Review of the 2008 Resistivity Surveys at the WCS Facility, Andrews County, Texas

by

Jeffrey G. Paine
TBPG License No. 3776, Geophysics

Prepared for

Texas Commission on Environmental Quality
under Interagency Contract No. 58204-69718, Work Order 1, Amendment 7

Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin
University Station, Box X
Austin, Texas 78713-8924

April 15, 2009
Revised May 12, 2009

Introduction

Technos, Inc. completed two resistivity surveys on behalf of Waste Control Specialists, LLC (WCS) at the WCS facility in Andrews County, Texas. These surveys, conducted between January 24-27, 2008 and August 29-September 2, 2008, are summarized in three reports (Technos 2008a, 2008b, and 2008c). Results of the January survey, including processing and analysis of resistivity lines A and B extending northeast from the northern boundary of the proposed Federal Waste Disposal Facility, are reported in Technos 2008a. Discussion of those results led to additional resistivity surveying along lines C and D, which extend across and northward from the Byproduct Disposal Site as described in Technos 2008b. The general lack of agreement between processed resistivity data and known depths to a significant conductive layer (the redbeds) identified in boreholes and in geophysical logs led to additional processing and analysis of the resistivity data, which is summarized in a supplemental report (Technos 2008c). Technos subsequently provided resistivity data files from both surveys to allow a preliminary independent assessment of the resistivity data.

Troubling aspects from the report on the January 2008 survey included (a) the poor agreement between the resistivity-depth sections and the known depth to a relatively conductive layer (the resistivity data significantly overestimated the depth to the redbeds), (b) the poor agreement between borehole conductivity data and resistivity values in the inverted depth sections, and (c) the conclusion that surface resistivity data would not be useful in examining water saturation trends in the shallow subsurface at the site. Many of the same issues remained in the second report following the August-September acquisition and processing. The supplemental processing described in Technos 2008c was intended to address these issues by reprocessing the resistivity data and examining trends in unprocessed data at different electrode spacings to identify a possible relationship between water saturation and apparent resistivity, but only partly satisfied that objective. We have briefly examined the raw resistivity data provided by Technos to further investigate issues of conversion of raw resistivity data to true resistivity-depth profiles and possible correlations between field data and water saturation along lines A, B, C, and D.

Relationship between Water Saturation and Apparent Resistivity

We agree with the conclusion in the Technos reports that it is unlikely that surface geophysical methods can “resolve” the thickness of the water-saturated section (meaning to accurately determine the depths at the top and bottom of the saturated section), but remain unconvinced that electrical methods (including resistivity or electromagnetic induction) cannot be used to examine water-saturation trends across the site.

Technos compared apparent resistivity measurements at different electrode spacings to known saturated thicknesses at wells adjacent to lines A, B, C, and D, and reported those results in Figure 2 of Technos 2008c, concluding that there was no correlation between water saturation and apparent resistivity. They produced apparent resistivity plots at Wenner-array electrode spacings of 60, 80, and 100 ft, which indeed show little if any correlation with saturated thickness. In examining the electrode spacings available for analysis from the raw resistivity data provided by Technos, it can be seen that other spacings can be used for this analysis (Figure 1). Because exploration depth generally increases with electrode spacing (at least for similar array types), we can also examine the relationship between water saturation and apparent resistivity at electrode spacings that explore deeper than those examined by Technos. For example, the a-spacings used by Technos (60, 80, and 100 ft) correspond to total half-array lengths of 90, 120, and 150 ft respectively (Figure 1). Longer half-array lengths for both Wenner and Schlumberger array configurations are available for these data, albeit with progressively less complete coverage along the lines. Whereas the 60- and 100-ft data (converted to apparent conductivity rather than apparent resistivity) show little correlation with saturated thickness (Figures 2a, 3a, 4a, and 5a) for each line, the deeper-exploring Schlumberger spacings (half-array lengths of 180 and 225 ft) show greater correlation with saturated thickness (Figures 2b, 3b, 4b, and 5b). This suggests that the electrode spacings chosen for the Technos analysis did not explore deeply enough to be strongly influenced by water saturation, whereas the longer electrode spacings are progressively more influenced by water saturation and may be useful in understanding subsurface saturation trends at the site.

Poor Match between Resistivity-Depth Sections and Depth to Redbeds

The inversions of the resistivity data for both surveys generally show poor agreement between the resistivity-depth sections and known depths to the relatively conductive, clay-rich redbeds as determined from borehole data (Technos 2008a, b) and generally overestimated subsurface resistivities. Additional inversion approaches discussed in Technos 2008c (Figure 1) again show a general lack of correlation between what we expect to be the top of an electrically conductive unit (the redbeds, or clay/claystone) and the resistivity-depth section. The top of the clay/claystone unit generally correlates with the top of a resistive zone on the depth sections, again indicating a substantial divergence between the depth section and geologic “reality.” The raw resistivity data provided by Technos show apparent resistivities that are similar to values measured by Technos using borehole instruments, suggesting that the borehole data are indeed representative of the area surveyed using surface resistivity methods. I completed several 1-dimensional inversions of the resistivity data at borehole locations and other selected locations along each of the lines. These inversions, done using only the Schlumberger-array data acquired by Technos (they acquired mixed Wenner- and Schlumberger-array data), also produced resistivity values similar to those acquired using the borehole instrument. There was better agreement at some locations between the 1-D inversions (using the software IX1D by Interpex) and reality than there was between the resistivity-depth section and reality. Three examples are included where there is a lack of agreement between borehole and surface resistivity data.

Line B near TP-15

We combined Schlumberger array measurements near well TP-15 (centered at 475 to 480 ft from the south end of Line B) to produce an inverted conductivity-depth profile at this well. The variation in apparent conductivity with electrode spacing (Figure 6a) indicates that the general conductivity profile consists of a resistive layer at the surface, a conductive layer beneath that, a second resistive layer below that, and a slight increase in conductivity at the longest spacings suggesting a basal conductive layer. The inverted depth section produced by Technos indicates that the depth to the basal conductive layer is about 75 ft at this location (Technos 2008a, fig. 5), about 17 ft deeper than indicated in

TP-15. IX1D inversions at this location (Figure 6b) are similar in basic configuration to the Technos inversion, but also indicate a greater depth to the conductive layer than the known depth to the conductive redbeds. Although the shape is similar, the IX1D inversion depicts layer conductivities significantly higher than those shown on the Technos inverted section. The IX1D-inverted conductivity values are closer to those measured using borehole instruments than those depicted on the Technos section. A possible cause of the mismatch with between the known depth to the redbeds and the inverted depth to the basal conductive layer is that the resistivity measurements did not reach the intended investigation depth and did not adequately sample the redbeds at this location. Another possibility is that the inverted depth to the underlying conductive layer is reasonably correct, but there is no significant conductive layer associated with the top of the redbeds. Borehole conductivity logs seem to support the general interpretation that the top of the basal conductive layer determined from surface geophysical measurements should correlate to a stratigraphic position near the top of the redbeds and that the resistivity method did not adequately sample material below the top of the redbeds.

Line C near TP-74

The resistivity-depth section along Line C (Technos 2008b, Figure 3) depicts considerable variation in resistivity structure on the southern half of the line, which includes the position of well TP-74. A review of raw apparent resistivity measurements in this area reveals large lateral change at the longer separation electrode distances (Figure 4), which is difficult to reconcile with reality (the electrical properties of the large subsurface volumes contributing to the measured signal are not likely to change greatly over such short distances) and would lead to problems with any inversion approach. Despite this, we combined Schlumberger array measurements near well TP-74 in an attempt to produce a comparative conductivity-depth profile. Apparent conductivity measurements display a trend of increasing apparent conductivity with increasing electrode spacing, with a large increase at the longest spacing (Figure 7a). A four-layer inversion at this site yields a poor fitting error, unrealistic conductivities for the surface and basal layers, and a poor fit with known water level and redbed depths at TP-74. The raw resistivity data are thus suspect over much of the southern half of this line where large excursions in long-spacing apparent resistivity data are present. This could be caused by unusual subsurface geometries (major changes in electrical properties over short distances) or unknown acquisition issues.

Line D near TP-64

Several wells are located near resistivity Line D. The closest to the line is TP-64, located about 8 ft east of the line at about 2530 ft from the south end of the line (Technos 2008b, fig. 4). At this location, there is poor agreement between the depth to the redbeds in the borehole (65 ft) and the depth to the basal conductive layer in the resistivity-depth section (greater than 80 ft). The raw resistivity data acquired using the Schlumberger configuration show a common pattern consisting of a low-conductivity layer at the surface that is underlain by a more conductive layer, which is in turn underlain by a more resistive layer (Figure 8a). There is a slight increase in apparent conductivity at the longest electrode spacings that suggests the presence of a basal conductive layer, although it is not well constrained. Inversions of these data to a conductivity-depth profile using IX1D (Figure 8b) depict reasonable conductivity values for each of the layers, show good agreement between the known depth to the redbeds (65 ft) and the depth to the top of the basal conductive layer (66 ft), and a low fitting error. In this case the IX1D inversion improves upon the two-dimensional inversion used in the original processing.

Conclusions

In summary, both the borehole and surface resistivity data suggest that electrical methods may indeed be useful in examining moisture content variations across the WCS site. Surface methods, including resistivity and EM, cannot be expected to resolve the thickness of the saturated zone, particularly where it is thin. An examination of the raw resistivity data provided by Technos suggests that data acquired using longer electrode spacings do indeed show a correlation with saturated thickness, with higher apparent conductivities accompanying thicker saturated sections.

Comparative one-dimensional inversions at select locations of data provided by Technos suggest that the inversion approach used in analyzing the data from the WCS site overestimated true subsurface resistivities, which might contribute to the apparent poor agreement with borehole geophysical data. Most of the raw resistivity data appear to be representative of true subsurface conditions, except along the southern half of Line C where large lateral variations in long-spacing data were observed that make inversions and interpretations difficult. This may be caused by unusual subsurface conditions or unknown acquisition issues.

Our analysis suggests that the overall data quality is good and that different inversion approaches yield similarly shaped conductivity-depth profiles but differing layer depths and conductivities. If the redbeds do represent a basal, highly conductive layer as inferred from shallow and deep borehole logs (Technos, 2008a), the most likely explanation for the poor agreement between resistivity-depth profiles along lines A, B, C, and D and the known depth to the conductive redbeds is that the survey achieved insufficient exploration depth to adequately constrain the conductivity and configuration of the basal conductive layer (redbeds). The need for long electrode separations to achieve adequate exploration depth may limit the ability of the resistivity method to achieve the lateral resolution required to examine local variations in water saturation and redbed depth. Other electrical methods, such as time-domain electromagnetic induction, may provide better lateral resolution and greater exploration depth than the resistivity method.

The electrical response to changes in water saturation and to stratigraphic boundaries such as the redbed – Ogallala-Antlers-Gatuna (OAG) contact has been demonstrated in borehole geophysical logging and suggested by surface resistivity data. This observation implies that electrical methods can be useful in mapping changes in water saturation across the site, determining depth to redbeds, and in monitoring change in water saturation over time.

References

Technos, Inc., 2008a Final Report, Geophysical Survey at the WCS Facility, Andrews County, Texas: For Waste Control Specialists, LLC, Andrews, Texas, Technos Project No. 08-108, 11 p.

Technos, Inc., 2008b, Addendum, Final Report, Geophysical Survey at the WCS Facility, Andrews County, Texas: For Waste Control Specialists, LLC, Andrews, Texas, Technos Project No. 08-108, 9 p.

Technos, Inc., 2008c, Supplemental Report, Additional Resistivity Processing for the Geophysical Survey at the WCS Facility, Andrews County, Texas: For Waste Control Specialists, LLC, Andrews, Texas, Technos Project No. 08-108, 5 p.

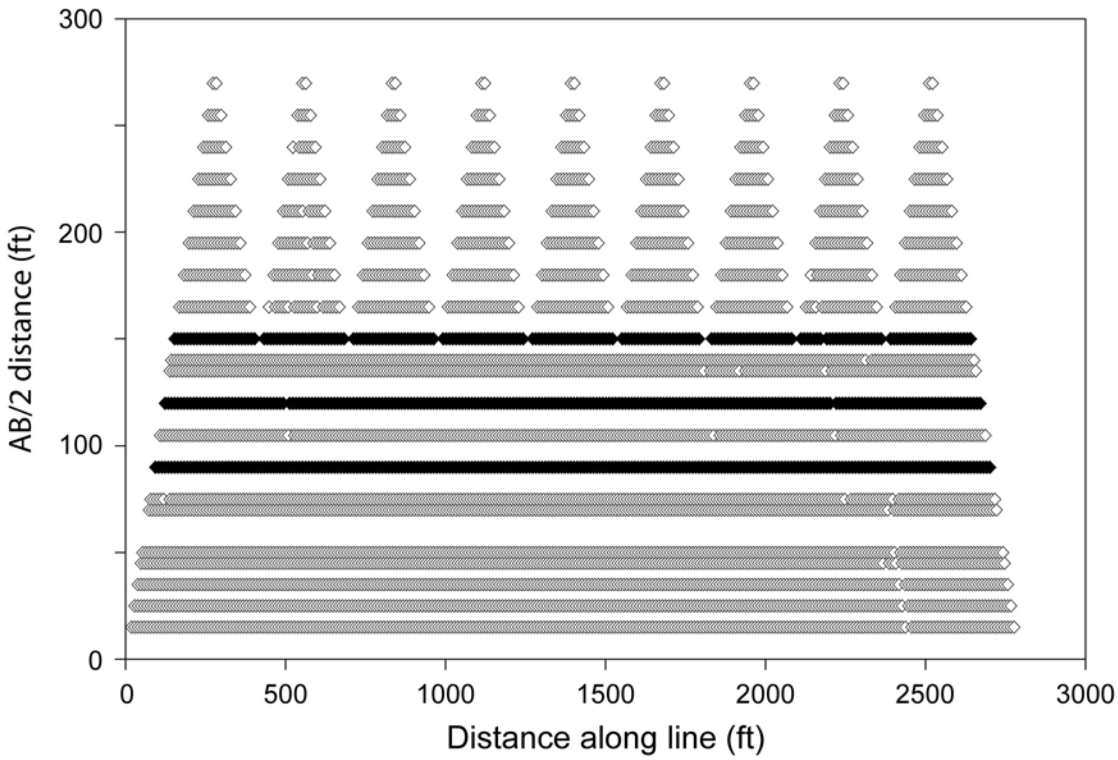
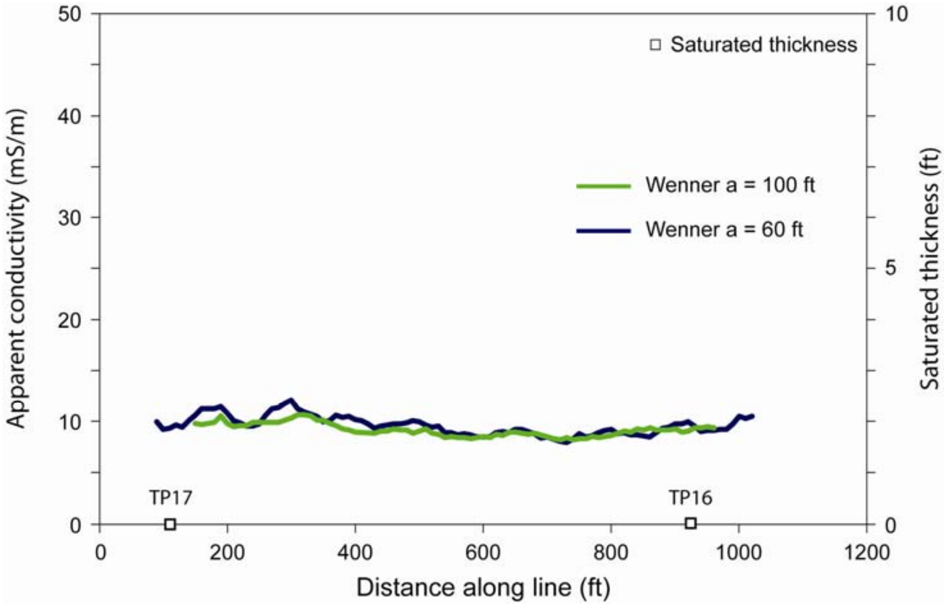


Figure 1. Distribution of electrode spacings along Technos resistivity line D including Wenner and Schlumberger array types. AB/2 distance represents half the distance between the most distant of four electrodes constituting a single apparent resistivity measurement. Adjacent electrode spacing was 10 ft (Technos, 2008b). Dark symbols correspond to Wenner spacings used in Technos 2008c to examine the correlation between water saturation and apparent resistivity (recast as apparent conductivity in Figures 2a, 3a, 4a, and 5a). AB/2 distances of 180 ft and 225 ft correspond to Schlumberger array measurements shown in Figures 2b, 3b, 4b, and 5b. Lines A, B, and C have similar electrode-spacing patterns.

(a)



(b)

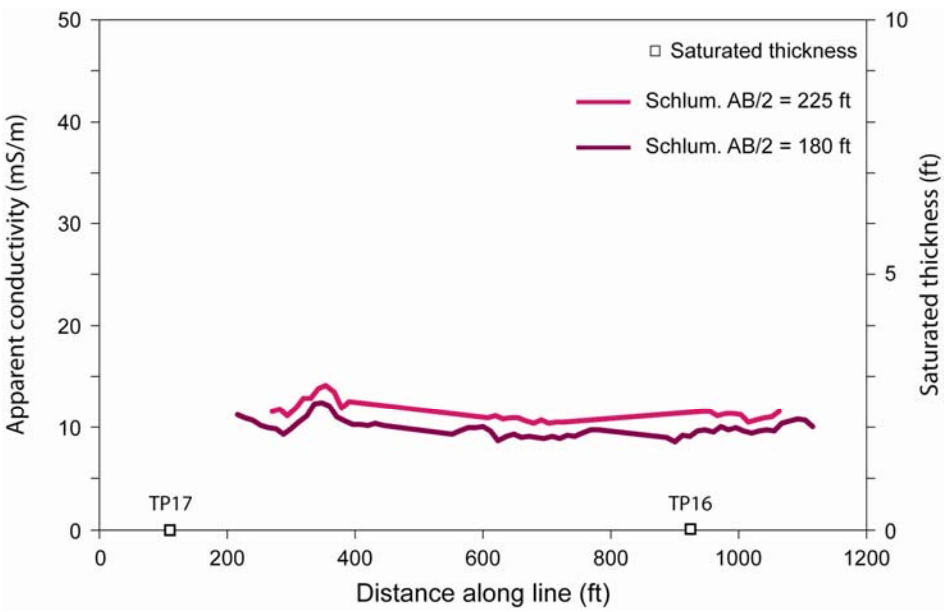
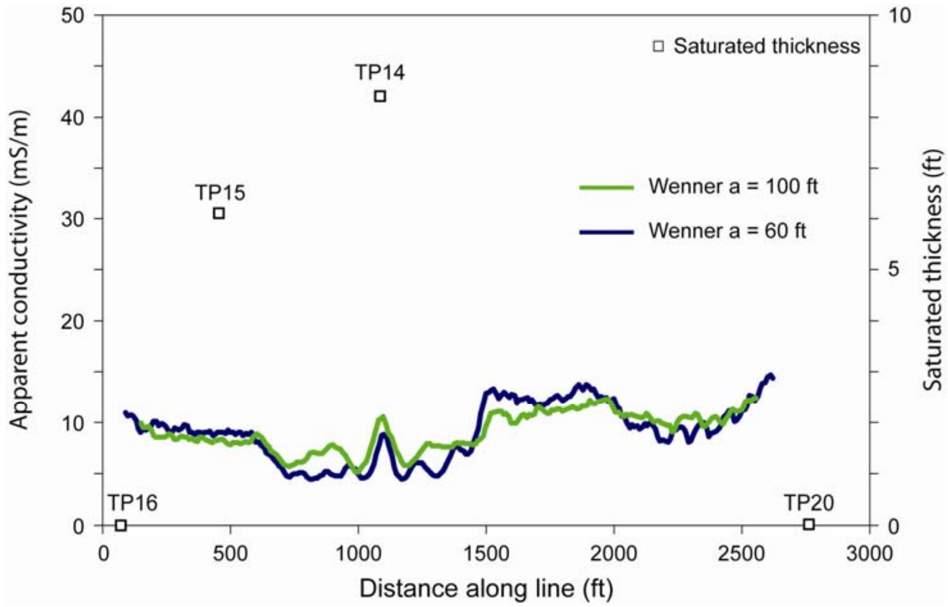


Figure 2. Comparison of apparent conductivity and water saturation along Line A. (a) Wenner 60- and 100-ft a-spacing data from Technos 2008c. (b) Schlumberger 180- and 225-ft AB/2 spacing data from raw resistivity data files.

(a)



(b)

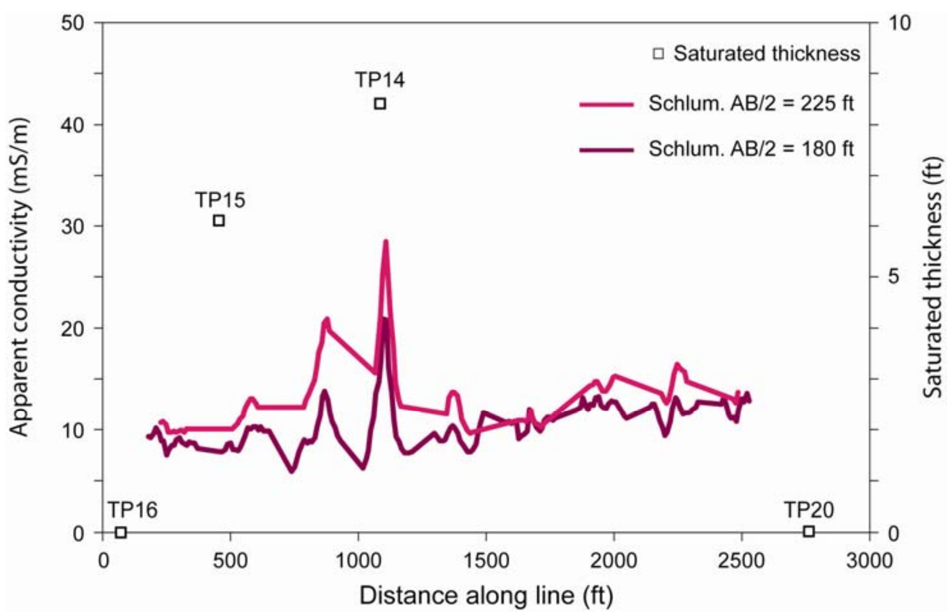
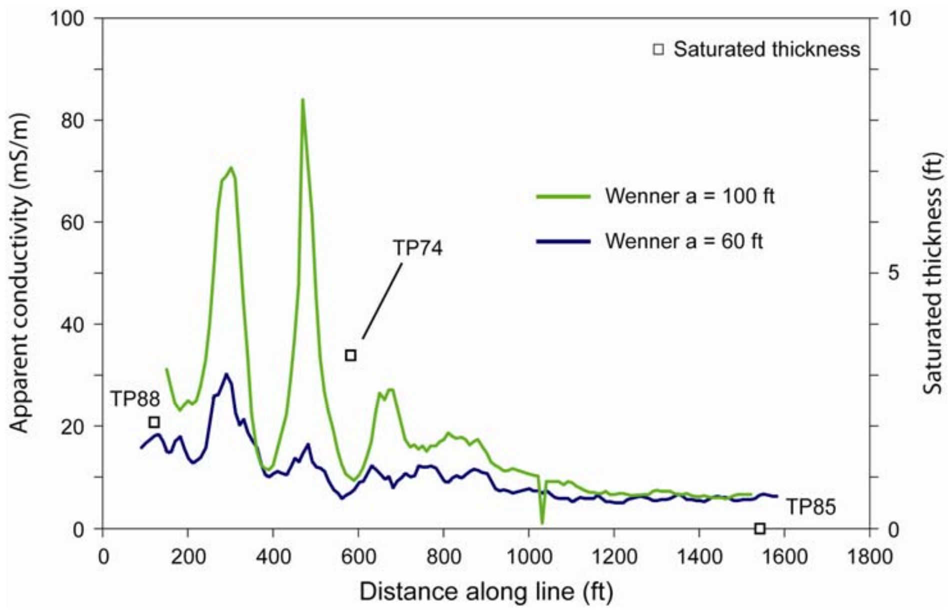


Figure 3. Comparison of apparent conductivity and water saturation along Line B. (a) Wenner 60- and 100-ft a-spacing data from Technos 2008c. (b) Schlumberger 180- and 225-ft AB/2 spacing data from raw resistivity data files.

(a)



(b)

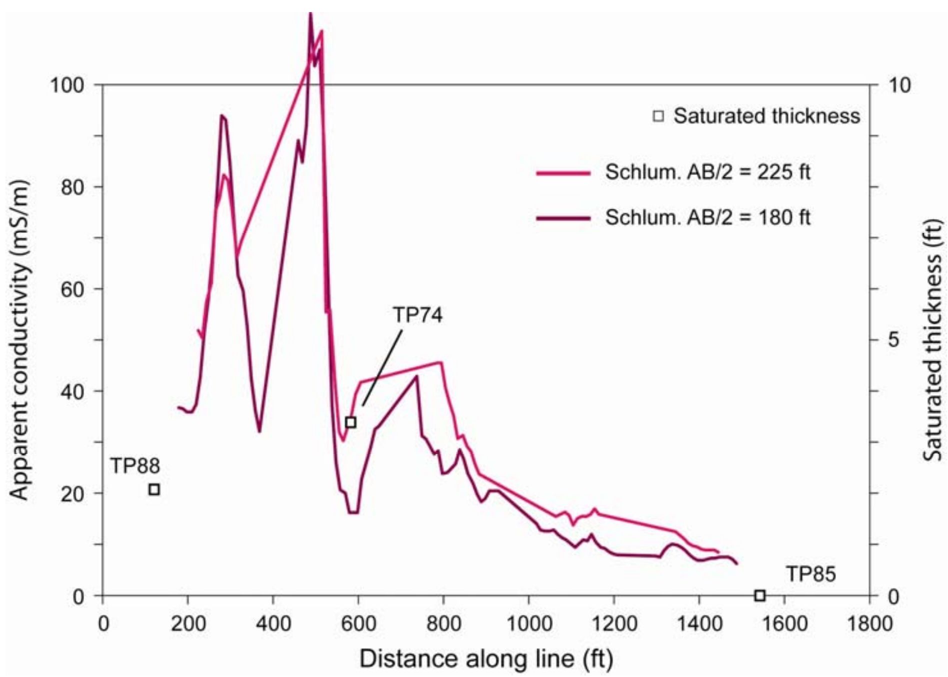
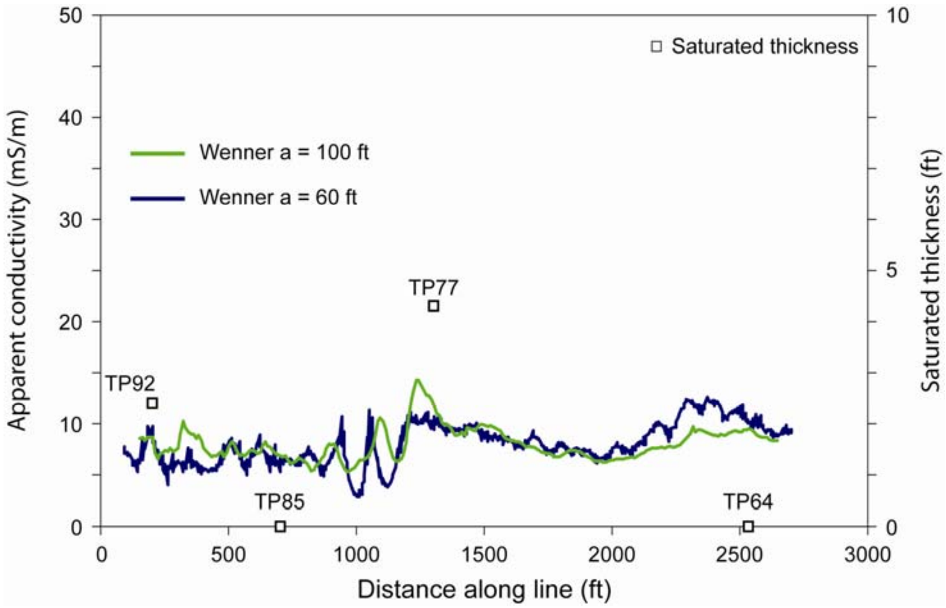


Figure 4. Comparison of apparent conductivity and water saturation along Line C. (a) Wenner 60- and 100-ft a-spacing data from Technos 2008c. (b) Schlumberger 180- and 225-ft AB/2 spacing data from raw resistivity data files.

(a)



(b)

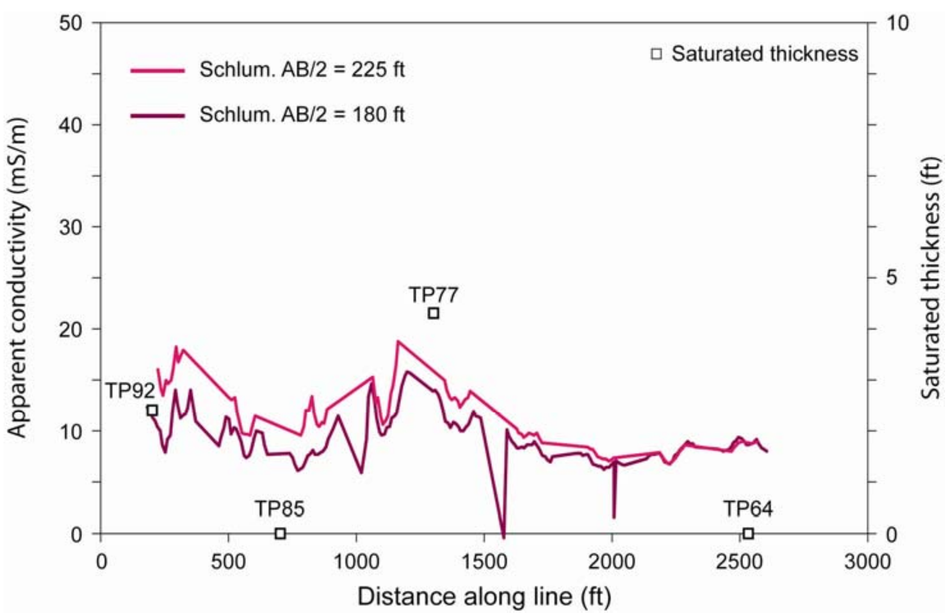


Figure 5. Comparison of apparent conductivity and water saturation along Line D. (a) Wenner 60- and 100-ft a-spacing data from Technos 2008c. (b) Schlumberger 180- and 225-ft AB/2 spacing data from raw resistivity data files.

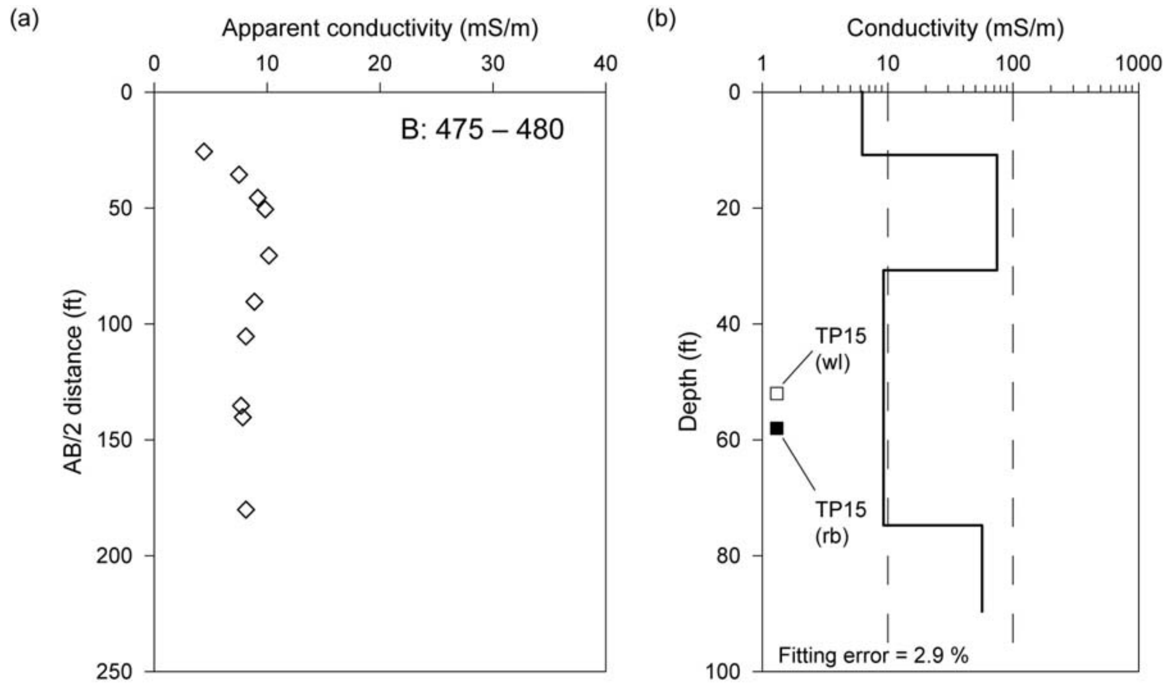


Figure 6. Depth inversion of resistivity data along Line B near well TP-15 (475 to 480 ft from the south end of the line). (a) apparent conductivity measurements using a Schlumberger array configuration at various electrode spacings. AB/2 values are half the distance between the outer electrodes (A and B) in the Schlumberger configuration. (b) inverted conductivity-depth profile using the apparent conductivity values and IX1D software. Also shown are reported water level (wl) and redbed (rb) depths at well TP-15. The overestimated depth to the basal conductive layer is likely due to insufficient sampling of the basal layer at the longest AB/2 spacings.

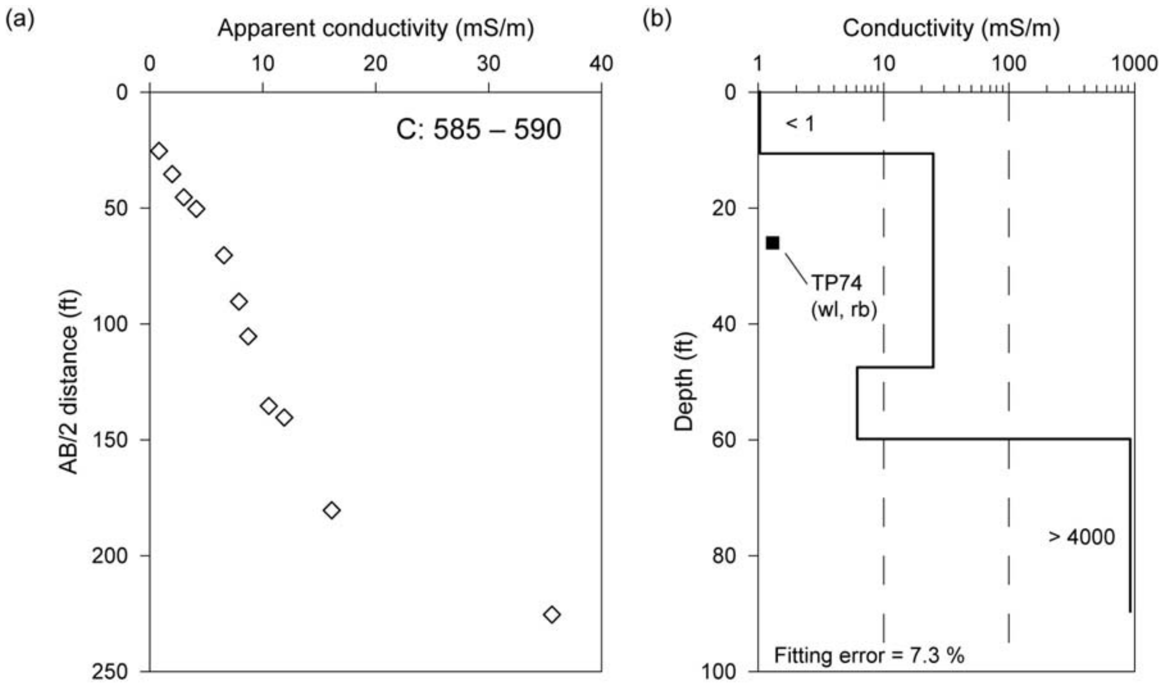


Figure 7. Depth inversion of resistivity data along Line C near well TP-74 (585 to 590 ft from the south end of the line). (a) apparent conductivity measurements using a Schlumberger array configuration at various electrode spacings. AB/2 values are half the distance between the outer electrodes (A and B) in the Schlumberger configuration. (b) inverted conductivity-depth profile using the apparent conductivity values and IX1D software. Also shown are reported water level (wl) and redbed (rb) depths at well TP-74. Unrealistic conductivity values and poor agreement between resistivity and well data are likely due to large lateral variations in long-spacing resistivity data that exist over much of the southern half of Line C.

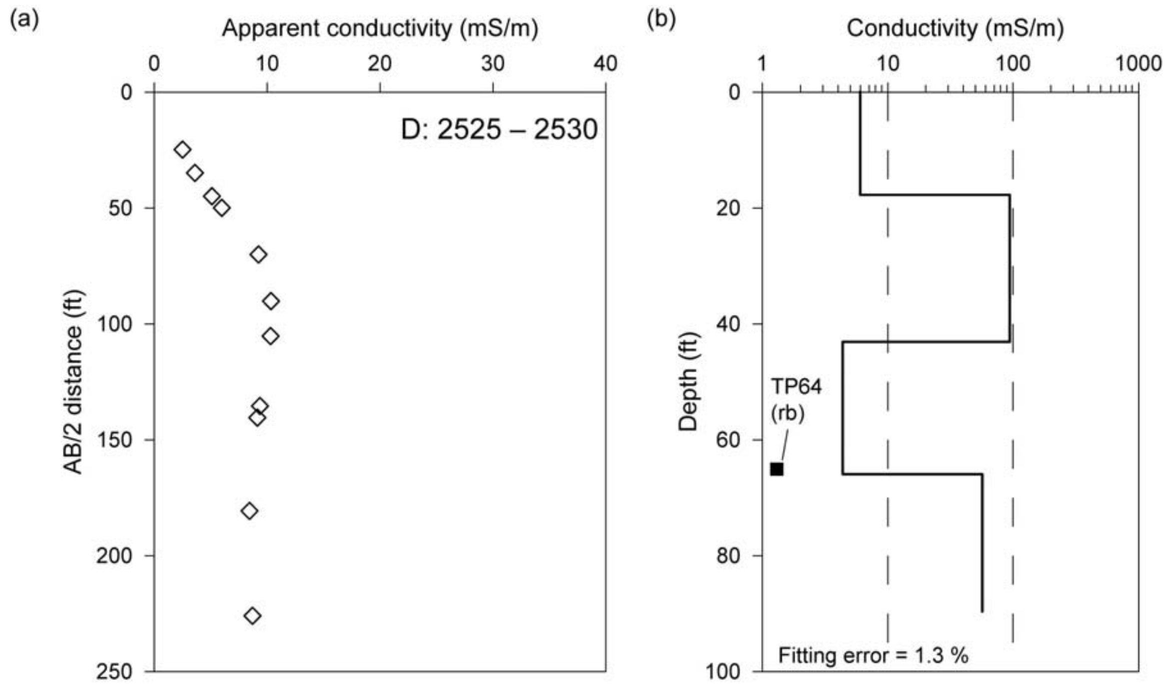


Figure 8. Depth inversion of resistivity data along Line D near well TP-64 (2525 to 2530 ft from the south end of the line). (a) apparent conductivity measurements using a Schlumberger array configuration at various electrode spacings. AB/2 values are half the distance between the outer electrodes (A and B) in the Schlumberger configuration. (b) inverted conductivity-depth profile using the apparent conductivity values and IX1D software. Also shown are reported redbed (rb) depths at well TP-64. At this location, the conductivity values are reasonable, there is good agreement between the depth to redbeds and the depth to the basal conductive layer, and the fitting error is low despite relatively poor constraints provided by the resistivity data on the basal conductive layer.