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

**Subject:** SOI -- Electromagnetic Induction (EMI) Assistance **Date:** 26 June 2000

**To:** Richard D. Swenson
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**Purpose:**
To provide further electromagnetic induction (EMI) field assistance to the St. Regis Mohawk Tribe's Environmental Division.

**Participants:**
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Radnor, PA
Jim Snyder, Water Quality Technician, St. Regis Mohawk Tribe's Environmental Division, Massena, NY
Ted Trevail, MLRA Soil Scientist, USDA-NRCS, Plattsburg, NY

**Activities:**
All field activities were completed during the period of 6 to 8 June 2000.

**Background:**
This is a continuation of the study that was conducted on 14 to 18 June 1999, and described in my trip report of 30 June 1999. While boring a deep water well for a casino, a strata containing saline water was intercepted by the drill. Until it was breached by the well, the salty water had been confined within the underlying bedrock. Saline water has moved outward from this deep well and contaminated the local aquifer. Since the last investigation several wells have experienced reduced and acceptable levels of salt, while others, which are more distant from the contaminant source well, have become contaminated with salts. At the request and under the direction of the St. Regis Mohawk Tribe's Environmental Division an EMI survey was conducted in selected areas of the Reservation. These areas have wells that are experiencing increased salt levels. The purpose of this survey was to use EMI in an attempt to help delineate and better understand the distribution and movement of the salt-contaminated water.

**Equipment:**
A GEM300 sensor, developed by Geophysical Survey Systems, Inc.,[1] was used in this study. This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 19,950 Hz with a fixed coil separation (1.3 m). Won and others (1996) have described the use and operation of this sensor. With the GEM300 sensor, the depth of observation is considered "skin depth limited." The skin-depth represents the maximum depth of observation. It is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signal. The theoretical observation depth of the GEM300 sensor is dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequency. Multifrequency sounding with the GEM300 allows multiple depths to be profiled with one pass of the sensor.

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

The position of each observation points was obtained with Rockwell Precision Lightweight GPS Receivers (PLGR)[2]. The receiver was operated in the continuous mode. The mixed satellite mode was used. The Universal Transverse Mercator (UTM) coordinate system was used. Horizontal datum was the North American 1927. The horizontal zone was 18T. Horizontal units were expressed in meters.

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc.,[2] was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search.

**Study Area:**
Within the selected survey area, soil patterns were highly complex. Soils included members of the Adjidaumo and Wegatchie series on lower lying areas, and members of the Grenville, Hogansburg, and Malone series on uplands. The very deep, poorly drained and very poorly drained Adjidaumo soil formed in fine-textured sediments deposited in marine environments. Adjidaumo soil is a member of the fine, mixed, nonacid, frigid Mollic Endoaquept family. The very deep, poorly drained Wegatchie soil formed in silty lake deposits. Wegatchie soil is a member of the fine-silty, mixed, nonacid, frigid Mollic Endoaquept family. The very deep, well drained Grenville soil formed in glacial till. Grenville soil is a member of the coarse-loamy, mixed, superactive, frigid Typic Eutrudept family. The very deep, moderately well drained Hogansburg soil formed in glacial till having a high content of limestone. Hogansburg soil is a member of the coarse-loamy, mixed, semiactive, frigid Aquic Eutrudept family. The very deep, somewhat poorly drained Malone soil formed in glacial till. Malone soil is a member of the coarse-loamy, mixed, active, nonacid, frigid Aeric Epiaquept family.

The survey area consists of relatively flat poorly and very poorly drained wetlands punctuated by several low hills. Surface ditches drain large areas. Most areas traversed were used for either pasture or hay, or were idle. Glacial till and lacustrine materials are underlain principally by the Beekmantown dolostone.

Data supplied by the Environmental Division showed well depths ranging from 32 to 129 feet. All reported wells terminated in either limestone or black shale.

**Field Procedures:**
Random traverses were made across the study area. Figure 1 shows the locations of the EMI observation points. Because of variations in accessibility, these traverses were not uniformly distributed across the study area. Traverses were made in accessible areas and outside of residential areas. While most traverses were located in hayland or pastureland, several were conducted in wooded or overgrown, bushy areas.

Along each traverse line, measurements were taken at a distance of about 100 feet. This process provided a total of 678 observation points. The coordinates of each observation point were obtained with a Rockwell PLGR. Measurements were taken with the GEM300 sensor held at hip-height in the vertical dipole orientation. At each observation point, inphase, quadrature phase, and conductivity data were recorded with the GEM300 sensor at four different frequencies (390, 1590, 6390, and 9810 Hz). These were the same frequencies used in the June 1999 survey.

**EMI:**
Background:
Electromagnetic induction (EMI) is a noninvasive geophysical tool that can be used for detailed site investigations. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Results of EMI surveys are interpretable in the field. This geophysical method can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction 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

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conductivity of earthen materials. The electrical conductivity of soils is influenced by the volumetric water content, type and concentration of ions in solution, temperature and phase of the soil water, and amount and type of clays in the soil matrix (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). It was assumed that the layer(s) contaminated with salt-water would have significantly higher conductivity than overlying or confining layers and would be detectable with EMI.

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.

Depth of Observation:
Extremely high levels of background noise or electromagnetic interference were experienced at 390 Hz. Values ranged from 625.8 to 968.3 mS/m and averaged 815.2 mS/m. These values were considered erroneous, reflecting interference from nearby transmissions rather than the apparent conductivity of the underlying earthen materials. As a consequence, data collected at 390 Hz were not evaluated further.

The depth of observation or the "skin depth" can be estimated with the following formula given by McNeill (1996):

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

Where s is the ground conductivity (mS/m) and f is the frequency (kHz). With the GEM300 sensor held at hip height in the vertical dipole orientation, apparent conductivity averaged 10.5, 34.0, and 36.2 mS/m at frequencies of 1590, 6390, and 9810Hz, respectively. Based on equation [1], the selected frequencies and these averaged conductivities, the estimated skin depths (observation depths) were 113.2 ft (34.5 m) at 1590 Hz, 63.0 ft (19.2 m) at 6390 Hz, and 61.0 ft (18.6 m) at 9810 Hz. However, while the induced magnetic fields may achieve these depths, the strengths of the response from these depths are probably too weak to be sensed by the GEM300.

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

**Results:**
Apparent conductivity data collected with the GEM300 sensor is shown in figures 2 to 4. The frequency at which data were collected is shown above each plot. The depth of observation is assumed to increase as the frequency decreases. Spatial patterns shown in each plot reflect actual measured values of apparent conductivity, the frequency and unequal distribution of observation sites, and the computer simulated expression of the data set.

**Table 1**

**Basic Statistics for theGEM300**
**Apparent Conductivity**
(All values are in mS/m)

| | | | Quartiles | | | |
|---|---|---|---|---|---|---|
| Frequency | Minimum | Maximum | 1st | Median | 3rd | Average |
| 390 | 625.8 | 968.3 | 773.5 | 815.1 | 857.5 | 815.2 |
| 1590 | -33.0 | 48.7 | -1.6 | 12.9 | 21.9 | 10.5 |
| 6390 | -2.7 | 75.7 | 21.9 | 36.5 | 47.8 | 34.0 |
| 9810 | -8.0 | 78.8 | 22.9 | 37.8 | 50.1 | 36.2 |

Table 1 summarizes the results of this survey. Values of apparent conductivity were remarkably similar for data collected at 9810 and 6390 Hz. These frequencies provided similar observation depths (61 and 63 feet respectively). Values of apparent

conductivity recorded at these frequencies are believed to reflect the water and clay contents of the soils and glacial drift. At a frequency of 9810 Hz, apparent conductivity averaged 36.2 mS/m. One half of the observations had values between 22.9 and 50.1 mS/m. At a frequency of 6390 Hz, apparent conductivity averaged 34.0 mS/m. One half of the observations had values between 21.9 and 47.8 mS/m.

Data collected at frequencies of 9810 and 6390 Hz are plotted in figures 2 and 3, respectively. Values (see Table 1) and spatial patterns are similar in each plot. Low and negative values are believed to represent better-drained, upland areas of till that are shallower to bedrock. Compared with areas underlain with the fine-textured lacustrine or marine deposits, areas of underlain with till are on slightly higher lying, better-drained uplands and have coarser textures. In areas underlain by till, the lower clay and moisture contents result in lower values of apparent conductivity.

Values of apparent conductivity obtained at a frequency of 1590 Hz were lower. A possible cause for this reduction in apparent conductivity was the inclusions and averaging of the more resistive layers of the underlying dolostone bedrock in the sounded observation depth. At a frequency of 1590 Hz, apparent conductivity averaged 10.05 mS/m. One half of the observations had values between –1.58 and 21.9 mS/m.

Data collected at 1590 Hz are plotted in Figure 4. Though lower (see Table 1), spatial patterns obtained at 1590 Hz are similar to those obtained at 6390 and 9810 Hz. Values of apparent conductivity appear to principally reflect differences in soil types, glacial sediments, and moisture contents. Areas underlain with the fine-textured lacustrine or marine deposits are more poorly drained and have higher water and clay contents. These properties result in higher values of apparent conductivity. Upland areas are overlain with glacial till and are better-drained and shallower to bedrock The lower clay and moisture contents of these areas result in lower values of apparent conductivity.

**Conclusions:**

1. 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 or well logs). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

2. Simulations prepared from correctly interpreted EMI data provide the basis for assessing site conditions. Spatial patterns of apparent conductivity (see figures 2, 3, and 4) reflect differences in glacial drift (till versus glacial lacustrine or marine sediments), depth to bedrock, and soil types. Values of apparent conductivity decrease with increasing depth (lower frequency) of observation.

3. At frequencies of 6390 and 9810 Hz, data were slightly higher in the areas surveyed in June of 2000 than in the areas surveyed in June 1999. Difference is presumed to reflect dissimilarities in soil type, moisture content, glacial materials, and temperature. At 1590 Hz, data collected during this survey were conspicuously lower than data collected during the 1999 survey. Areas surveyed during the 2000 survey were more distant from the contaminant source well. The lower values of apparent conductivity, measured during this survey (June 2000) could reflect the weakening of the salt-water contaminant plume with increased distance from source, and its diminishment with the passage of time.

4. A separate copy of this trip report has been forwarded to Ted Trevail for presentation to the St. Regis Mohawk Tribe's Environmental Division.

It was my great pleasure to work again in New York, with members of the Mohawk Tribe, and with Ted Trevail.

With kind regards,

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**References:**

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

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

McNeill, J. D. 1980. Electrical Conductivity of soils and rocks. Technical Note TN-5. Geonics Ltd., Mississauga, Ontario. p. 22.

McNeill, J. D. 1996. Why doesn't Geonics Limited build a multifrequency EM31 or EM38 meter? Technical Note TN-30. Geonics Limited, Mississauga, Ontario. 5 p.

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

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

# EMI Survey of
# Salt-Affected Area
# Mohawk Nation Territory at Akwesasne

## Location of Observation Points

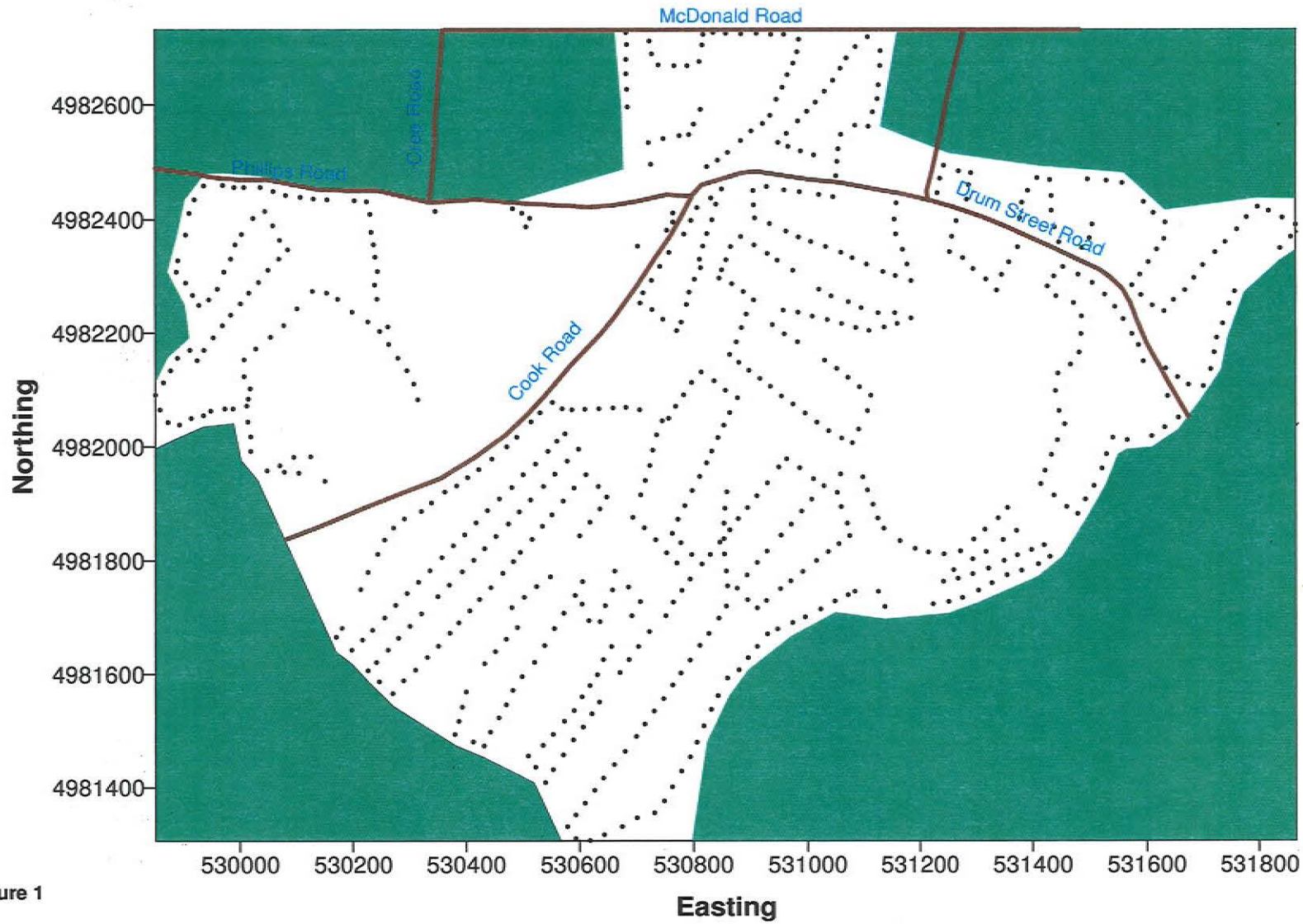


Figure 1

# EMI Survey of
# Salt-Affected Area
# Mohawk Nation Territory at Akwesasne

GEM300 Sensor
9810 Hz
June 2000

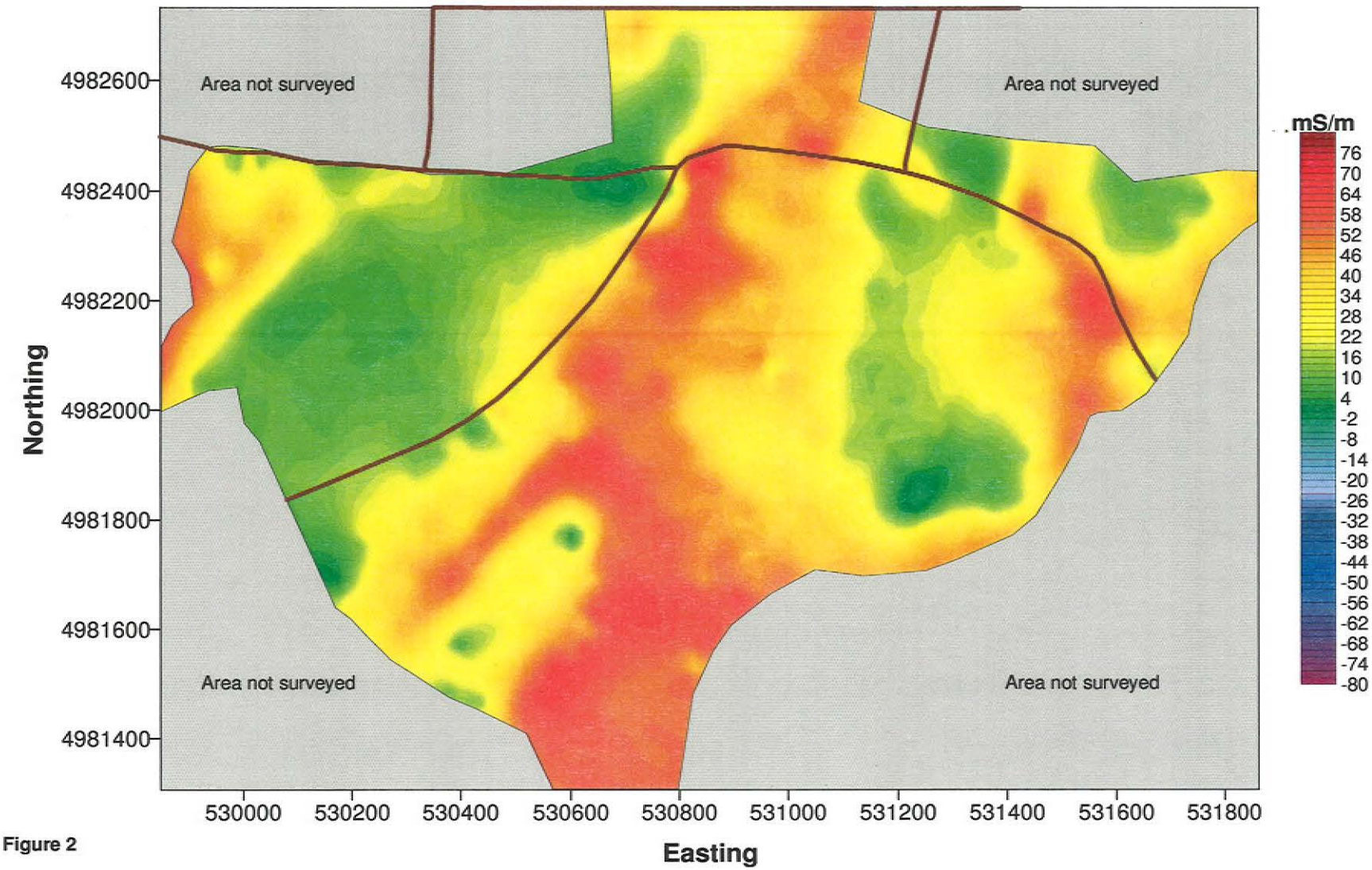


Figure 2

# EMI Survey of
# Salt-Affected Area
# Mohawk Nation Territory at Akwesasne

GEM300 Sensor
6390 Hz
June 2000

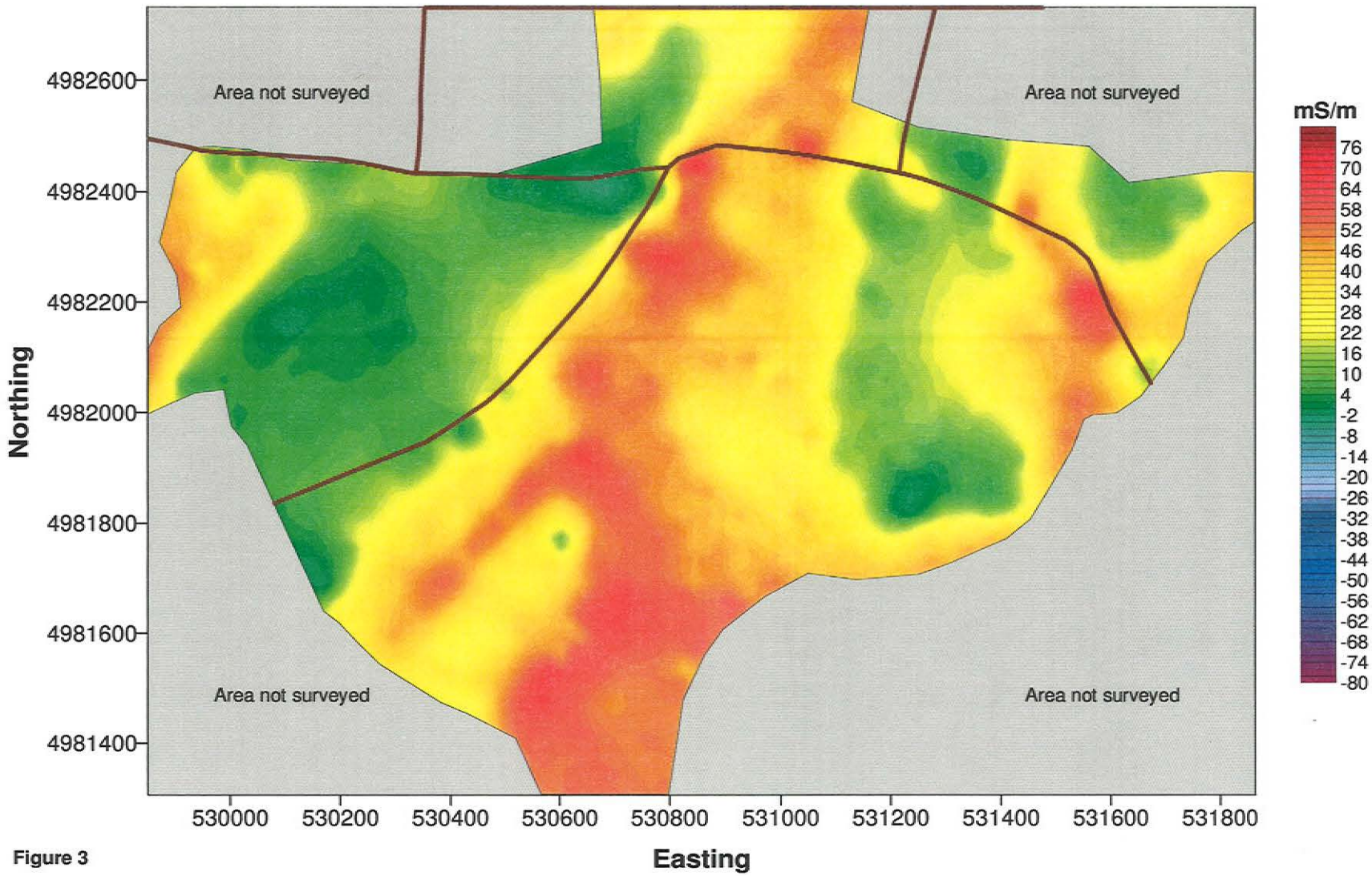


Figure 3

# EMI Survey of
# Salt-Affected Area
# Mohawk Nation Territory at Akwesasne

GEM300 Sensor
1590 Hz
June 2000

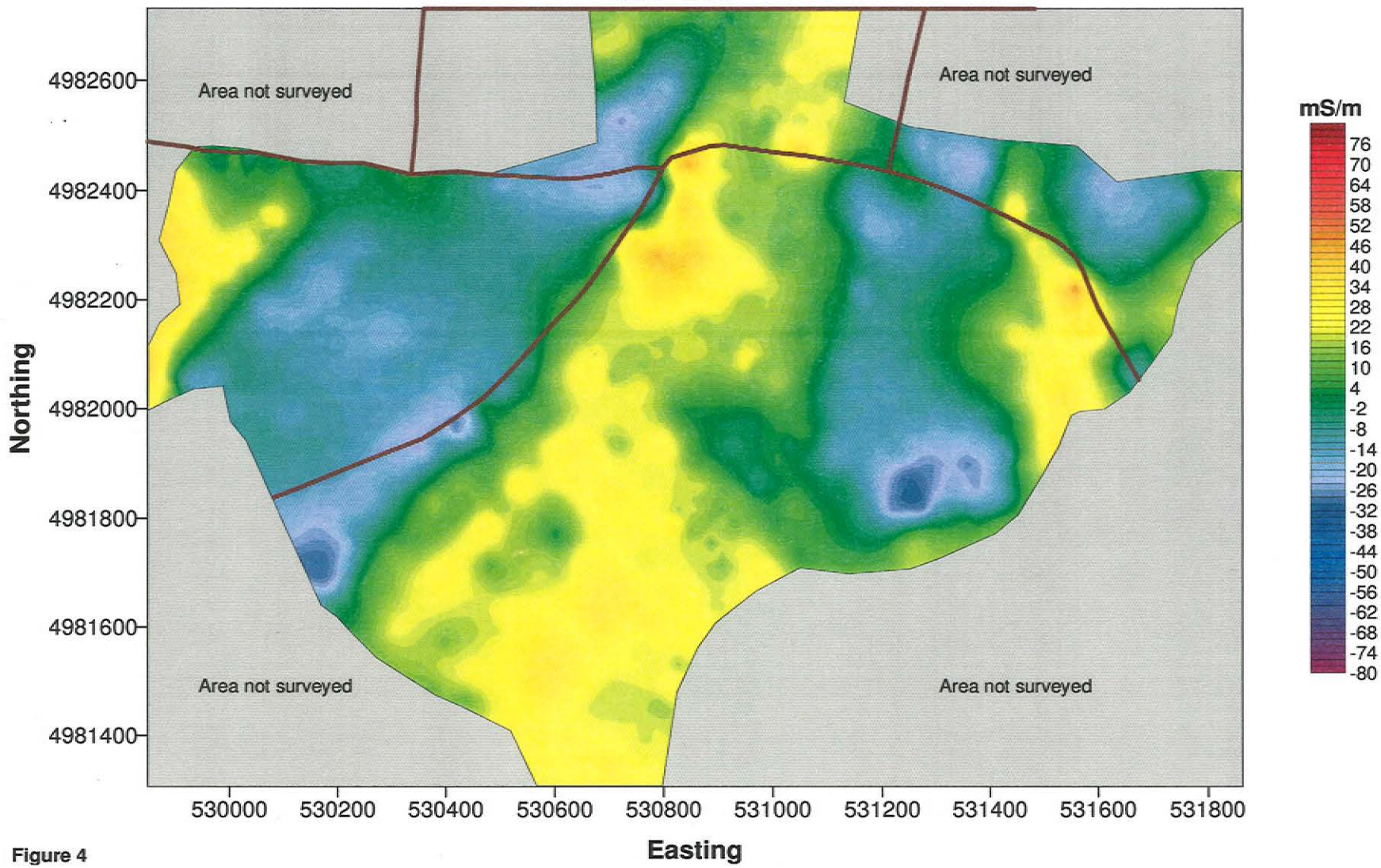


Figure 4