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:** 30 June 1999

To: Richard D. Swenson
State Conservationist
USDA-NRCS,
The Galleries of Syracuse
441 S. Salina St., Suite 354
Syracuse, NY 13202-2450

Purpose:
To provide electromagnetic induction (EMI) field assistance to the St. Regis Mohawk Reservation.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Radnor, PA
Mike Dubo, Air 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 14 to 18 June 1999.

Background:
While drilling a deep well for a casino, a confined layer of salt water was intercepted in the underlying bedrock. Following this event, unacceptable levels of salt have been measured in several wells within the Mohawk Nation Territory at Akwesasne. The St. Regis Mohawk Tribe's Environmental Division has prepared a map of the salt-affected wells. The purpose of this study was to use EMI in an attempt to help map out and understand the distribution of the salt-contaminated water.

Equipment:
An EM34-3 meter malfunctioned and could not be used in this investigation. However, a GEM300 multifrequency sensor was available. The GEM300 is a newly developed EMI meter manufactured by Geophysical Survey Systems, Inc. * This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20000 Hz with a fixed coil separation (1.8 m). Won and others (1996) have described the use and operation of this sensor.

The position of each observation points was obtained with Rockwell Precision Lightweight GPS Receivers (PLGR). * 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.

* 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.,* was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search.

Study Area:
Soil patterns were highly complex within the study area. Soils mapped within the study area included Adjidaumo, Churchville, Hogansburg, Munuscong, and Muskellunge. The very deep, poorly drained and very poorly drained Adjidaumo soil formed in fine sediments deposited in marine environments. Adjidaumo soils are members of the fine, mixed, nonacid, frigid Mollic Endoaquepts family. The very deep, somewhat poorly drained Churchville soil formed in clayey lacustrine sediments overlying loamy glacial till. Churchill soils are members of the fine, illitic, mesic Aeric Epiaqualfs family. The very deep, moderately well drained Hogansburg soil formed in glacial till having a high content of limestone. Hogansburg soils are members of the coarse-loamy, mixed, semiactive, frigid Aquic Eutrochrepts family. The very deep, somewhat poorly drained Muskellunge soils formed in water deposited materials. Muskellunge soil is a member fine, mixed, active, frigid Aeric Epiaqualfs family. The deep, poorly drained and very poorly drained Munuscong soils formed in loamy glaciofluvial deposits over calcareous clayey materials on lake plains and ground moraines. Munuscong soils are members of the coarse-loamy over clayey, mixed, nonacid, frigid Mollic Epiaquepts family.

The relatively flat landscape of the study area is punctuated by several low hills formed in glacial till. Surface ditches drain a large portion of the study areas. Most areas traversed are used for either pasture or hay, or are 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. The locations of both contaminated and uncontaminated wells within the study area are shown in all figures.

Field Procedures:
Random traverses were made across the study area. Figure 1 shows the location of traverse lines and 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 traverse were conducted in wooded or overgrown, bushy areas. Traverses were conducted along the centerline of Cook and Tarbell roads. However, because of obvious signal interference from utility lines, these traverses and observation points (137 points) were not used in the enclosed plots showing the spatial distribution of apparent conductivity (figures 2 to 5).

Along each traverse line, measurements were taken at a distance of about 100 feet. This process provided a total of 1150 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 frequencies are comparable to those of the EM34-3 meter with a 40-m (400 Hz), 20-m (1600 Hz), and a 10-m (6400 Hz) and the EM31 meter (9800 Hz). Conventionally, EMI data is displayed as apparent conductivity expressed in milliSiemens per meter (mS/m). This convention has been followed in this report. While inphase and quadrature data were recorded and stored on disc, these values are not shown or discussed in this report.

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

---

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

conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific observation depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the 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, 1980b). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976). Before the survey was begun, it was assumed that the layer(s) of salt-water contamination 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 the properties of earthen materials. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used.

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. Won (1980 and 1983) has noted that observation depths are governed by the "skin-depth effect." Skin-depth is the maximum depth of observation for an EMI sensor operating at a certain 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 meter.

A nomogram was developed (Won, 1980) to approximate the observation depths at different frequencies. Unfortunately, independent researchers have not extensively tested this nomogram. In addition, it is believed that the nomogram is off by one order of magnitude (Dan Delea, Geophysical Survey Systems, Inc., personal communication). Assuming that this assumption is correct, the average values for apparent conductivity listed in Table 1 were used to establish an inexact estimate of the observation depth at each frequency. The theoretical depth of observations are about 105 feet at 390 Hz, 82 feet at 1590 Hz, 39 feet at 6350 Hz, and 33 feet at 9810 Hz. As these depths could not be verified, they represent merely estimates.

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 data from this study. 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 5. 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 number and unequal distribution of observation sites, and the computer simulated expression of the data set.

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 the shallowest observation depths (33 and 39 feet respectively). Values of apparent conductivity recorded at these frequencies are comparatively high for earthen materials and are believed to reflect high clay and water contents of the soils and glacial drift. At a frequency of 9810 Hz, apparent conductivity averaged 29.3 mS/m. One half of the observations had values between 21.9 and 43.7 mS/m. At a frequency of 6390 Hz, apparent conductivity averaged 30.2 mS/m. One half of the observations had values between 21.4 and 44.7 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 (appearing as green or purple areas in these figures) are believed to represent areas of till or shallower depths to bedrock. Compared with the fine-textured lacustrine or marine deposits, areas of till are on slightly higher lying, better drained, hills and have coarser textures. The lower clay and moisture contents of these areas of till would produce lower values of apparent conductivity.

Table 1

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

Frequency	Minimum	Maximum	Quartiles 1st	Median	3rd	Average
390 Hz	-161.5	351.7	21.2	53.5	82.2	51.4
1590 Hz	-55.2	119.1	14.9	29.9	42.2	27.7
6390 Hz	-181.9	74.9	21.4	33.6	44.7	30.2
9810 Hz	-270.6	69.6	21.9	34.9	43.7	29.3

Values of apparent conductivity obtained at a frequency of 1590 Hz were slightly 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 27.7 mS/m. One half of the observations had values between 14.9 and 42.2 mS/m.

In Figure 4, a noticeable band of high apparent conductivity is evident along the length of Tarbell Road. This band could indicate the occurrence of a subsurface zone of salt enrichment. Two contaminated wells lie within this band of higher apparent conductivity. This band of higher apparent conductivity could also indicate an area underlain by shale bedrock (shale is more conductive than dolostone). While present at both 9810 Hz and 6390 Hz (see figures 2 and 3), this band is less well expressed in these higher frequency and shallow-sensing data sets.

Values of apparent conductivity obtained at 390 Hz were substantially higher and more variable than data collected at the other frequencies. At a frequency of 390 Hz, apparent conductivity averaged 51.4 mS/m. One half of the observations had values between 21.2 and 82.2 mS/m. The high values are believed to reflect the interception of salt-affected groundwater within the sounded observation depth.

Spatial patterns evident in Figure 5 reveal a broad area of moderate to high apparent conductivity extending eastward from Tarbell Road. This area includes a majority of the plotted contaminated wells. However, this area also contains some uncontaminated wells. In general, within this area of moderate to high apparent conductivity, the uncontaminated wells occur in areas of moderate (shown as yellow) rather than high (shown as red) apparent conductivity. A majority of the uncontaminated wells occur west of Tarbell Road in areas of moderate to low 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. Values of apparent conductivity noticeably increased with measurements obtained at 390 Hz. This low frequency provided the greatest observation depth. The high measurements may reflect the occurrence of salt-affected groundwater. However, other factors (variations in lithology: shale or dolostone) may produce similar results. In general, the distribution of moderate to high apparent conductivity measured at 390 Hz conforms to the locations of the contaminated wells.

3. The casino whose well produced the groundwater contamination problem is situated to the south of the study area. The southwest portion of the study area lies at the shortest distance from the casino. If the interpretations contained in this report are correct, groundwater contamination appears to have progressed more rapidly to the northeast rather than to the north or northwest of the casino.

4. A separate copy of this trip report and a disc containing the EMI and GPS data are forwarded to Ted Trevail for

presentation to the St. Regis Mohawk Tribe's Environmental Division.

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

With kind regards,

James A. Doolittle

James A. Doolittle
Research Soil Scientist

cc:
J. Culver, Director, USDA-USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
T. Goddard, State Soil Scientist, USDA-NRCS, The Galleries of Syracuse, 441 S. Salina St., Suite 354, Syracuse, NY, 13202-2450
H. Smith, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
Ted Travail, MLRA Soil Scientist, USDA-NRCS, 6064 Route 22, Suite 1, Plattsburg, NY, 12901-9601

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. 1980a. Electromagnetic terrain conductivity measurement at low induction numbers. Technical Note TN-6. Geonics Limited, Mississauga, Ontario. p. 15.

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

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. 1980. A wideband electromagnetic exploration method - Some theoretical and experimental results. Geophysics 45:928-940

Won, I. J. 1983. A sweep-frequency electromagnetic exploration method. pp. 39-64. IN: A. A. Fitch (editor) Development of Geophysical Exploration Methods. Elsevier Applied Science Publishers, Ltd. London.

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 Obsrvation Points

Figure1

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

GEM300 Sensor
9810 Hz

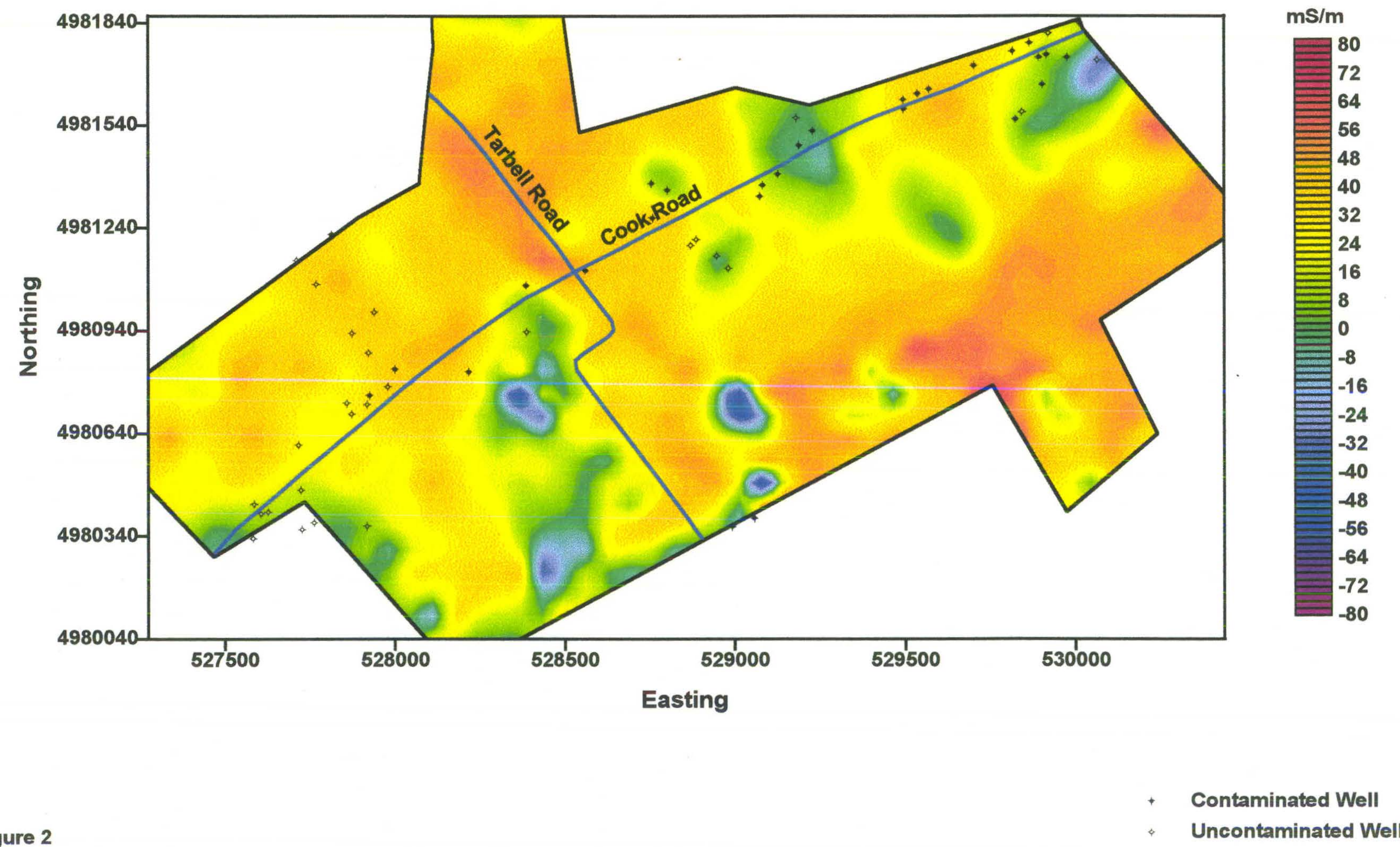

Figure 2

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

GEM300 Sensor
6390 Hz

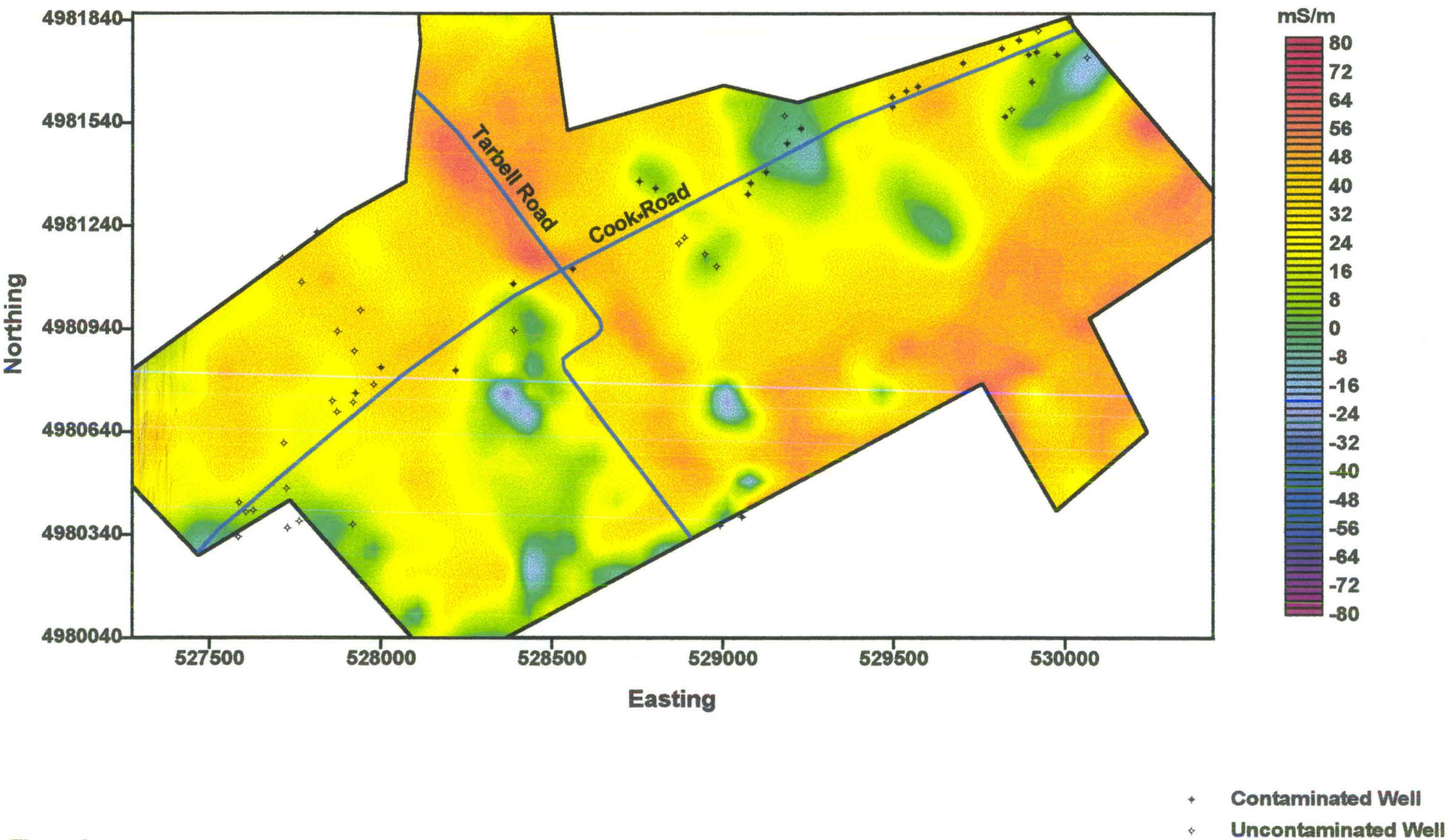

Figure 3

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

GEM300 Sensor
1590 Hz

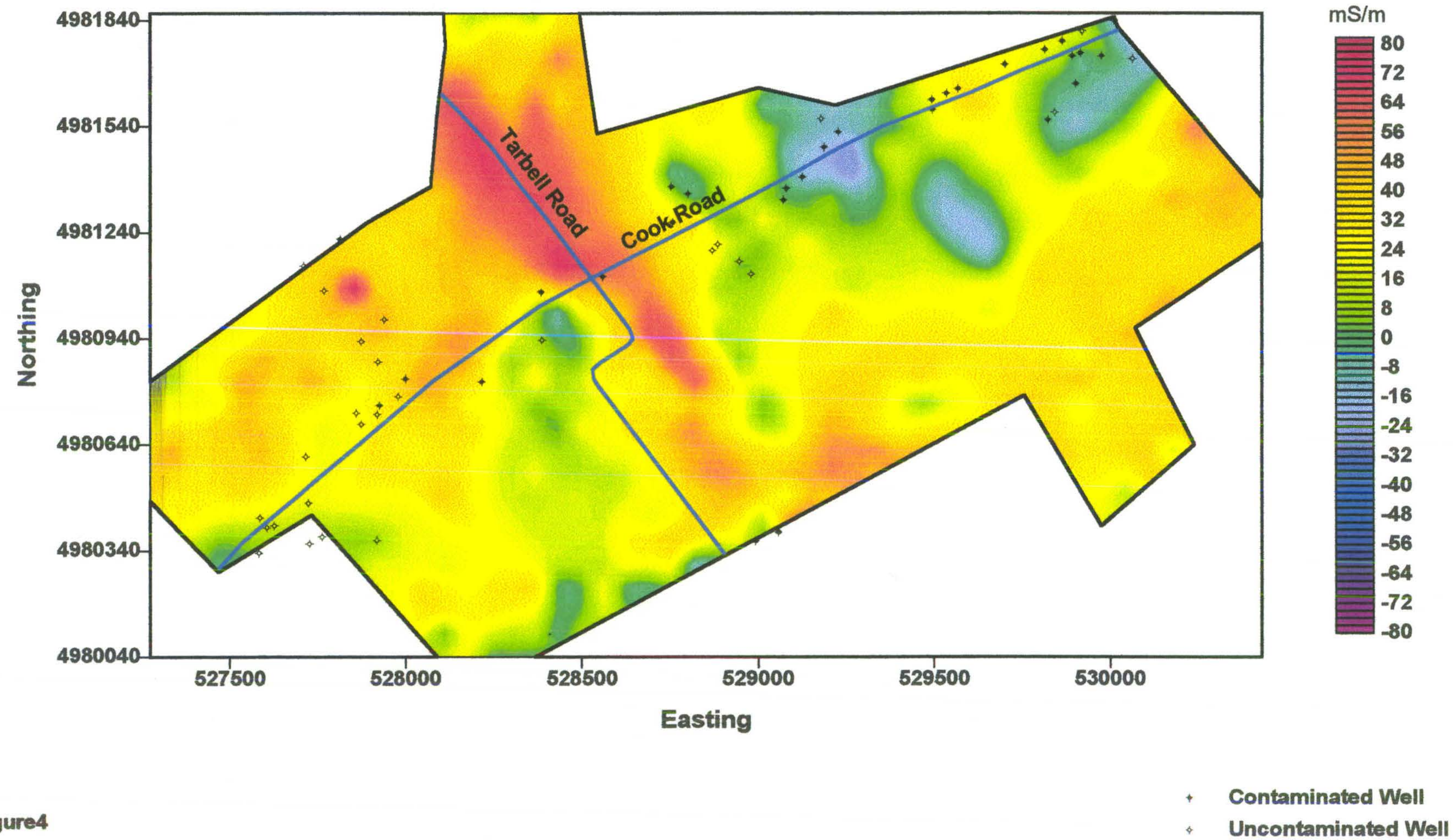

Figure4

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

GEM300 Sensor 390 Hz

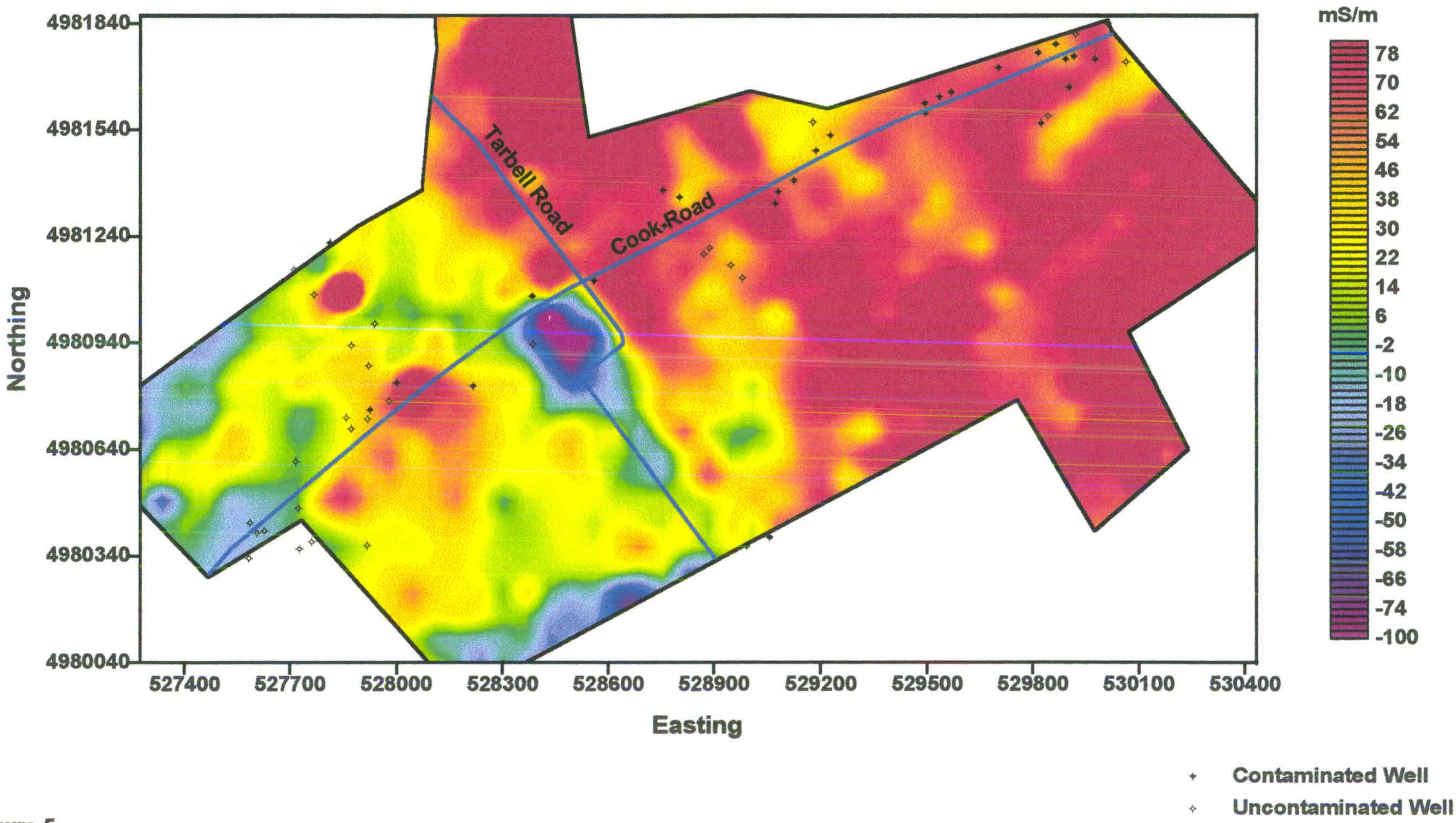

Figure 5