Geophysical Techniques Applied to a Stream-Aquifer System

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Abstract

In north-central Kansas the Republican River and its associated alluvial sediments are important regional surface and groundwater sources. A test site adjacent to the Republican River (near Clay Center, KS), has been established within the porous alluvial sediments to study stream-aquifer interaction and aquifer heterogeneity. The site is monitored with seven observation wells oriented along a line perpendicular to the river channel and centered around a productive irrigation well. Geophysical techniques, including direct-push electrical conductivity (EC), ground penetrating radar (GPR), and shallow seismic reflection, are used to investigate the hydrologic properties of the site.

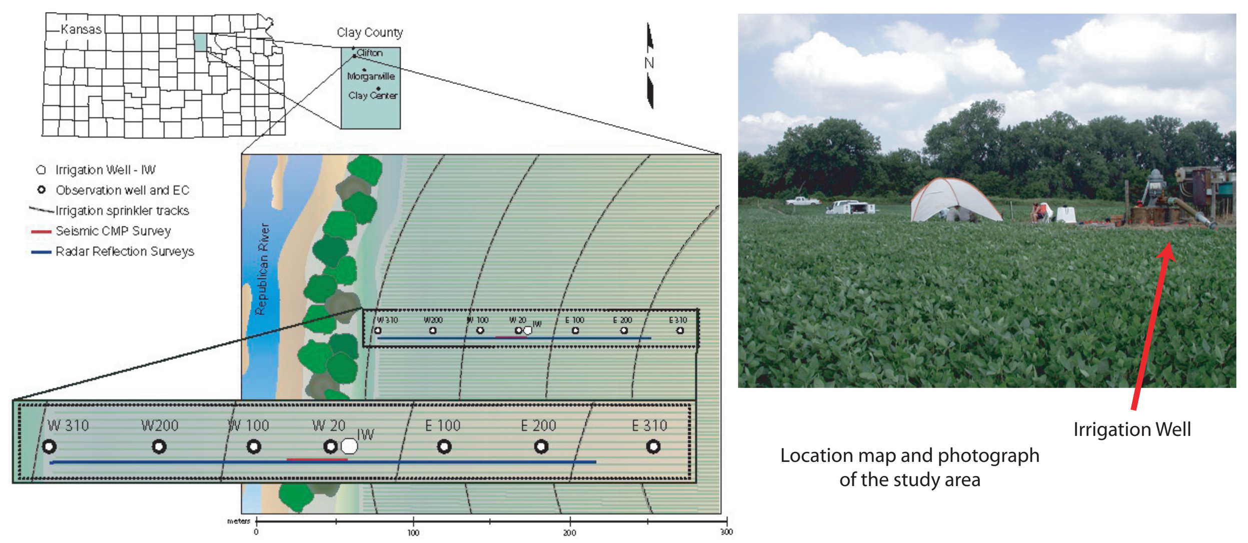
Electrical conductivity profiling is commonly used for gross lithologic definition of the subsurface. Recently, EC has been used to extract additional information about subsurface characteristics based on the three main parameters that control the electrical properties of soils: lithology, water content, and water chemistry. At the Clay Center test site EC profiles were obtained at seven locations, approximately 33 meters apart. These closely spaced conductivity profiles provide a general description of the vertical and lateral variation of the subsurface lithology. On the EC profiles the water table is indicated by an abrupt change in electrical conductivity. This indicator was observed during undisturbed hydrologic conditions and during a pumping test.

GPR reflection data were acquired in line with the observation wells at the Clay Center test site and were integrated with the EC profiles. Radar data collected during undisturbed hydrologic conditions imaged shallow lithologic alterations, but did not image as deep as the water table. Variations in reflection character and attenuation of the GPR signal demonstrate close agreement with subsurface electrical conductivity variations and provide the means to extend the EC data laterally, between observation wells.

High-resolution shallow seismic reflection data sets were collected to image the top of the saturated zone during and after the pumping test. Differences as well as similarities in the arrival times and amplitudes of P-wave reflections are evident in both data sets. Preliminary data analysis identifies a water table reflection both during and after the pumping test.

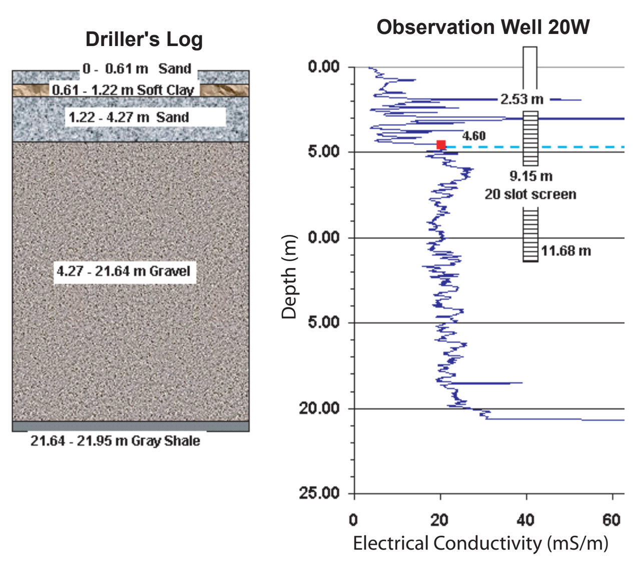
The geophysical techniques employed provide complementary information about the hydrologic properties of the subsurface. Integration of electrical conductivity profiles, GPR reflection data, and shallow seismic reflection data offer the potential for improved subsurface characterization.

Clay Center Test Site



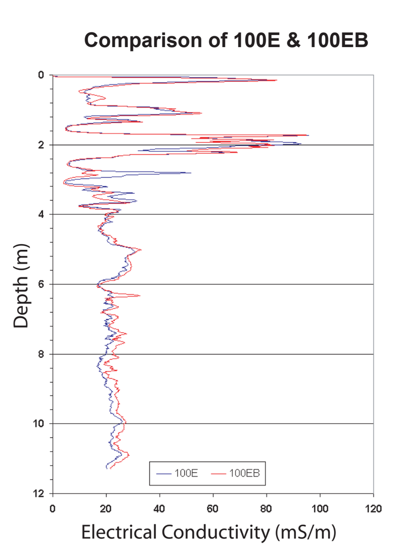
Location map and photograph of the study area

Electrical Conductivity (EC)

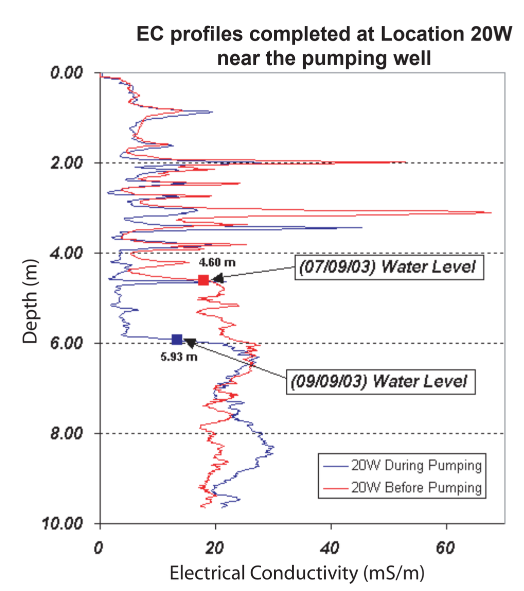


The geophysical methods employed focus on the upper 21.5 meters of sediment associated with the modern-day Republican River. The section consists of alternating sequences of clay, sand, and gravel deposited on an irregular bedrock surface of shale inferred as the Permian Wellington Formation. The driller's log describes the lithology at the test site.

The Electrical Conductivity Profile is a direct-push method (Geoprobe Systems) where an electrical resistivity probe is hydraulically advanced into unconsolidated material. For a detailed description of EC Profiling refer to Christy et al., 1994, and Schulmeister et al., 2003.

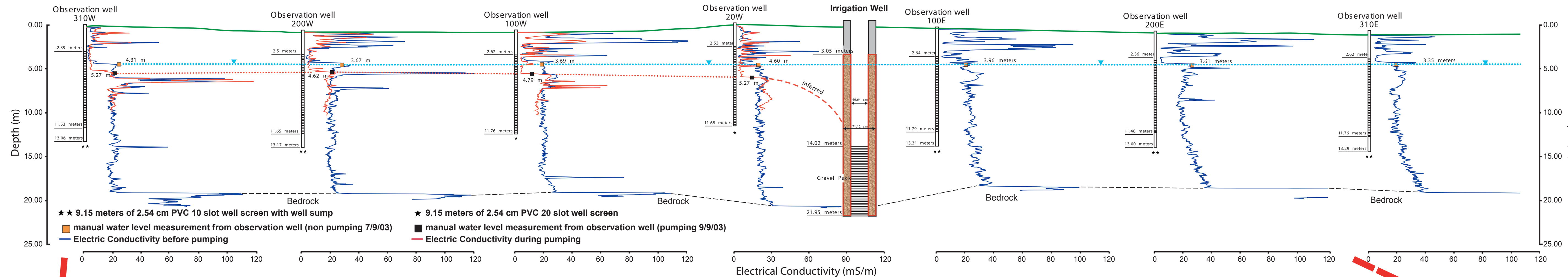


The quality and repeatability of EC measurements at this site were assessed by profiles100E and 100EB acquired consecutively and spaced 30 cm apart.

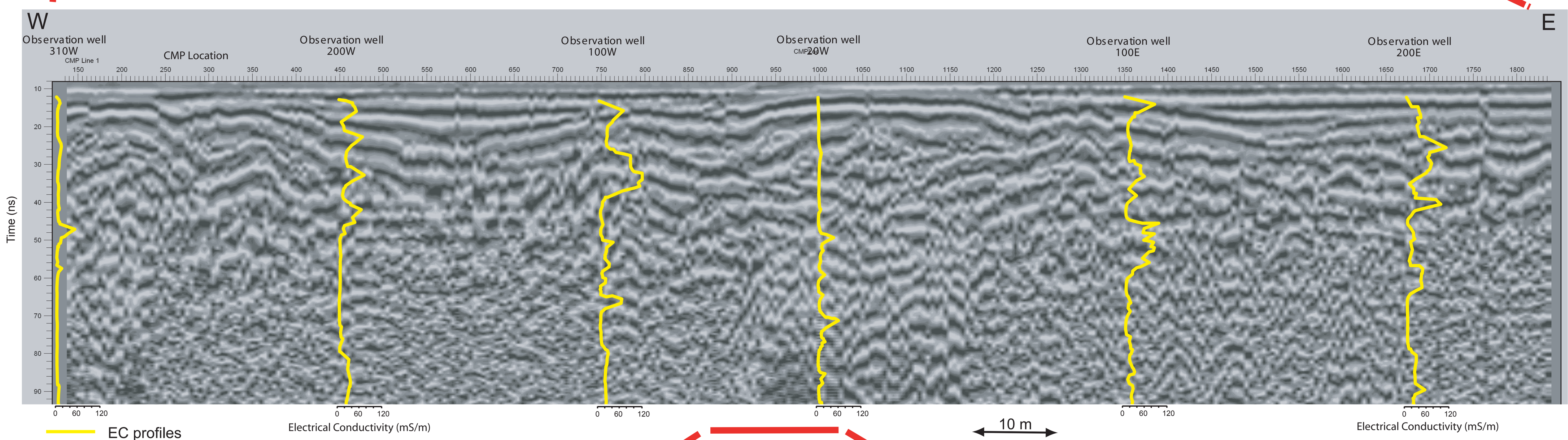


The separation between the two curves clearly identifies the lowering of the saturated/unsaturated interface due to pumping and seasonal water table decline. The labeled points are manual water-level measurements collected in 20W. The blue EC profile was completed within 30 cm of Well 20W (red EC profile) during late pumping times (approximately 48 hrs @ 4163 lpm or 1100 gpm) and at maximum drawdown (1.33 meters).

Electrical Conductivity Profile



Ground-Penetrating Radar Profile



Ground penetrating radar common-offset reflection profiles and CMP data were acquired at 225 MHz and 110 MHz center frequencies. The radar data imaged the upper 4 meters of the site that consists of sand and clay layers as identified in the driller's log and the EC profiles. The figure above displays a 225 MHz center frequency GPR profile acquired in line with the observation wells, with the electrical conductivity profiles overlaid.

Shallow Seismic CMP Profile

Shallow Seismic Acquisition and Processing

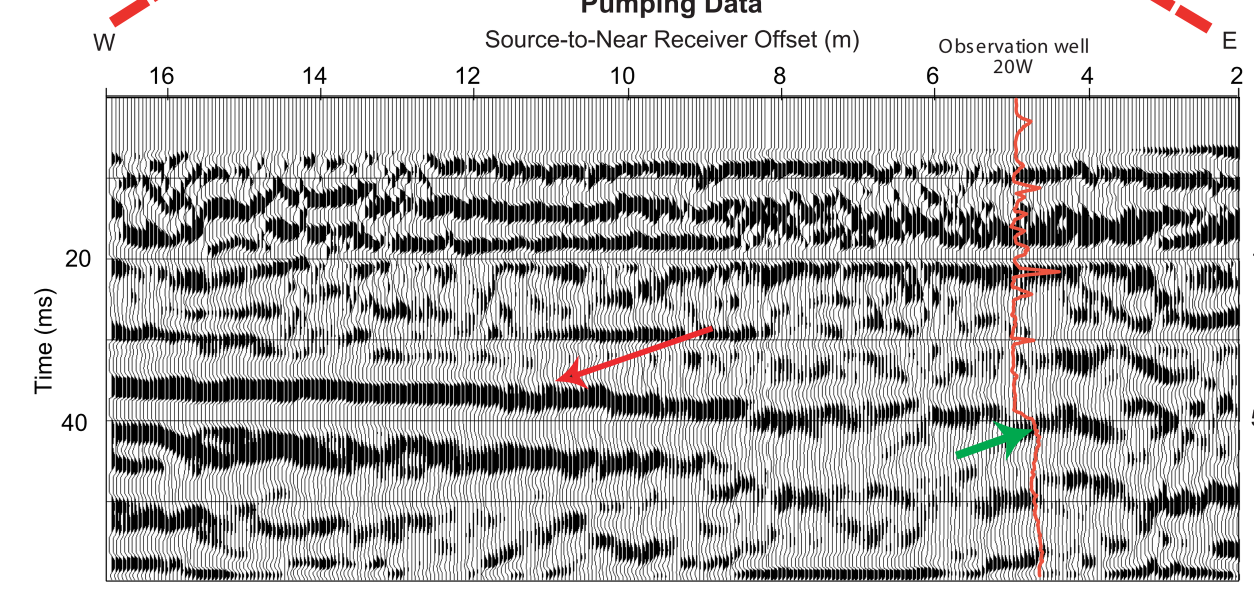
Two common midpoint (CMP) seismic reflection surveys employing identical field procedures were conducted at the test site. The first survey was conducted during a pumping test where the aquifer was dewatered at 1100 gpm. The second survey was conducted approximately 18 hours after the pumping ceased, while the aquifer recovered.

Seismic data were recorded on two 72-channel Geometrics Strataview seismographs with 24-bit A/D conversion using Mark Products 100-Hz vertical geophones. Data were recorded for 256 ms at a sampling interval of 0.125 ms. Receiver spacing was 10 cm for a spread length of 14.3 m. The seismic source was a .22 caliber rifle firing long rifle ammunition into a ~15 cm prepunched hole, offset from the receiver line ~10 cm. The initial source-to-receiver offset was 5 m. The source was advanced at a 10-cm interval through the receiver spread until the final source-to-near receiver distance was 5 m.

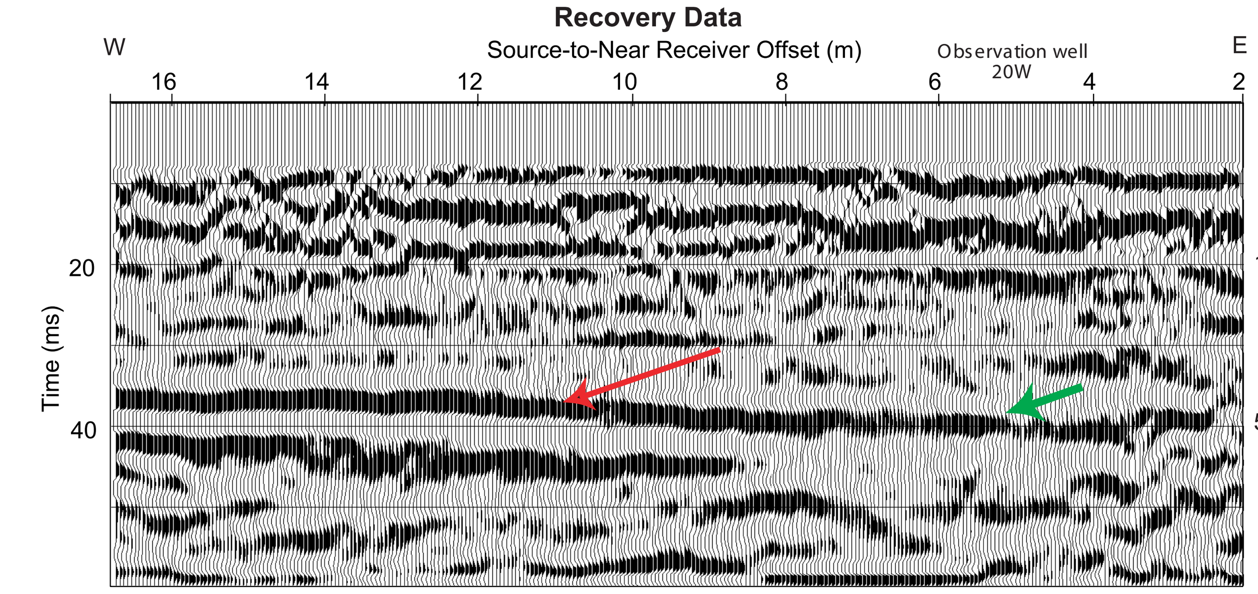
Established CMP processing techniques for shallow seismic data were applied according to the methods presented by Baker (1999) and Steeples and Miller (1990).

All seismic data are displayed with a 200-500 Hz bandpass filter with 12 db rolloff slopes and a 10 ms AGC.

Pumping Data



Recovery Data

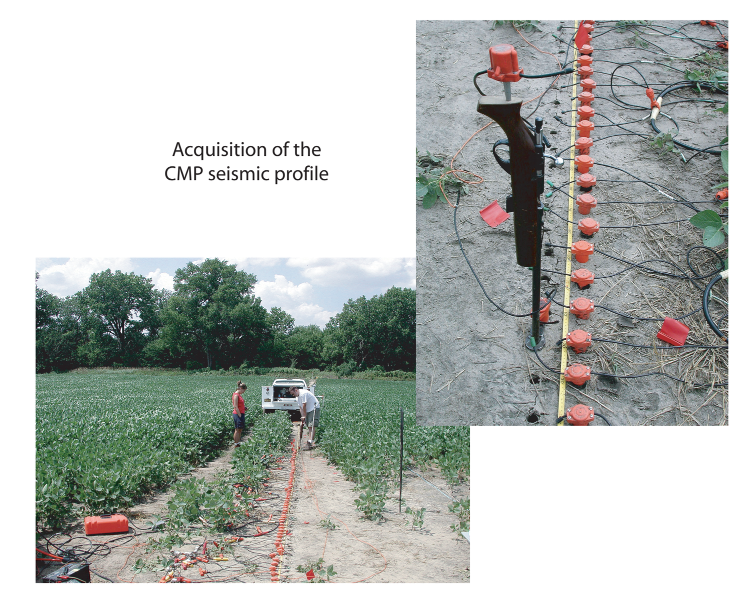


Legend

Interpreted seismic water table reflection.

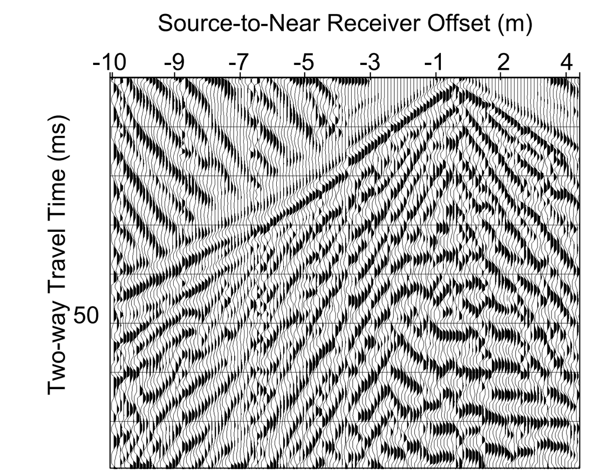
Approximate water table location from measured water level at observation well 20 during seismic data acquisition.

EC profile acquired during pumping one month after the seismic data acquisition. Water table monitoring at observation well 20 indicates same water table elevation during seismic and EC surveying.

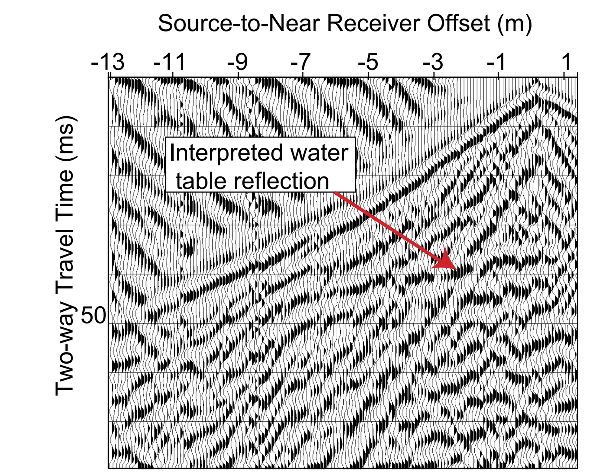


Acquisition of the CMP seismic profile

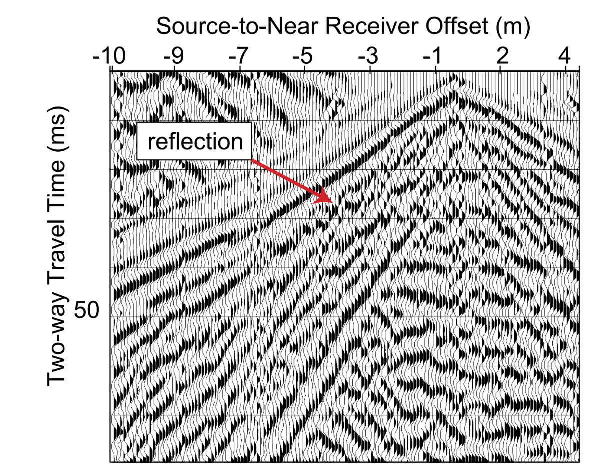
Shallow Seismic Field Files



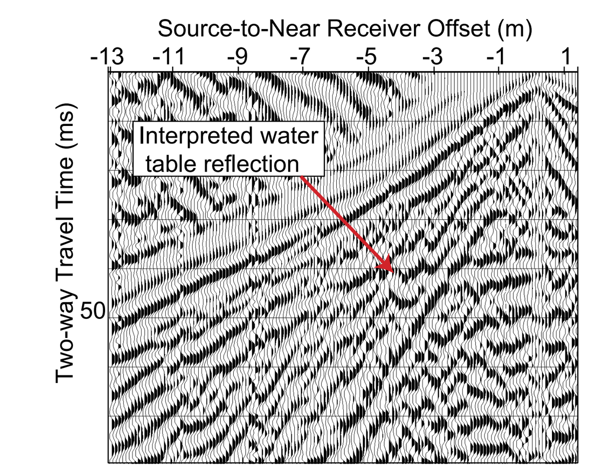
Shot gather 155 acquired during pump test on 8/13/03.



Shot gather 181 acquired during pump test on 8/13/03.



Shot gather 155 acquired after a recovery period from a pump test on 8/13/03. The reflection at ~ 21 ms on the bottom shot gather is obscured by pump noise on the upper shot gather.



Shot gather 181 acquired after a recovery period from a pump test on 8/13/03.

Conclusions

Geophysical techniques, including direct-push electrical conductivity, ground penetrating radar, and shallow seismic reflection, were used to investigate the hydrologic properties of a stream-aquifer system. The techniques employed are in general agreement and yield complementary hydrogeophysical information about the site.

EC direct-push logging provided detailed lithologic profiles at seven observation wells, successfully identified the water table, and monitored water level changes during pumping. GPR reflection surveying imaged shallow lateral lithologic changes in line with the EC profiles. High-resolution seismic reflection imaged shallow lithologic variations as well as the deeper unsaturated/saturated sediment interface.

The complementary geophysical techniques employed offer the capability for improved hydrogeophysical characterization of the subsurface.

References

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