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

Subject: Soils – Joint USDA - NRCS & ARS Red River Valley of the North Salinity Assessment Project

Date: September 6, 2006

To: Paul Benedict
MLRA Office Leader
USDA-NRCS,
220 East Rosser Avenue
P.O. Box 1458
Bismarck, ND 58502-1458

Joseph McCloskey
State Soil Scientist
USDA-NRCS
375 Jackson Street, Suite 600
St. Paul, MN 55101-1854

Purpose:
Salinity is a major cause of soil degradation and reduced crop production in MLRA 56, the Red River Valley of the North. Since 1993, in response to a wetter weather patterns, noticeable areas of salt-affected soils have grown considerably in this resource area. The joint USDA - NRCS & ARS Red River Valley of the North Salinity Assessment Project seeks to develop a methodology that will incorporate geophysical measurements and image processing techniques to estimate and map soil salinity. The study discussed in this report is a precursor for fieldwork that will be initiated in the spring of 2007.

Principal Participants:
Keith Anderson, MLRA Project Coordinator, USDA-NRCS, Fargo, ND
Matt Baltes, GIS Specialist, USDA-NRCS, Thief River Falls, MN
Chris Davis, Soil Scientist, USDA-NRCS, Fargo, ND
Dan Delea, Product Specialist, GSSI, Salem, NH
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Larry Edland, Soil Data Quality Specialist, USDA-NRCS, Bismarck, ND
John Holton, Soil Conservation Technician, USDA-NRCS, Bismarck, ND
Manuel Matos, Soil Scientist, USDA-NRCS, Fargo, ND
David Potts, MLRA Soil Survey Coordinator, USDA-NRCS, Thief River Falls, MN
Michael Ulmer, Soil Data Quality Specialist, USDA-NRCS, Bismarck, ND
Hal Weiser, Soil Scientist, USDA-NRCS, Jamestown, ND
Lance Duey, Soil Scientist, USDA-NRCS, Devils Lake, ND

Activities:
All field activities were completed during the period of 21 to 25 August 2006.

Summary:

1) During the week, EC_a data were collected in the field and forwarded to Dr Scott Lesch (Principal Statistician, George Brown Salinity Laboratory, USDA-ARS, Riverside, CA) for examination. Using the

ESAP program, Scott generated an optimal sampling design based on EC_a data for two of the surveyed fields. Based on the results of the ESAP program, Scott forwarded the coordinates of 18 sample sites to NRCS soil scientists who sampled the pedons (by horizon) for soil characterization. These samples will be shipped to the National Soil Survey Laboratory in Lincoln, Nebraska, for analysis. Following the laboratory analysis of these soil samples, the raw EC_a data will be converted into soil salinity data using either regression models or deterministic techniques. The EC_a data will be used to develop preliminary models for the salt-affected areas within this MLRA.

2) Areas mapped as Bearden silty clay loam were found to have lower and less variable EC_a than areas mapped as Bearden silty clay loam, saline. However, non-saline areas of Bearden soils displayed uncharacteristically high values of EC_a. These values may attest to a low level (hidden salinity) of salinity that affects crops in this region. Apparent conductivity increases with increasing depth of observations (measurements obtained in the shallower-sensing horizontal dipole orientation were generally lower than measurements obtained in the deeper-sensing vertical dipole orientation). This relationship is attributed to the high specific conductance of the groundwater, its relatively shallow depth, and effects of capillary rise on saline ground conditions.

3) Spatial EC_a patterns are highly variable and complex. Intricate patterns appear to dot each site and soil polygon with no apparent causal explanation other than variations in surface topography. The micro-topography provides clues as to the distribution of soluble salts on the glacial Lake Agassiz Plain.

4) All sites contain areas of both high and low EC_a. An inference from this relationship is that soluble salts and salinity are unevenly distributed across each site. In areas of Bearden silty clay loam, EC_a averaged between 69 to 111 mS/m.

5) Although my trip report of June 19, 2006 outlines the Joint USDA - NRCS & ARS Red River Valley of the Salinity Project, a formal work plan (as outlined in the National Soil Handbook) will be developed this fall by Jim Doolittle, Dennis Corwin, and Mike Ulmer.

6) Dan Delea, Product Specialists, Geophysical Surveys Systems, Inc. participated in this study. Dan is evaluating the performance of GSSI's "Profiler," a multifrequency EMI meter and comparing measured data with those of the EM38DD meter.

It is my pleasure to be involved in this project and to work with the soil scientists of North Dakota and Minnesota.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
R. Ahrens, Director, National Soil Survey Center, USDA-NRCS, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
K. Anderson, MLRA Coordinator, NDSU Walster Hall, Room 207, State University Station, PO Box 5638, Fargo, ND 58105-5638

D. Corwin, Soil Scientist, USDA-ARS, George Brown Salinity Laboratory, 450 West Big Springs Road, Riverside, CA 92507-4617
D. Hammer, National Leader for Soil Investigations, USDA-NRCS-NSSC, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
S. Lesch, Principal Statistician, George Brown Salinity Laboratory, 450 West Big Springs Road, Riverside, CA 92507-4617
J. Richardson, Research Soil Scientist, Soil Investigation Staff, USDA-NRCS, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 60, Federal Building, Room G-08, 207 West Main Street, Wilkesboro, NC 28697
Mike Ulmer, Soil Data Quality Specialist, USDA-NRCS, 220 East Rosser Avenue. P.O. Box 1458, Bismarck, ND 58502-1458

Equipment:
The electromagnetic induction meter used in this study was the EM38DD (manufactured by Geonics Limited, Mississauga, Ontario).[1] Geonics Limited (2000) describes the operating procedures of the EM38DD meter. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One meter acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on). The EM38DD meter weighs about 2.8 kg (6.2 lbs), is portable, and requires only one person to operate. No ground contact is required with this meter. The EM38DD operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively.

The Geonics DAS70 Data Acquisition System was used with the EM38DD meter to record and store both EC_a and position data.[1] The acquisition system consisted of the EM38DD meter; an Allegro CE or CX field computer (Juniper Systems, North Logan, UT) with the Geomar's Trackmaker 38DD software (Geomar Software, Inc., Mississauga, Ontario); and a Garmin Global Positioning System (GPS) Map 76 receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack) (Garmin International, Inc., Olathe, KS).[1] When attached to the acquisition system, the EM38DD meter is keypad operated and measurements can be automatically triggered.

To help summarize the results of this study, the SURFER for Windows (version 8) program, developed by Golden Software, Inc.,[1] was used to construct the two-dimensional plots shown in this report. Grids were created using kriging methods with an octant search.

Study Sites:
Portions of seven fields were surveyed. All sites were located in cultivated fields own by David Berklund. We are deeply grateful to Mr. Berklund for his insight and the availability of his fields for this study. At the time of this investigation, all of the selected sites were in wheat stubble. The locations of the study sites are shown in Figure 1 and listed in Table 1. All sites are located in Brenna Township (T. 151 N., R. 51 W.).

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

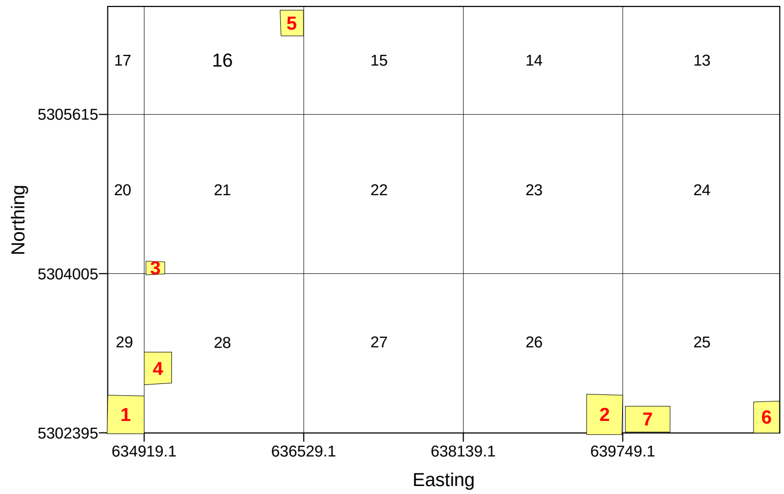

Figure 1. Locations of study sites within Brenna Township. Section numbers are shown in black and the identity of the study sites are shown in red.

All sites are in areas of Bearden soil. Bearden is a member of the fine-silty, mixed, superactive, frigid Aeric Calciaquolls taxonomic family. This soil formed in calcareous silt loam and silty clay loam lacustrine sediments. Sites 1, 3, and 5 are located in polygons of Bearden silty clay loam, saline (M. U. 270). Sites 2, 6, and 7 are located in polygons of Bearden silty clay loam (M. U. 126). Site 4 contains polygons of both Bearden silty clay loam and Bearden silty clay loam, saline. In general, in Brenna Township, soils become less salt affected towards the east and southeast, and towards the Red River of the North.

Table 1.
Locations of EMI study sites

Site Name	Location
Berklund-#1	SE1/4, SE1/4, Section 29 T. 151 N., R. 51 W.
Berklund #2	SE1/4, SE1/4, Section 26 T. 151 N., R. 51 W.
Berklund #3	SW1/4, Section 21 T. 151 N., R. 51 W.
Berklund #4	NW1/4, SE1/4, Section 28 T. 151 N., R. 51 W
Berklund #5	SE1/4, NE1/4, Section 16 T. 151 N., R. 51 W.
Berklund #6	SE1/4, SE1/4, Section 25 T. 151 N., R. 51 W.
Berklund #7	SW1/4, SW1/4, Section 25 T. 151 N., R. 51 W

Field Procedures:
The EM38DD meter was operated in the continuous mode with measurements recorded at 1-sec intervals. The EM38DD was towed along the ground surface in a plastic toboggan with its long axis parallel to the direction of traverse (see Figure 2). With the exception of Berklund Site #3, the spacing between traverse lines was about 30 paces. At Berklund Site #3, the spacing between traverse lines was about 12 paces. At the time of this investigation, the soil temperature at a depth of 20 inches was 64^{o}F. Data shown in this report were not temperature corrected.

Figure 2. An EM38DD meter was towed along the ground surface in a plastic toboggan.

Figure 3. A team of soil scientists from North Dakota and Minnesota assists with soil sampling.

During the week, EC_a data from Sites 1 and 6 were forwarded to Dr Scott Lesch for examination. Using the ESAP program (Lesch et al., 1995a, 1995b, 2000), Scott generated an optimal sampling design based on EC_a data for the two fields. The coordinates of these sample sites were e-mailed to the soil scientists in the field. Soil scientists from North Dakota and Minnesota sampled (by horizon) 18 pedons (see Figure 3). Tables 2 and 3 provide pertinent data on the pedons sampled at Sites 1 and 6, respectively. In each table, the locations (UTM), site identifiers (from ESAP program), and the sample pedon numbers are listed. These samples will be shipped to the National Soil Survey Laboratory in Lincoln, Nebraska, for analysis. Following laboratory analysis of these soil samples, the raw EC_a data will be converted into soil salinity data using either regression models or deterministic techniques. The EC_a data will be used to develop preliminary models for salt-affected areas within this MLRA.

Table 2
Soil sampling sites at "Berklund's Site 1."
SE1/4, SE1/4 Section 29, T. 151 N., R. 51 W.

Easting	Northing	Site Identifier	Pedon #
634896.43	**5302731.52**	**159**	**06ND035-001a**
634848.89	**5302446.87**	**347**	**06ND035-001**
634843.94	**5302651.83**	**454**	**06ND035-001b**
634795.18	**5302495.99**	**699**	**06ND035-001d**
634793.69	**5302570.11**	**736**	**06ND035-001c**
634770.86	**5302423.00**	**974**	**06ND035-001e**
634739.08	**5302631.86**	**1097**	**06ND035-001g**
634710.77	**5302726.99**	**1186**	**06ND035-001f**
634689.00	**5302505.50**	**1364**	**06ND035-001h**
634633.23	**5302643.89**	**1780**	**06ND035-001i**
634610.09	**5302466.17**	**1953**	**06ND035-001j**
634552.00	**5302684.81**	**2217**	**06ND035-001k**

Table 3
Soil sampling sites at "Berklund's Site 6."
SE1/4, SE1/4 Section 25, T. 151 N., R. 51 W.

Easting	Northing	Site Identifier	Pedon Number
641313.00	5302734.38	**103**	S06ND035-02a
641307.32	5302608.90	191	S06ND035-02
641229.68	5302749.25	569	S06ND035-02b
641140.28	5302587.00	967	S06ND035-02c
641112.70	5302733.41	1091	S06ND035-02d
641065.47	5302634.60	1376	S06ND035-02e

Results:
Basic statistics from the seven study sites are shown in Table 4. In general, delineations of Bearden silty clay loam, saline, have higher and more variable EC_a than delineations of Bearden silty clay loam. However, in delineations of Bearden silty clay loam, values of EC_a appear atypically high for supposedly non-saline map unit. Some

portions of delineations mapped as Bearden silty clay loam, saline, are presently barren with little crop residue (see Figure 6; Site #3). At the time of the soil survey (Doolittle et al., 1981), similar barren areas would have been mapped as Ojata silty clay loam (M.U. 95). It is doubtful that these areas were overlooked by soil scientists during field mapping; the present condition is believed to reflect the increasing salinity problem that exists within the Red River Valley of the North.

Apparent conductivity increases with increasing depth of observations (measurements obtained in the shallower-sensing horizontal dipole (H) orientation were generally lower than measurements obtained in the deeper-sensing vertical dipole (V) orientation) (see Table 4). This relationship is attributed to the high specific conductance of the groundwater, its relatively shallow depth, and effects of capillary rise to saline ground conditions.

Table 4
Basic statistic for the survey sites.
Sites dominated by polygons of Bearden sicl and Bearden sicl, saline, are shown in black and red, respectively. Site 4 contains both map units and is shown in blue.
(Values of EC_a are expressed in mS/m.)

Site	Dipole	Number	Minimum	25% tile	75% tile	Maximum	Mean	St Dev
1	V	2330	33.00	96.13	182.75	346.25	141.09	56.66
1	H	2330	13.50	73.75	158.38	343.25	119.08	58.32
3	V	920	82.38	178.88	301.63	439.88	241.29	78.82
3	H	920	50.38	173.13	286.13	429.00	233.38	74.83
5	V	876	49.75	113.88	259.88	417.25	193.37	86.34
5	H	876	10.50	66.88	223.50	407.13	155.94	91.16
4	V	1999	32.50	91.88	211.38	346.13	156.67	69.98
4	H	1999	12.25	68.50	191.50	323.38	132.61	71.81
2	V	4188	46.13	65.25	106.00	225.25	88.72	32.44
2	H	4188	30.38	49.63	83.63	203.50	69.30	27.45
6	V	1423	8.00	65.38	109.88	229.00	91.63	37.82
6	H	1423	0.00	49.13	93.63	244.88	75.56	36.17
7	V	1789	46.00	81.00	136.38	258.63	110.91	38.63
7	H	1789	27.25	64.13	106.38	209.88	87.03	32.38

The spatial distribution of EC_a with each study site is shown in Figures 4 through 10. The same range, isoline interval, and color scheme have been used in each plot. This was done to facilitate comparisons among the sites. The locations and identity of the pedons sampled at sites 1 and 6 are shown in Figures 4 and 9, respectively.

For each site, a common theme is the highly variable and complex spatial EC_a patterns. Small and scattered EC_a patterns appear to dot, speckle or pock mark each site with no apparent causal explanation other than variations in surface topography. In general, patterns appear to form cellular or cuneiform networks.

The topography of the Agassiz Lake Plain District is flat, but a very subtle system of intersecting ridges and a swell and swale micro-topography exists. Benz et al. (1976) noted that swells vary from several inches to several feet higher than adjoining swales and are spaced 75 to 200 feet apart. Benz et al. (1964) observed that the concentration of soluble salts in the groundwater is higher under swells or ridges. These differences in salt concentration of the groundwater between the swells and swales were evident to depths as great as 20 feet (Benz et al., 1964). While noting that there is no satisfactory explanation for the fracture patterns and the swell and swale topography of the glacial Lake Agassiz Lake Plain, Horberg (1951) interpreted these features as fossil tundra features. Beneath the ridges, Horberg (1951) noted evidence of deformed lake clays, involution, and wedges structures. In addition, Horberg interpreted the ridges to be “inherited features from pre-existing structures produced in lake clays by tectonic movement or the breaking up of ground lake-ice.” He also assumed that these features may reflect “regional fractures in the underlying bedrock” that “extend upwards through the overlying glacial drift and lake clay.” If so, these features may provide clues as to the distribution of salt-affected areas. In Horberg article, the distribution of minor ridges in eastern Pembina County, as evident on a photo-mosaic of the area may provide, with further onsite investigations, an outline of the areas most susceptible to salinity.

Although topography may provide clues as to the spatial EC_a patterns evident on the accompanying plots and the distribution of soluble salts in these soils (Benz et al., 1976), this parameter was not assessed during this investigation. Because of the flatness of the terrain, the swell and swale topography is not readily apparent and easily overlooked from the ground surface.

All sites contain areas of higher and lower EC_a. As the contribution from soluble salts is believed to dominate the EMI response, it is assumed that soluble salts and salinity are unevenly distributed across each site. In areas of Bearden silty clay loam, EC_a averaged between 69 to 111 mS/m with a range of 0 to 259 mS/m. These values are considered high for a non-saline soil and may attest to a low level (hidden salinity) of salinity that affects crops.

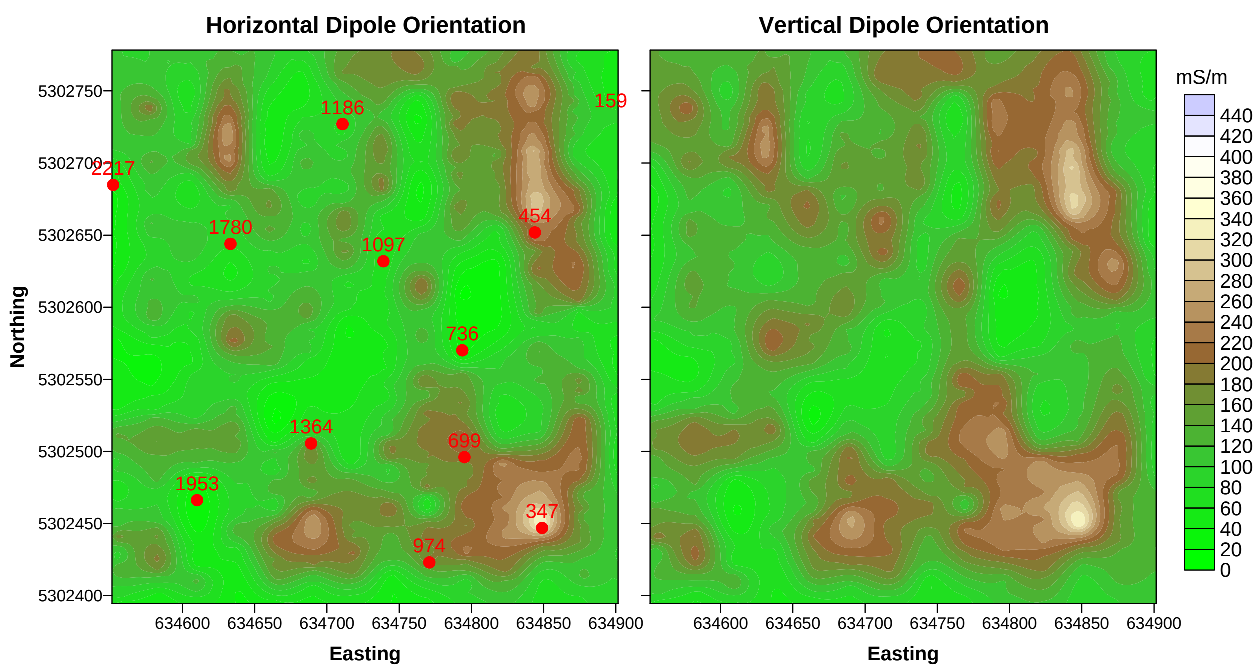

Figure 4. Plots of EC_a data collected with the EM38DD meter at Berklund Site #1.

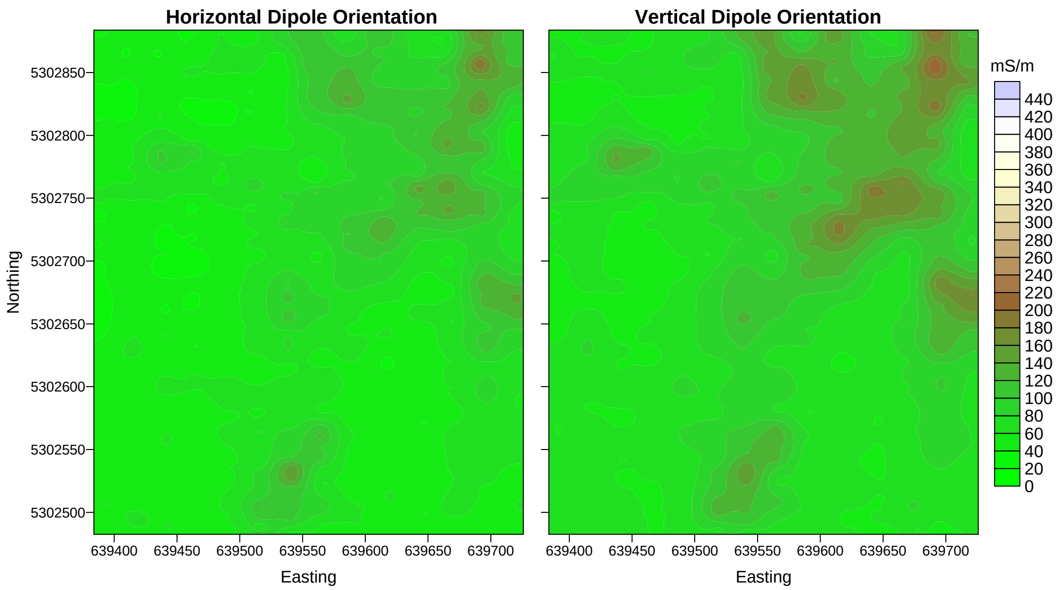

Figure 5. Plots of EC_a data collected with the EM38DD meter at Berklund Site #2.

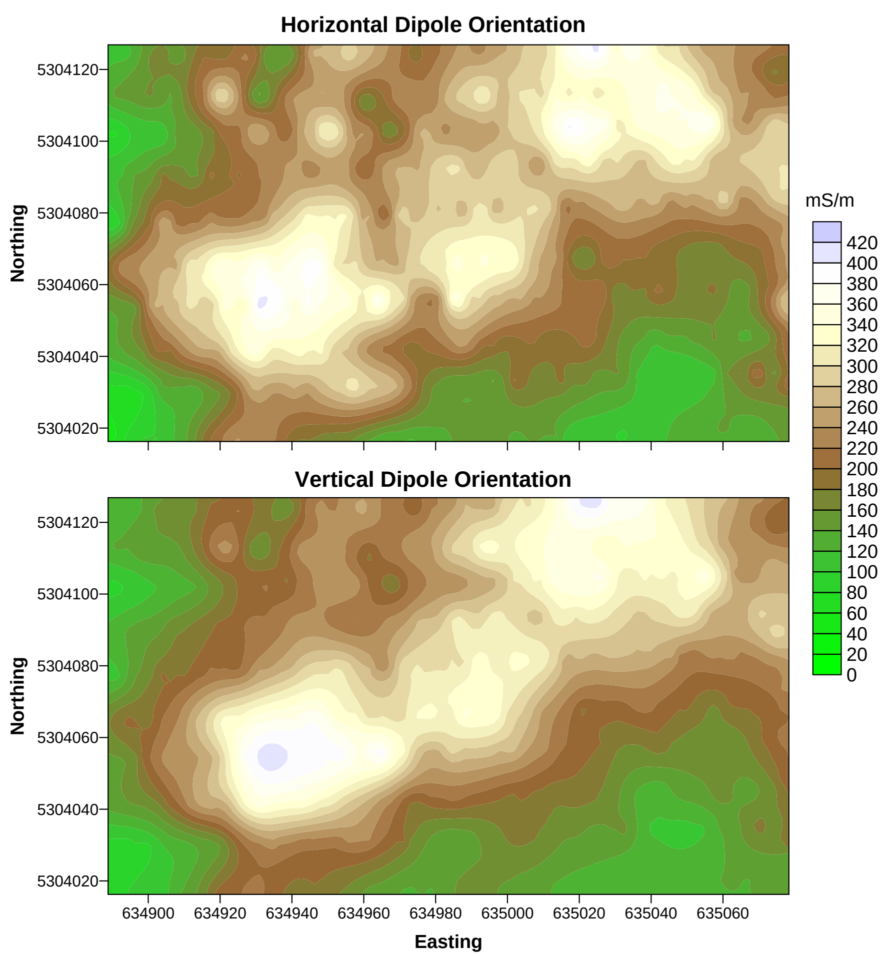

Figure 6. Plots of EC_a data collected with the EM38DD meter at Berklund Site #3.

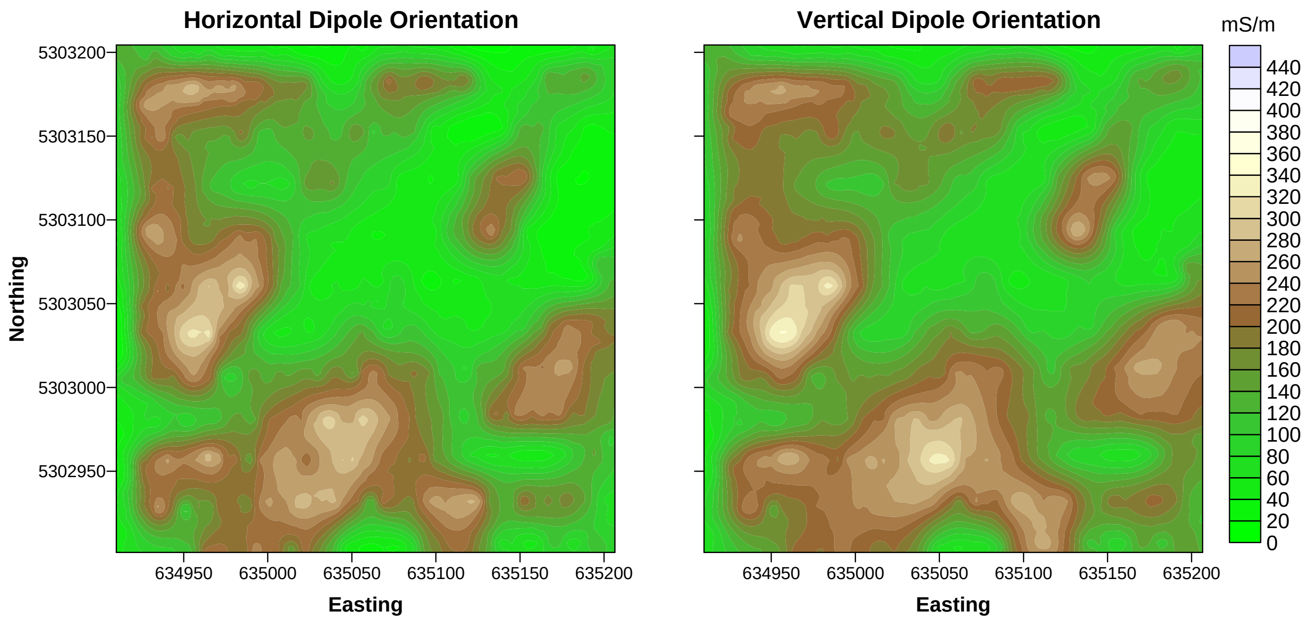

Figure 7. Plots of EC_a data collected with the EM38DD meter at Berklund Site #4.

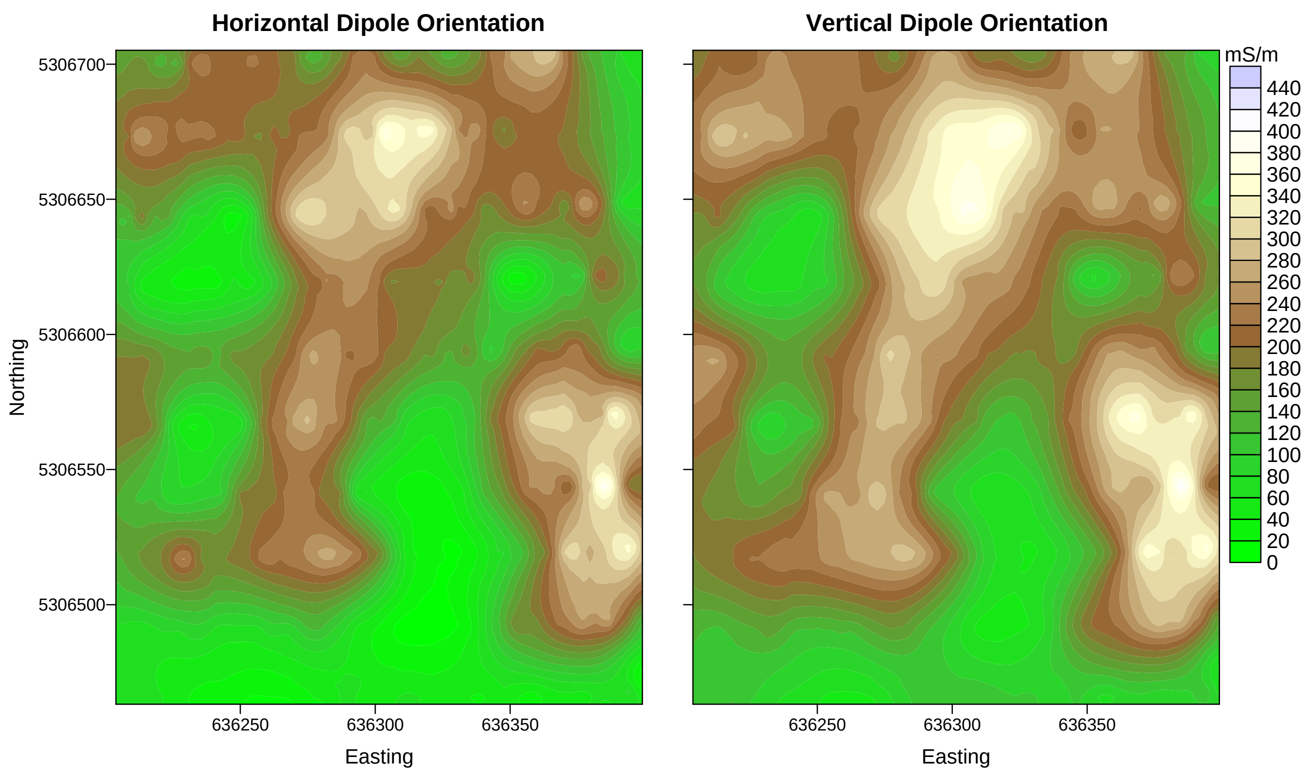

Figure 8. Plots of EC_a data collected with the EM38DD meter at Berklund Site #5.

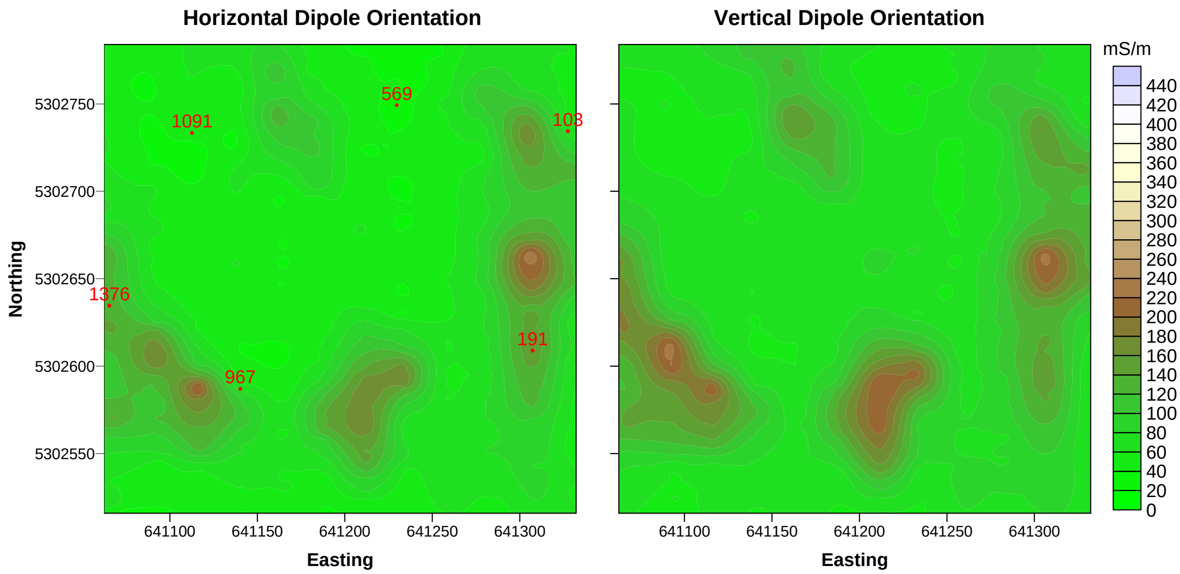

Figure 9. Plots of EC_a data collected with the EM38DD meter at Berklund Site #6.

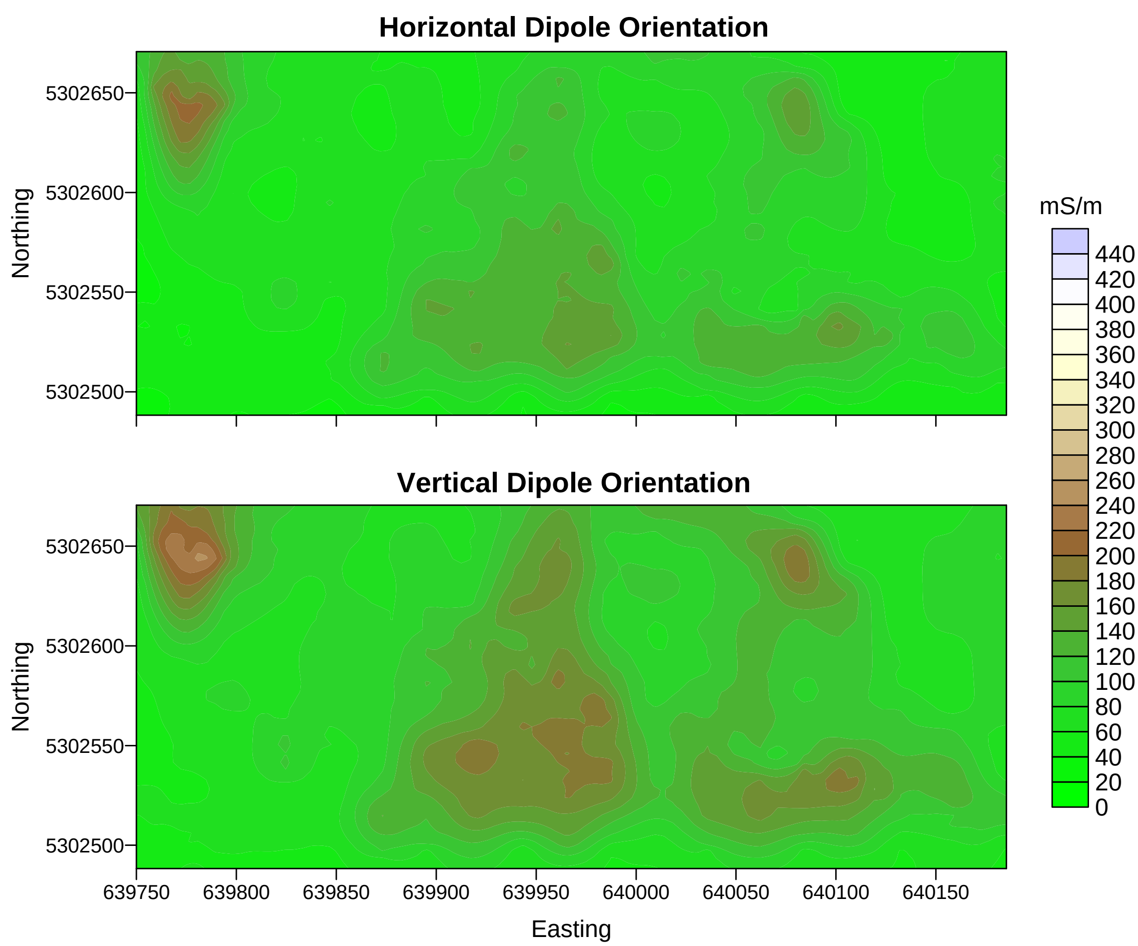

Figure 10. Plots of EC_a data collected with the EM38DD meter at Berklund Site #7.

References:

Benz, L. C., F. M. Sandoval, E. J. Doring, and W. O. Willis, 1976. Managing saline soils in the Red River Valley of the North. ARS-NC-42. USDA-ARS Northern Great Plains Research Center, Mandan, North Dakota.

Benz, L. C., F. M. Sandoval, R.H. Mickelson, and E. J. George, 1964. Microrelief influences in a saline area of ancient Glacial Lake Agassiz: II On shallow ground water. Soil Science Society of America Proceedings 28(4): 567-570.

Doolittle, J. A., C. J. Heidt, S. J. Larson, T. P. Ryterske, and M. G. Ulmer, 1981. Soil Survey of Grand Forks County, North Dakota. USDA-SCS. US Government Printing Office, Washington, DC.

Geonics Limited, 2000. EM38DD ground conductivity meter: Dual dipole version operating manual. Geonics Ltd., Mississauga, Ontario.

Horberg, L., 1951. Intersecting minor ridges and periglacial features in the Lake Agassiz Basin, North Dakota. Journal of Geology 59 (1): 1-18.

Lesch, S. M., D. J. Strauss and J. D. Rhoades, 1995a. Spatial prediction of soil salinity using electromagnetic induction techniques: 1. Statistical prediction models: A comparison of multiple linear regression and cokriging. Water Resources. Res. 31:373-386.

Lesch, S. M., D. J. Strauss and J. D. Rhoades, 1995b. Spatial prediction of soil salinity using electromagnetic induction techniques: 2. An efficient spatial sampling algorithm suitable for multiple linear regression model identification and estimation. Water Resources. Res. 31:3387-398.

Lesch, S. M., J. D. Rhoades, and D. L. Corwin, 2000. The ESAP Version 2.01r user manual and tutorial guide. Research Report #146. George E. Brown Jr., Salinity Laboratory, Riverside, CA, 153pp.