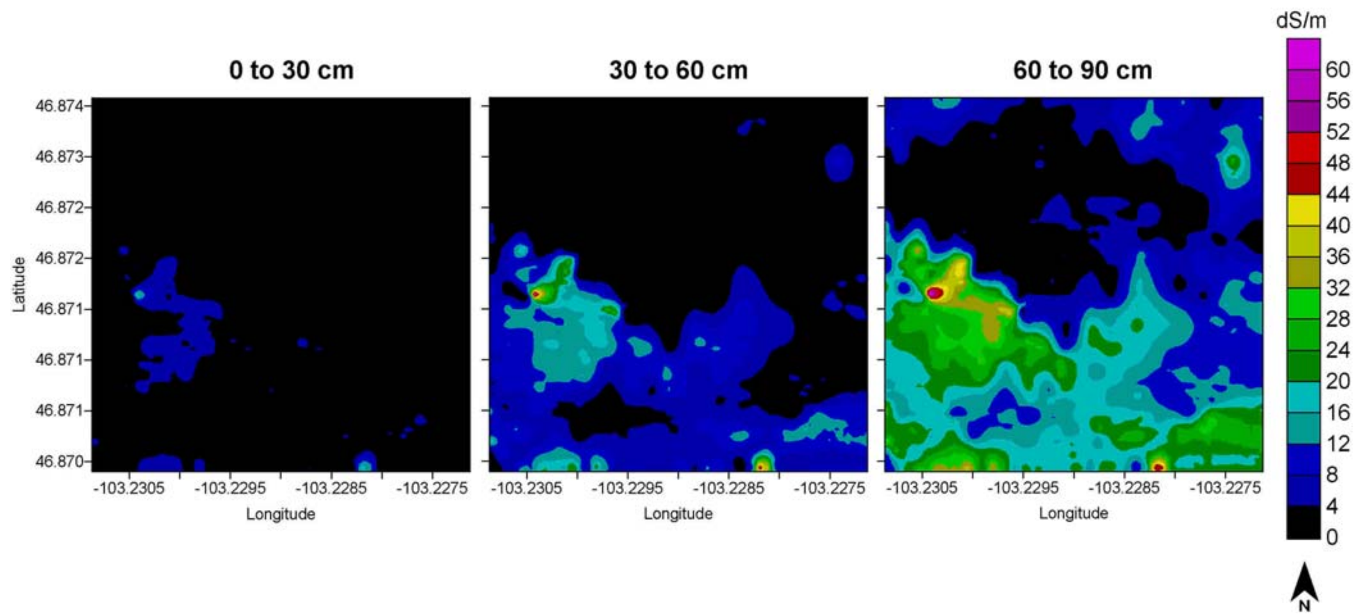

Figure 8. These plots of spatial EC_e data at the Stark County site were derived using the deterministic model in ESAP-Calibrate. The plots show (from left to right) the spatial distribution of EC_e within the 0 to 30, 30 to 60, and 60 to 90 cm depth intervals.

Table 4. Estimates of Salinity Class distributions (by %) for three different depth intervals at the two study sites.

Billings County site

	0-30 cm	30-60 cm	60-90 cm
Non-saline	0.78	0.15	0.00
Very slightly	0.15	0.21	0.01
Slightly	0.05	0.41	0.07
Moderately	0.01	0.18	0.42
Strongly	0.00	0.05	0.50

Stark County site

	0-30 cm	30-60 cm	60-90 cm
Non-saline	0.73	0.45	0.10
Very slightly	0.19	0.12	0.13
Slightly	0.07	0.15	0.15
Moderately	0.01	0.23	0.26
Strongly	0.00	0.04	0.36

Basic statistics for the estimated EC_e at the Billings and Stark County sites are listed in Tables 5 and 6, respectively. Comparing the two adjoining sites, at all depth intervals, the averaged EC_e was higher and the range was greater in the cultivated Billings County site than in the Stark County site, which was in rangeland. However, for all depth intervals, variability, as expressed by the standard deviation, was greater at the Stark County site. No conclusions can be drawn from these observations at this time. In each site, samples will be collected at the six optimal sample locations (Figure 2 and Table 3) for laboratory analysis. Following this analysis, the sample data will be subjected to the *ESAP-Calibrate* stochastic model for determination of soil salinity and SAR. At that point, EC_e results from the stochastic model will be compared with results from the deterministic model.

Table 5. Summary statistics of EC_e within the Billings County site that were estimated using the deterministic model of the ESAP-Calibrate program.

	0 to 30 cm	30 to 60 cm	60 to 90 cm
Number	7012	7012	7012
Minimum	0.00	0.00	2.35
25%-tile	0.16	3.12	12.44
75%-tile	1.79	7.74	20.04
Maximum	27.52	75.34	70.76
Mean	1.38	6.29	17.05
Standard Deviation	1.93	5.76	7.80

Table 6. Summary statistics of EC_e within the Stark County site that were estimated using the deterministic model of the ESAP-Calibrate program.

	0 to 30 cm	30 to 60 cm	60 to 90 cm

Number	3985	3985	3985
Minimum	0.00	0.00	0.00
25%-tile	0.00	0.00	4.31
75%-tile	2.15	8.43	19.48
Maximum	25.93	71.01	70.36
Mean	1.23	4.90	12.85
Standard Deviation	2.00	6.16	9.54

Terrain Analysis:
As noted early, during the execution of the EMI surveys, spatial EC_a patterns were visually correlated with landscape features. In general, EC_a appeared higher over exposed or shallow to soft bedrock areas, seepage areas, and swales. Using the elevation data collected with the Trimble AG114 GPS receiver, terrain surface plots of each study site were prepared and the spatial EC_e data were overlain on these plots. These plots are shown in Figures 9 and 10. In each figure, for the shallower, 30 to 60 cm depth interval, strongly saline (colored blue) areas appears to correspond to slope breaks where seepage occurs and depth to soft bedrock is relatively shallower or to lowering-lying concave swales. Areas of non-saline and very slightly soils correspond to convex and plain side slopes and summit areas (all of which are assumed to be local recharge areas). In each figure, for the deeper 60 to 90 cm depth interval, areas of non-saline and very slightly saline soils are more restricted and confined to some convex and plain side slopes and summits. For the deeper 60 to 90 cm depth interval, areas with strongly saline soil conditions expand greatly and are more pervasive.

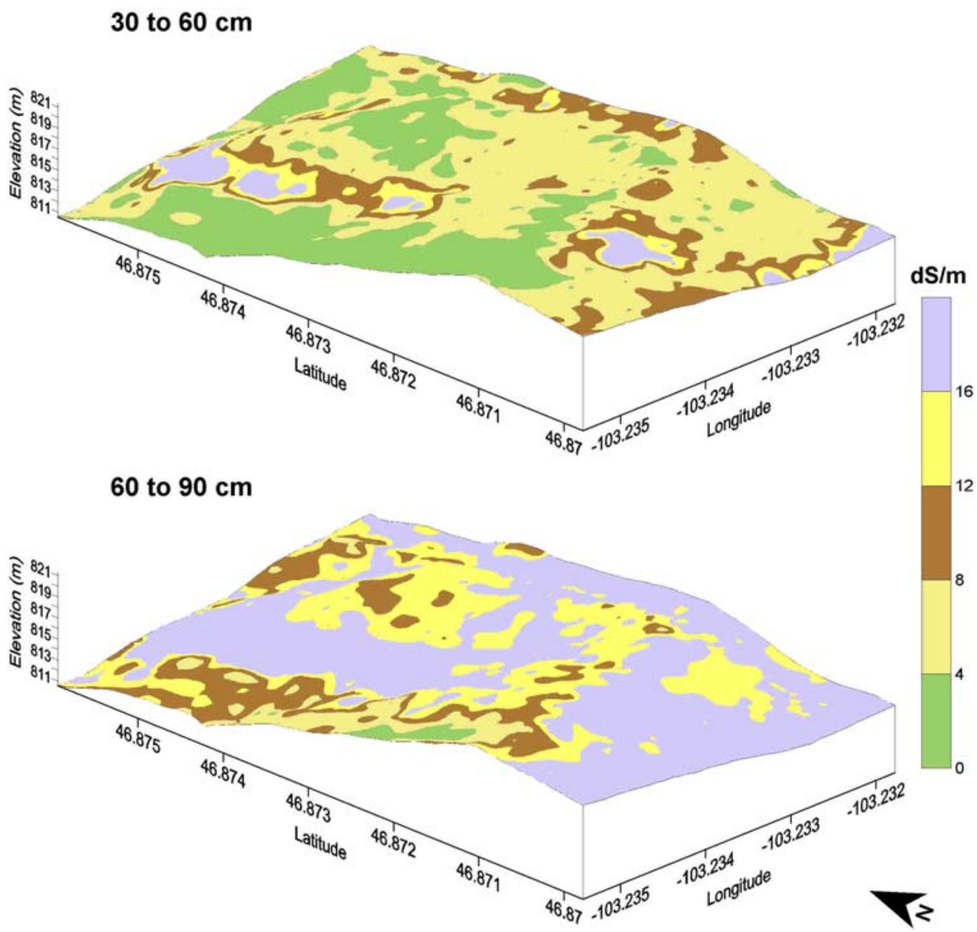

Figure 9. Three-dimensional images of the Billings County site with estimated spatial EC_e patterns for the 30 to 60 cm (upper plot) and the 60 to 90 cm (lower plot) depth intervals overlain.

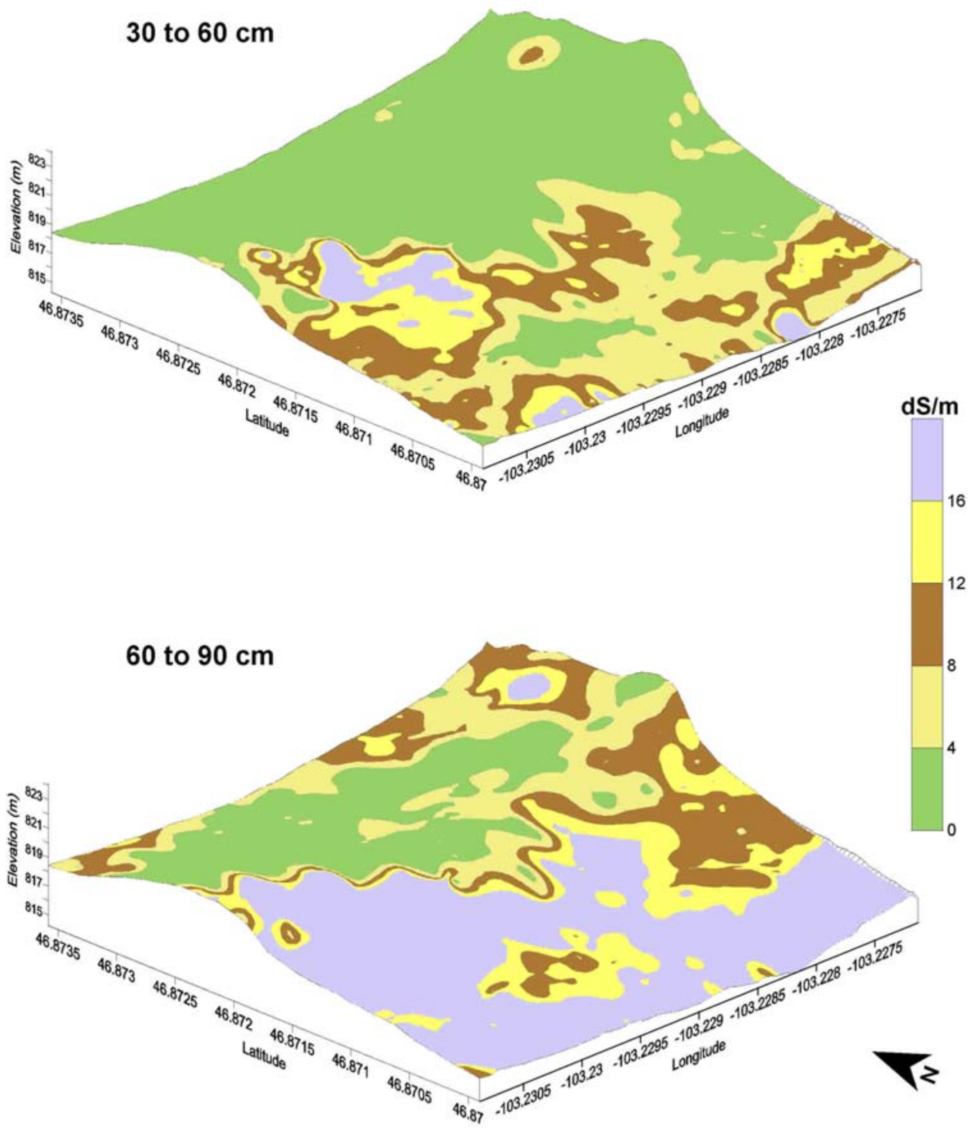

Figure 10. Three-dimensional images of the Stark County site with estimated spatial EC_e patterns for the 30 to 60 cm (upper plot) and the 60 to 90 cm (lower plot) depth intervals overlain.

Cass County: Fargo-Ryan Silty Clay, 0 to 1 percent slope (map unit 1241A):

An EMI survey was conducted on the Agricultural Research Farm of North Dakota State University (SW ¼ of Section 22, T. 140 n, R 49 W) in Cass County. The study site was cropped to alfalfa and is located in area of Fargo Ryan silty clays, 0 to 1 % slopes. The very deep, poorly drained and very poorly drained Fargo and Ryan soils form in clayey lacustrine sediments. Compare to Fargo, Ryan soils contain more salts and have natric horizons. The taxonomic classifications of these soils are listed in Table 7. At the time of this survey, though the surface layers were moist, soil cores revealed that these fine-textured soils were dry below depths of 60 cm.

Table 8 provides the basic statistics for the EMI survey in Cass County. In the deeper sensing, 100-cm intercoil spacing, EC_a averaged about 143 mS/m, and ranged from about 80 to 355 mS/m. One-half the EC_a measurements acquired with the 100-cm intercoil spacing were between about 119 and 165 mS/m. For the shallower-sensing, 50-cm intercoil spacing, EC_a averaged about 108 mS/m, and ranged from about 58 to 283 mS/m. One-half the measurements obtained with the 50-cm intercoil spacing were between about 94 and 119 mS/m.

Table 7. Taxonomic classification of the soils at the Cass County Site.

Soil Series	**Taxonomic Classification**
Fargo	Fine smectitic frigid Typic Epiaquerts
Ryan	Fine smectitic frigid Typic Natraquerts

Table 8. Basic statistics for EMI surveys conducted in an area of Fargo-Ryan silty clay.

	0 to 150 cm	0 to 75 cm
Observations	10301	10301
Minimum	80.01	58.22
25 % tile	119.07	94.43
75 % tile	165.36	118.82
Maximum	354.97	282.88
Average	143.36	107.74
Standard Deviation	31.89	19.27

Figure 11 contains plots of the EC_a data collected with EM38-MK2-2 meter at the Cass County site. Each plot also contains the positions of the 12 optimal sampling locations that were identified by the ESAP-RSSD program. As evident in Figure 11 and from the basic statistics in Table 8, EC_a increases with increasing soil depth. The increase is attributed to greater soluble salts contents at lower soil depth. Spatial patterns are largely similar in each plot. The amplitudes of the recorded measurements, however, are higher in the deeper-sensing, 100-cm intercoil spacing. Spatial patterns appearing on the plots in Figure 11 resemble the spatial mosaic of tonal patterns appearing on aerial photographs of this glacial lake plain.

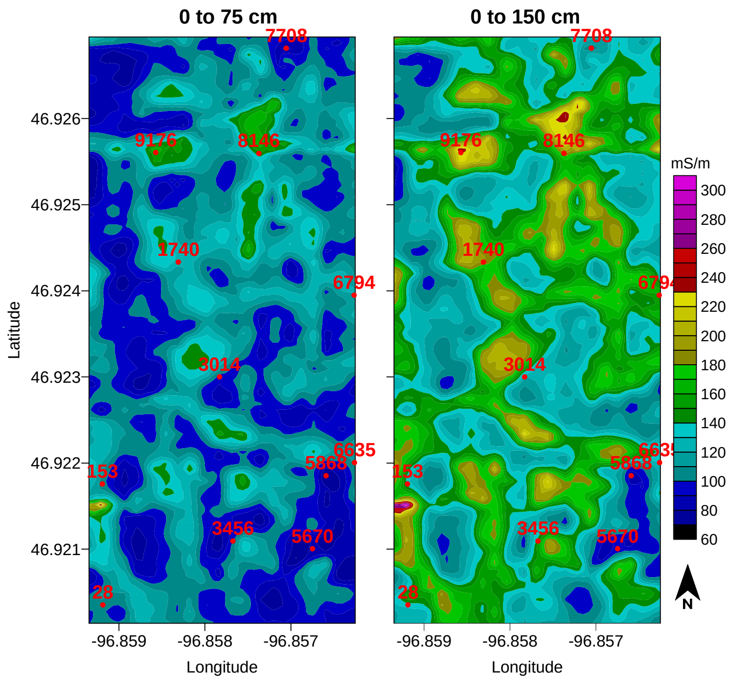

Figure 11. These plots of EC_a data were collected at the Cass County site. The left-hand and right-hand plots show the spatial distribution of EC_a recorded with the EM38-MK2-2 meter in the shallower-sensing 50-cm, and the deeper-sensing 100-cm intercoil spacings, respectively. The effective penetration depth of the meter for each intercoil spacing is listed above each plot.

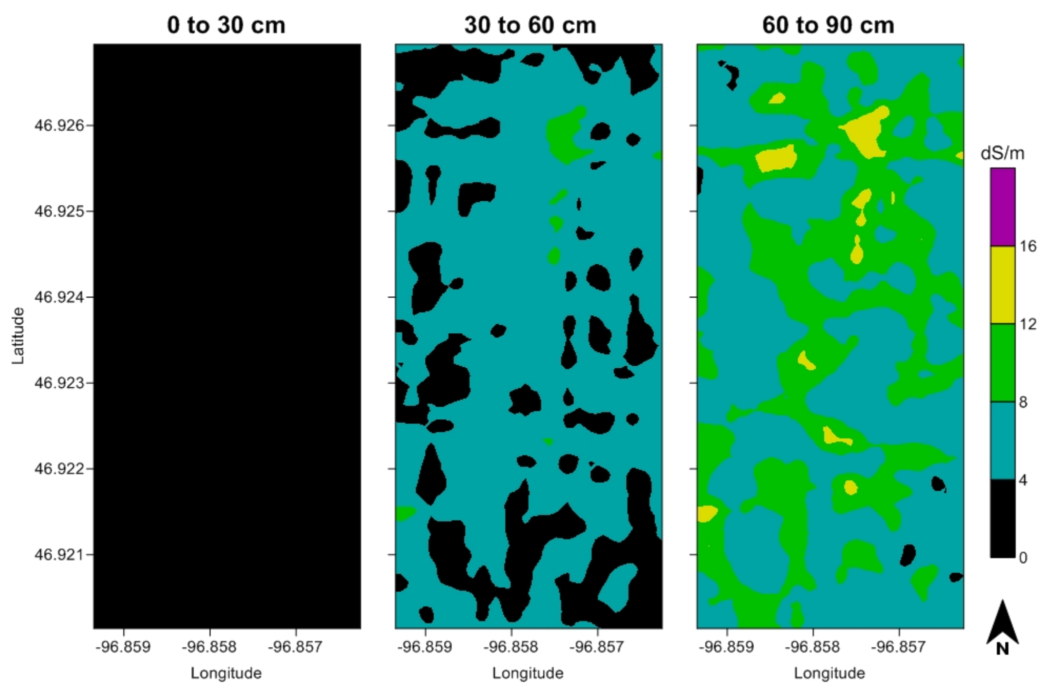

Figure 12. These plots of spatial EC_e data from the Cass County site were derived using the deterministic model in ESAP-Calibrate. The plots show (from left to right) the spatial EC_e patterns within the 0 to 30, 30 to 60, and 60 to 90 cm depth intervals.

Figure 12 shows the spatial and depth distributions of EC_e that were estimated from the *ESAP-Calibrate* deterministic model for the Cass County site. As evident in these plots, soil salinity increases with increasing observation depths. Soils are non-saline (<2 dS/m) and very slightly saline (2 to < 4 dS/m) in the upper 30 cm (collectively, 100 %). For the 30 to 60 cm depth interval, soils are dominantly very slightly and slightly (4 to <8 dS/m) saline (collectively, 96 %). For the 60 to 90 cm depth interval soils were mostly slightly and moderately (8 to <16 dS/m) saline (collectively, 98 %). The estimated salinity class distributions for the three depth intervals at the Cass County sites are provided in Table 9.

Table 9. Estimates of Salinity Class distributions (by %) for three different depth intervals at the Cass County Site.

	0-30 cm	**30-60 cm**	**60-90 cm**
Non-saline	0.97	0.01	0.00
Very slightly saline	0.03	0.30	0.02
Slightly saline	0.00	0.66	0.59
Moderately saline	0.00	0.03	0.39
Strongly saline	0.00	0.00	0.00

If soils are sampled and characterized within this study site, estimates of SAR can be computed using the stochastic model in *ESAP-Calibrate* program.

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