GEOPHYSICAL INVESTIGATIONS OF SALINIZATION

IN CRITTENDON FIELD, WINKLER COUNTY, TEXAS

by

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Introduction

Researchers at the Bureau of Economic Geology, The University of Texas at Austin, noninvasively measured the electrical conductivity of the ground near pipelines and monitor wells in the Crittendon Field in Winkler County, Texas. This geophysical survey, which supplemented an earlier survey completed in June 2008 (Paine and Collins, 2008), was completed to determine whether there is geophysical evidence of significant near-surface salinization where highly saline (and electrically conductive) produced water has infiltrated the shallow subsurface. Relatively dry soils such as those common in Winkler County have very low natural electrical conductivities. Addition of highly conductive saline water can increase the electrical conductivity of the soil by a factor of ten or more, making salinized ground a favorable target for geophysical surveys that measure the apparent conductivity of the ground. The geophysical instrument used in this project produces electrical conductivity profiles along a chosen path at the surface, much like borehole induction logs produce traces of conductivity change along a borehole. Segments showing sufficiently elevated conductivity are likely to be salinized within the exploration depth range of the instrument, which ranges from as shallow as the upper few meters to as deep as 50 m depending on instrument configuration and conditions in the area.

Electromagnetic (EM) induction methods have proven to be very effective in locating salinized areas, mapping the extent and intensity of salinization, and locating potential salinity sources (Paine, 2003; Paine and others, 1997, 2007). Early geophysical instruments employed to estimate soil salinity indirectly included transducers and electrode arrays to measure soil conductivity (Enfield and Evans, 1969; Halvorson and Rhoades, 1974). During the late 1970's and early 1980's, investigators began developing and using EM instruments to measure ground conductivity noninvasively and estimate soil and water salinity at depths ranging from less than 1 to more than 50 m. The EM method is popular because it can be rapidly and noninvasively applied. It is effective because a large increase in electrical conductivity typically accompanies the introduction of extremely conductive saline water (several hundred to several thousand millisiemens per meter [mS/m] [Hem, 1985]) into fresh water, soil, and rock that generally have low natural conductivities (a few tens to a few hundred mS/m [McNeill, 1980a]).

Methods

On November 12, 2008, Bureau staff conducted an electromagnetic induction (EM) survey at the T-Bar Ranch in northern Winkler County, Texas. The purpose of the survey was to determine whether there is evidence for the presence of highly electrically conductive ground related to elevated ground salinities within the exploration depth range of the EM instrument. This survey supplemented measurements made with the same instrument at the same site on June 4, 2008. We used a Geonics EM34-3 ground conductivity meter to measure apparent electrical conductivity of the ground at locations generally east and north of the June 2008 survey (fig. 1). Together, apparent ground conductivity was measured at more than 400 locations along seven lines near a salt-water disposal well, monitor wells, and pipelines on the ranch (fig. 1).

The Geonics EM34-3 is a frequency-domain electromagnetic induction instrument that noninvasively measures ground conductivity by creating a continuously changing magnetic field around a transmitter coil (Frischknecht and others, 1991). As the primary magnetic field changes, it induces currents to flow in the ground that are proportional in strength to the electrical conductivity of the ground. These ground currents create a secondary magnetic field. A second receiver coil is used to compare the strength and phase of the primary and secondary fields to determine an apparent conductivity of the ground. The instrument can be operated at three primary frequencies (6400, 1600, and 400 Hz) and corresponding coil separations (10, 20, and 40 meters) that explore to progressively greater depths (table 1). Exploration depths can also be changed by altering the coil orientation; the vertical dipole configuration (coils flat on the ground) explores about twice as deep as the horizontal dipole configuration (coils upright and in the same vertical plane). The horizontal dipole orientation responds disproportionately strongly to the shallower third of its nominal exploration depth, whereas the vertical dipole orientation responds disproportionately strongly to the center third of its nominal exploration depth (Geonics, 1996).

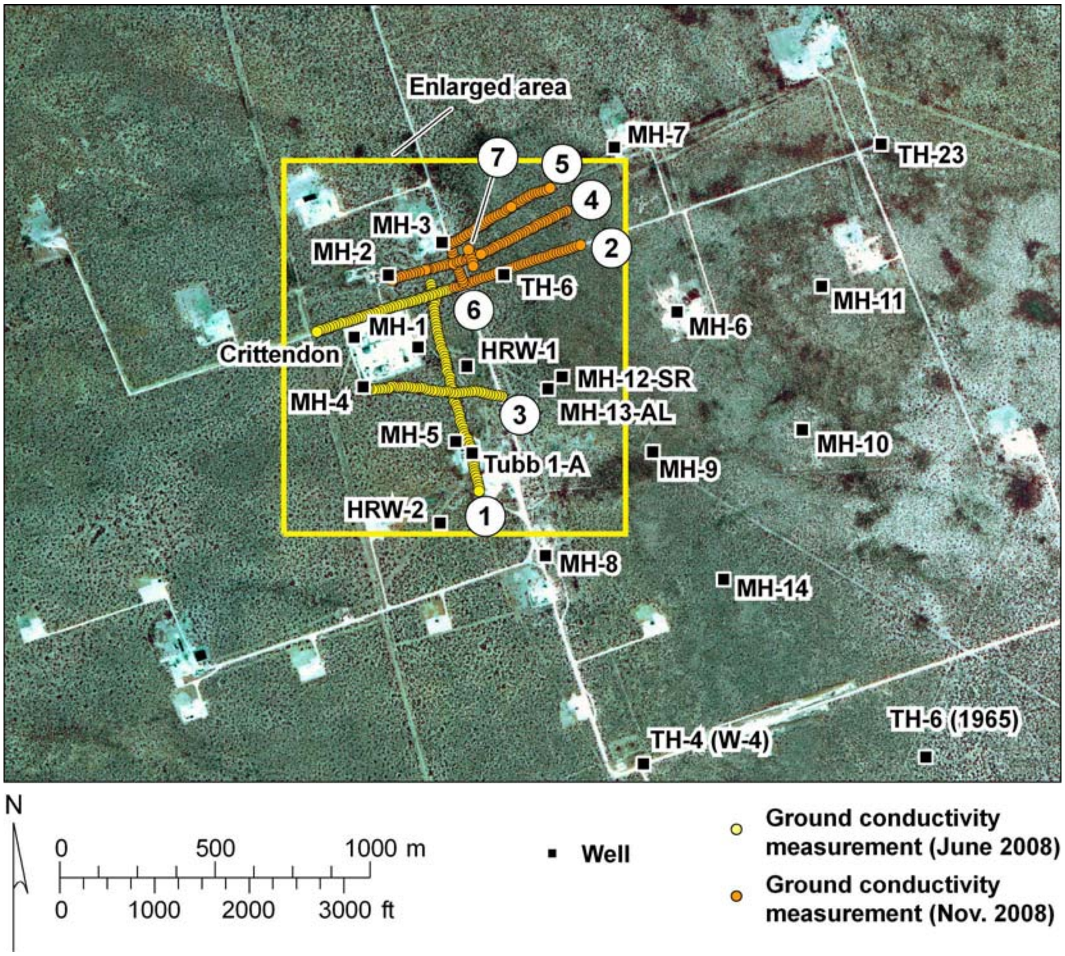

Figure 1. Aerial photograph of the geophysical survey area on the T-Bar Ranch in northern Winkler County, Texas. Circled numbers label geophysical lines. Colored circles indicate ground conductivity measurement locations visited in June 2008 (yellow) and November 2008 (orange). The area within the rectangle is enlarged on figs. 2 through 5. The aerial photograph was taken on September 9, 2004 as part of the National Agricultural Imagery Program and was obtained from the Texas Natural Resources Information System. Well names and locations provided by Lee Wilson and Associates.

Table 1. Approximate exploration depth of the Geonics EM34-3 ground conductivity meter. Actual exploration depth depends on signal strength, noise, and the conductivity of the ground (McNeil, 1980a, b; Geonics, 1996).

Coil separation (m)	Primary frequency (Hz)	Exploration depth, horizontal dipole (m)	Exploration depth, vertical dipole (m)
10	6400	6	13
20	1600	12	25
40	400	24	51

EM lines 1 through 6 were acquired using the 10-m coil separation and 6400 Hz primary frequency. Line 1 follows a salt-water disposal line, beginning just north of a caliche road near the Crittenden Field Office and continuing southward past the Tubb 1-A well (figs. 2 and 3). Line 2 is a roughly east–west line along a caliche road that begins east of well TH-6 and extends westward past the Crittenden Field Office to a point near a major pipeline. Line 3 is an east–west line that extends westward from a caliche road, crosses line 1 along the disposal line, and ends at monitor well MH-4 near the field office. EM line 4 extends eastward from well MH-2, intersecting and following a pipeline route near where the line crosses a caliche road. EM line 5 begins at a caliche road near well MH-3, following a pipeline route to the east-northeast. EM line 6, acquired along a caliche road, intersects lines 2, 4, and 5. Data were acquired using the deeper-exploring, 20-m coil separation and 1600 Hz primary frequency (table 1) along the western part of line 2, parts of lines 4 and 5, and line 7 (figs. 1, 4, and 5).

Results

Apparent conductivities for each of the lines, coil separations, and coil orientations are depicted as color-coded values on a 2004 aerial photographic base map (figs. 2 through 5). Relatively nonconductive values (less than 60 millisiemens per meter, or mS/m) are shown in shades of green. Elevated conductivities (greater than 60 mS/m) are shown in shades of yellow, orange, and red. A few negative apparent conductivities measured using the vertical dipole orientation indicate likely sites of buried metal. These values are shown in blue (figs. 3 and 5).

At the shallowest-exploring coil separation and frequency, most apparent conductivities are relatively low along lines 1 through 6 (figs. 2 and 3). Local elevated values extending for a measurement or two along line 1 are likely caused by buried metallic pipelines or other debris. Apparent conductivities along line 3 and the eastern halves of lines 2, 4, and 5 are extremely low, commonly less than 20 mS/m. Significant areas of elevated conductivity measured at the shallowest exploration depths are (1) a segment nearly 200-m long located north and west of the Crittendon Field Office (Area A, figs. 2 and 3); (2) along a 100-m-long segment of line 1 adjacent to the Tubb 1-A salt-water disposal well (Area B); and (3) along a more than 150-m-long segment of line 4 along a pipeline route (Area C). Stressed vegetation accompanies the elevated apparent conductivities in Area A and around surface pipeline structures in Area C. Additional short segments of elevated apparent conductivity were identified east of well MH-1 (line 1), near the intersection of lines 1 and 2, between well MH-2 and a caliche road (line 4), and east of MH-3 (line 5).

In Area A, ground conductivities measured with the 10-m coil separation are higher and more extensive using the deeper-exploring vertical dipole orientation and the horizontal orientation, indicating that ground conductivity increases with depth within the upper 13 m. Data acquired along line 2 using the 20-m coil separation (figs. 4 and 5) continue the trend of increasing apparent conductivity with increasing exploration depth in Area A, suggesting that highly conductive ground extends beyond the deepest depth investigated with this instrument. In addition, the western edge of highly conductive Area A was not reached by either the 10-m or 20-m coil separation along line 2.

A similar apparent conductivity trend is evident in Area C along line 4 (figs. 2 to 5). Significant elevation of apparent conductivity is measured for only a few locations in Area C (fig. 2) using the shallowest-exploring instrument configuration (nominally 6 m at 10-m separation, horizontal dipole orientation, table 1). Higher conductivities were measured over a greater distance in Area C using the deeper-exploring instrument configurations, including the vertical dipole orientation at 10-m coil separation (nominally 12-m exploration depth, fig. 3) and both the horizontal- and vertical-dipole orientations at 20-m coil separation (nominally 12- and 25-m exploration depths, figs. 4 and 5). These trends suggest increasing salinization with depth within the exploration depth range of this instrument configuration.

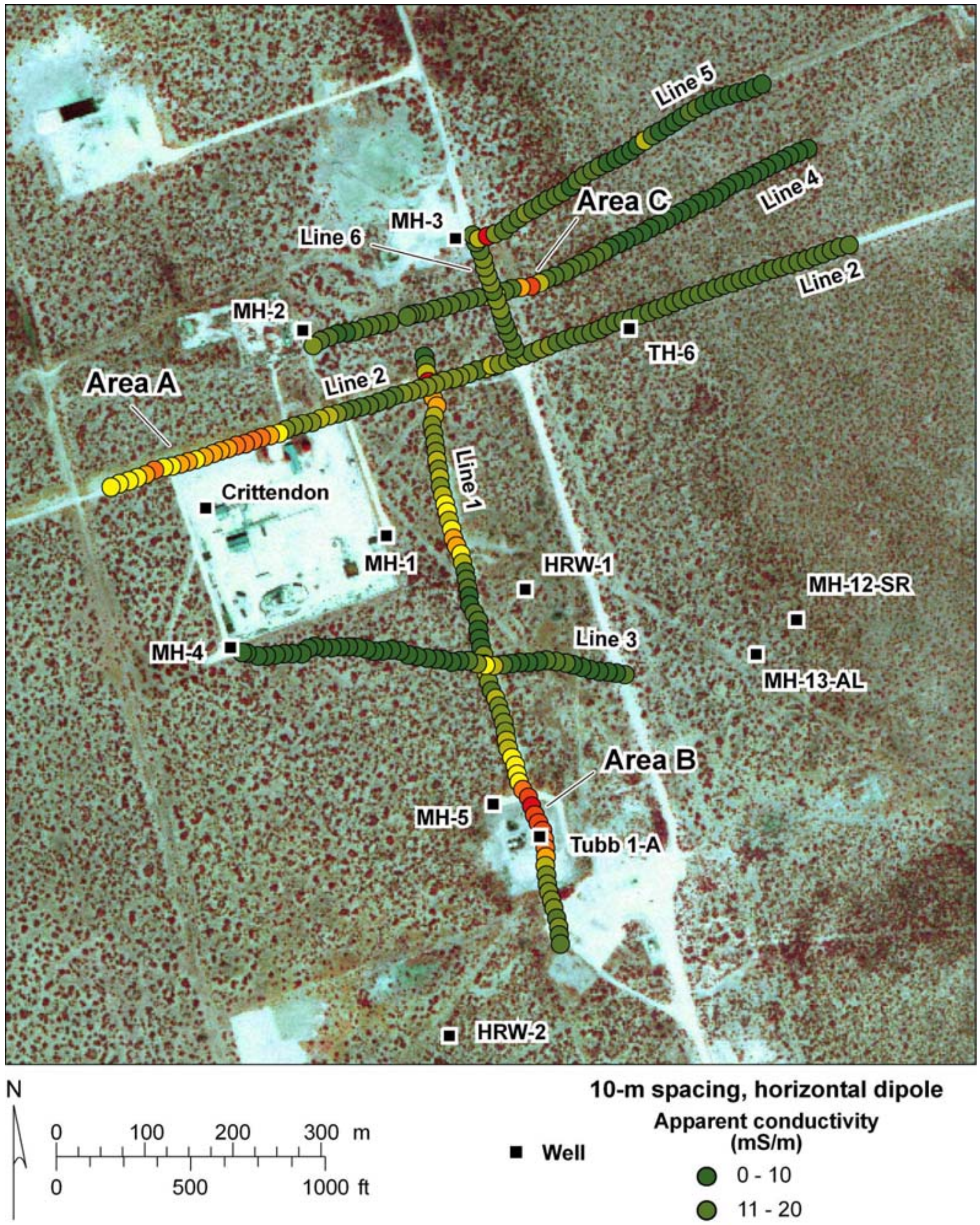

Figure 2. Apparent ground conductivities measured along EM lines 1 through 6 using a Geonics EM34-3 instrument operating at a 10-m coil separation, 6400 Hz primary frequency, and horizontal dipole coil orientation. The nominal exploration depth reaches 6 m (table 1), but the upper third of that depth range is the most significant contributor to the measured value.

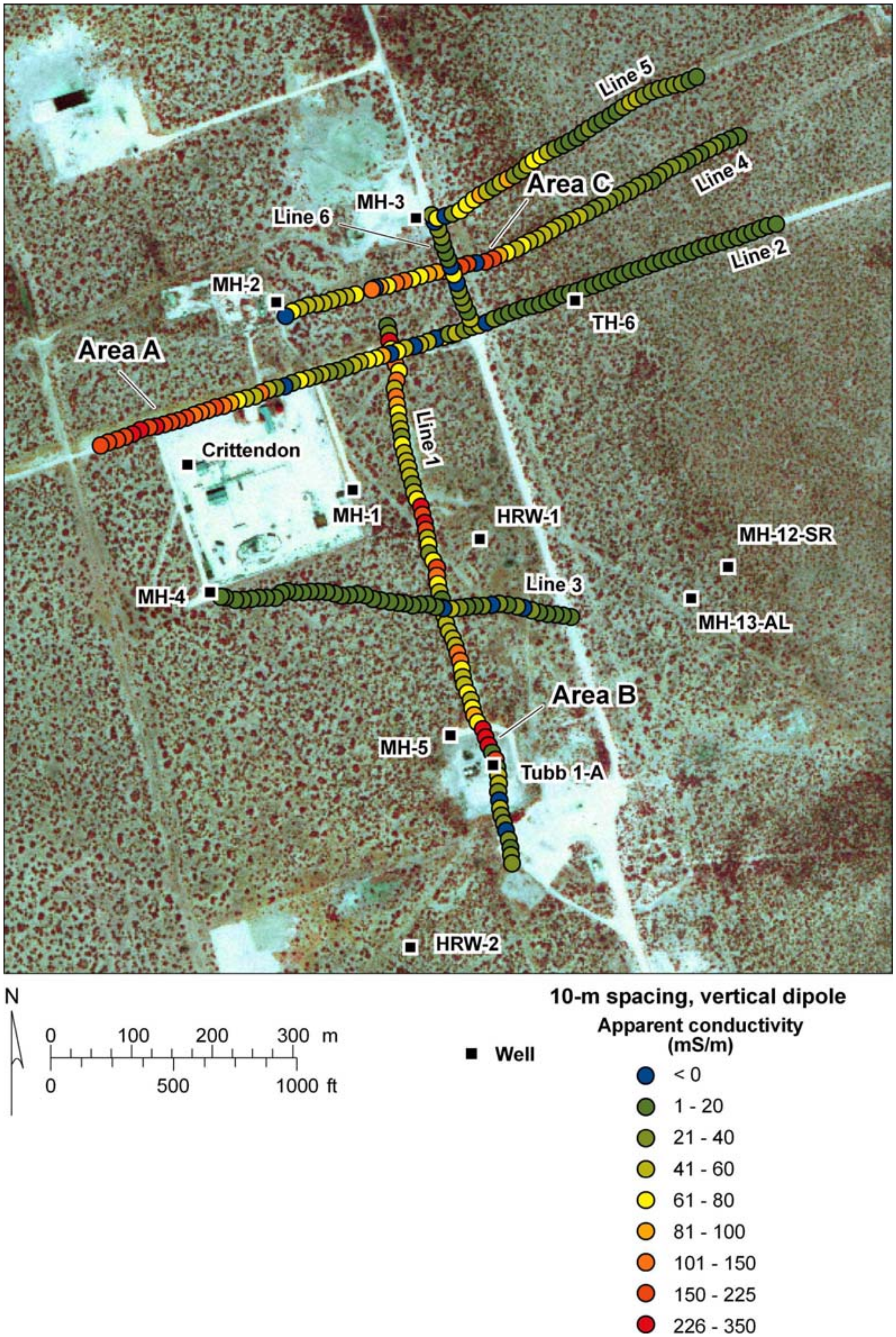

Figure 3. Apparent ground conductivities measured along EM lines 1 through 6 using a Geonics EM34-3 instrument operating at a 10-m coil separation, 6400 Hz primary frequency, and vertical dipole coil orientation. The nominal exploration depth reaches 13 m (table 1), but the middle third of that depth range is the most significant contributor to the measured value.

Figure 4. Apparent ground conductivities measured along EM lines 2, 4, 5, and 7 using a Geonics EM34-3 instrument operating at a 20-m coil separation, 1600 Hz primary frequency, and horizontal dipole coil orientation. The nominal exploration depth reaches 12 m (table 1), but the upper third of that depth range is the most significant contributor to the measured value.

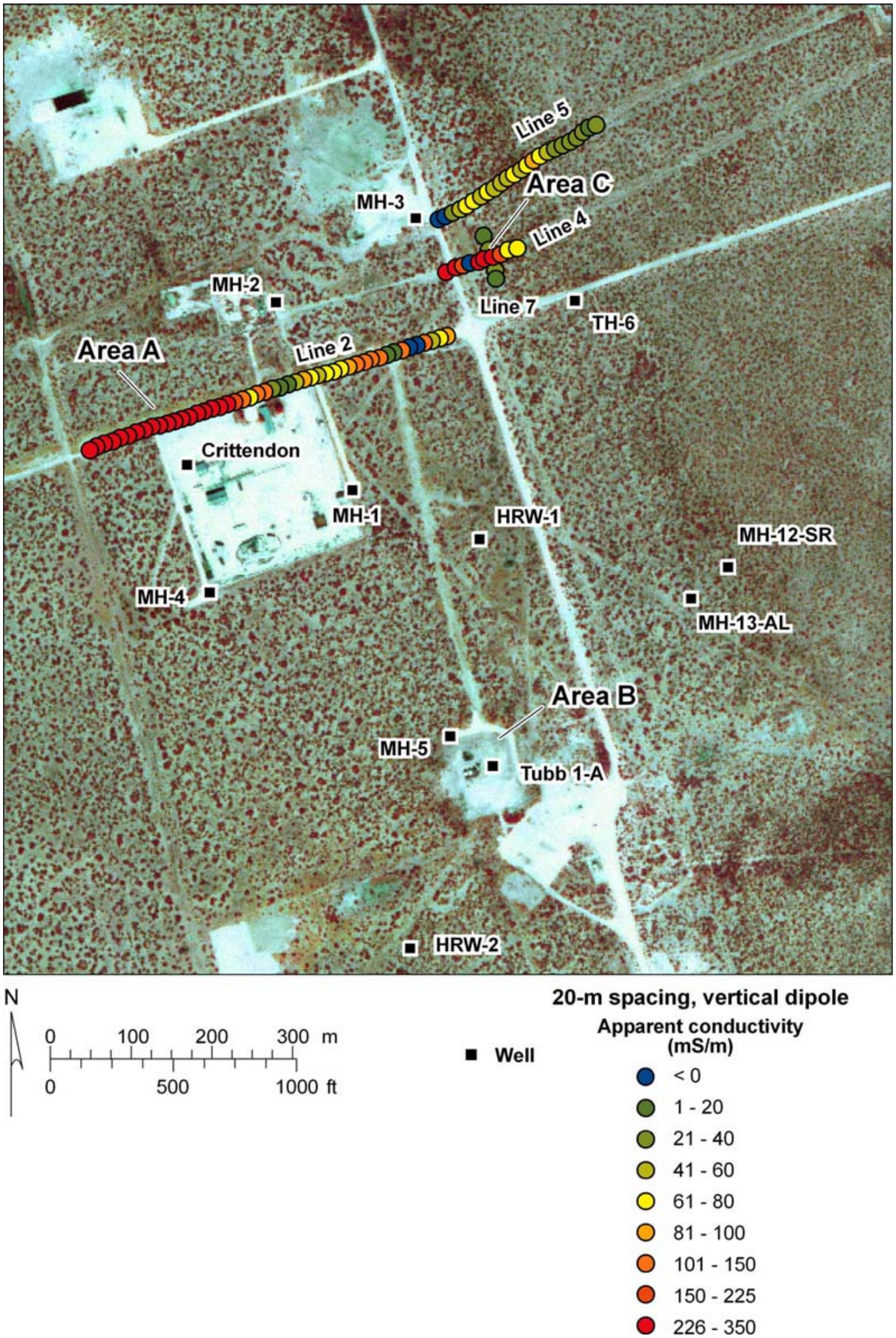

Figure 5. Apparent ground conductivities measured along EM lines 2, 4, 5, and 7 using a Geonics EM34-3 instrument operating at a 20-m coil separation, 1600 Hz primary frequency, and vertical dipole coil orientation. The nominal exploration depth reaches 25 m (table 1), but the middle third of that depth range is the most significant contributor to the measured value.

Interpretation

An electromagnetic induction (EM) survey along pipelines, open fields, and caliche roads on the T-Bar Ranch revealed three areas (A, B, and C, figs. 2 to 5) with apparent conductivities high enough to suggest salinization within the exploration depth range of the instrument. Area A is the largest of the three salinized areas, extending more than 200 m laterally and to a depth perhaps as great as 20 m or more. Conductivity trends in Areas A and C suggest that salinization intensity increases with depth within the exploration depth range of the instrument. Each of the areas has likely received significant amounts of saline water over extended periods of time from surface or near-surface sources.

Acknowledgments

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