Deep Sensing of Transient Electrokinetic Response of Aquifer-Aquitard System to Pumping

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Abstract

We consider the transient electrokinetic response of an aquifer-aquitard system to groundwater abstraction from the aquifer. The system was instrumented with 18 non-polarizable copper/copper sulphate electrodes installed at three different depths in the aquitard above the aquifer. The sensing electrodes were installed at depth of 1, 2, and 4 m below ground surface along three overlapping transects. The differential voltages relative to a single permanent electrode were measured with a Campbell Scientific CR1000 datalogger with a single multiplexer. Additionally, six piezometers screened in the top 1.5 m of the confined aquifer, were installed by direct-push. All the piezometers were instrumented with pressure transducers to measure directly the hydraulic response of the aquifer. The vertical variation of resistivity in the aquitard was measured on sediment cores recovered from one of the boreholes used to install the deepest piezometer. The resistivity distribution at antecedent sediment wetness (moisture content) was measured using the MC Miller resistivity boxes and meter, with wetness measured gravimetrically. Previous exploratory drilling and sampling activities at the site indicate that the aquifer is fractured greywacke sandstone overlain with clayey aquitard of semi-consolidated alluvial sediment, with the aquifer-aquitard contact at a depth of 10.3 m below the ground surface. We report the results of the site instrumentation, monitoring, characterization, hydraulic testing, and compare the results of parameter estimation using streaming potential and hydraulic data separately and jointly. We explore the effect of depth of installation of the electrodes in the aquitard on signal strength and quality and compare this to model predicted behavior using semi-analytical models from the literature. The results suggest the need for deep sensing of electrokinetic signals generated by groundwater flow to improve signal-to-noise ratios and the usefulness of self-potential data for hydrogeophysical characterization of aquifer-aquitard systems.

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Abstract

We consider the transient electrokinetic response of an aquifer-aquitard system to groundwater pumping. The system was instrumented with 18 $Cu/CuSO_4$ electrodes at depths of 1, 2, and 4 m below ground surface. SP responses were measured with a Campbell Scientific CR1000 datalogger. Six piezometers were installed by direct-push and instrumented with pressure transducers to measure the hydraulic response. Vertical variation of resistivity in the aquitard was measured on sediment cores recovered from one of the boreholes. We report the results of hydraulic tests conducted at the site and explore effect of depth of installation of the electrodes on signal strength and compare this to behavior predicted by semi-analytical models.

Field Site

- Tests conducted at the Cal Poly Groundwater Research & Education Field Site
- Part of the San Luis Obispo & Edna Valley Groundwater basin of the California Central Coast, 15 miles south east of Pacific coastline.
- Confined fractured sandstone aquifer overlain with semi-consolidated clayey alluvial aquitard unit and clay textured surficial soil.
- Aquifer thickness is unknown; Aquitard thickness is about 8 m; Well at site installed to 10 m.

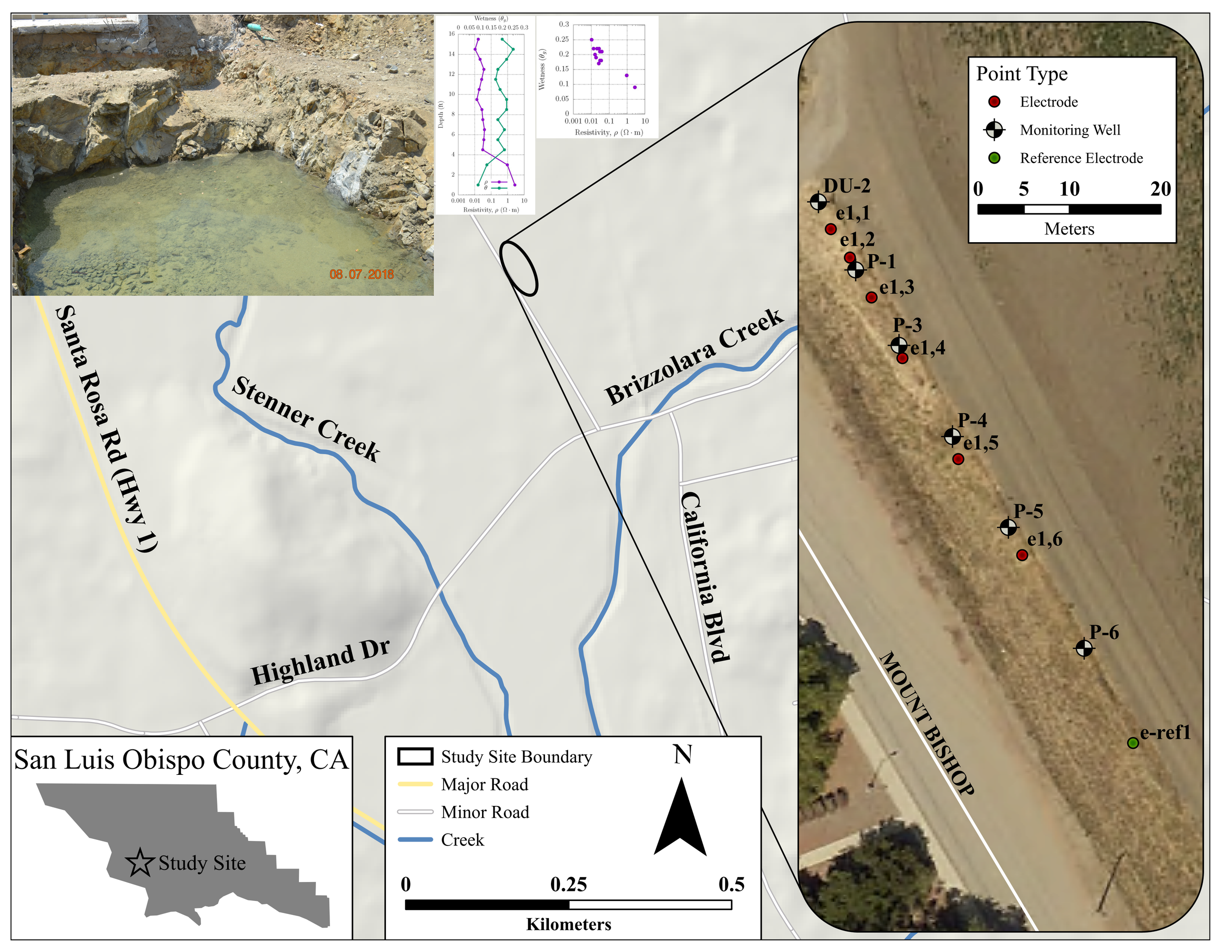

Figure 6: Map of Cal Poly Groundwater & Soil Biophysics Field Site showing transects of electrodes.

Study Objectives

1. Passively monitor background SP of near-surface aquifer-aquitard system, and measure transient drawdown & SP response to constant-rate pumping tests.
2. Compare SP responses at different depths below ground surface using shallow and deep electrode installations in aquitard.
3. Perform spectral decomposition of measured background SP signal to identify dominant frequency components in background data.
4. Denoise pumping test data by removing dominant frequency components determined from background data.
5. Estimate aquifer hydraulic properties from drawdown & SP data using semi-analytical models of [1, 2].

Materials & Methods

The field site was instrumented with

- 18 $Cu/CuSO_4$ electrodes at depths of 1, 2, and 4 m below ground surface, wired to CR1000 datalogger with AM16/32 relay multiplexer.
- Pressure transducers (PT2X) in 4 piezometers completed in top 1 m of aquifer.
- Surface 2 hp centrifugal pump with flowmeter.
- MC Miller Soil Resistivity meter & boxes

Figure 7: Electrode installation along radial transect.

Hand-augured 18 ($d = 3$-in.) holes (2 m intervals) to appropriate depths; Electrodes set in bentonite paste (in dilute $CuSO_{4(aq)}$) at bottom of holes; Conducted 8 constant-rate ($Q = 15$ gpm) pumping tests with surface discharge 50 m from well.

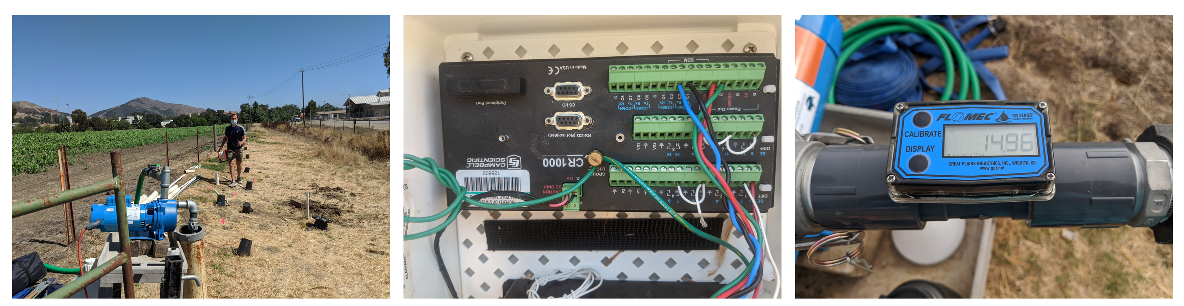

Figure 8: Pump, CR-1000 datalogger, and flowmeter.

Observations & Analysis of SP & Hydraulic Data

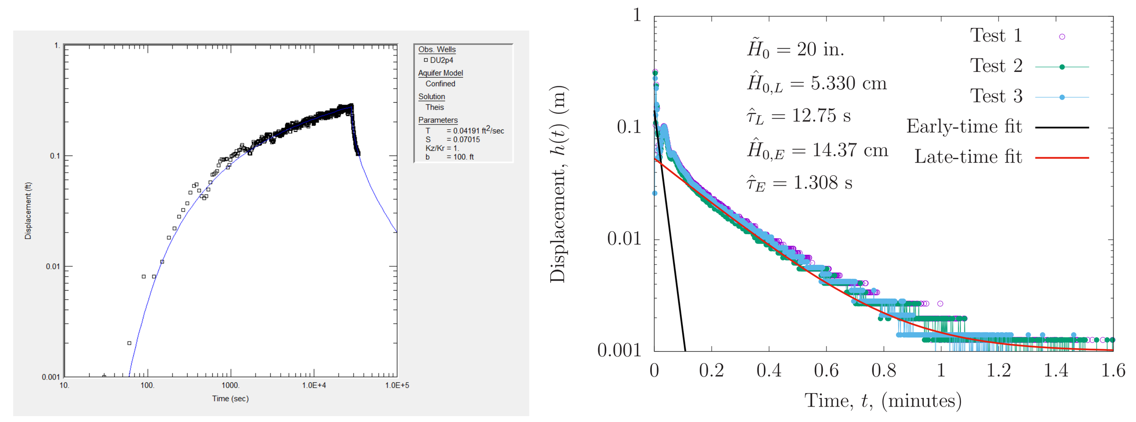

Figure 1: Analysis of pumping and pneumatic slug test data for estimation of aquifer hydraulic properties.

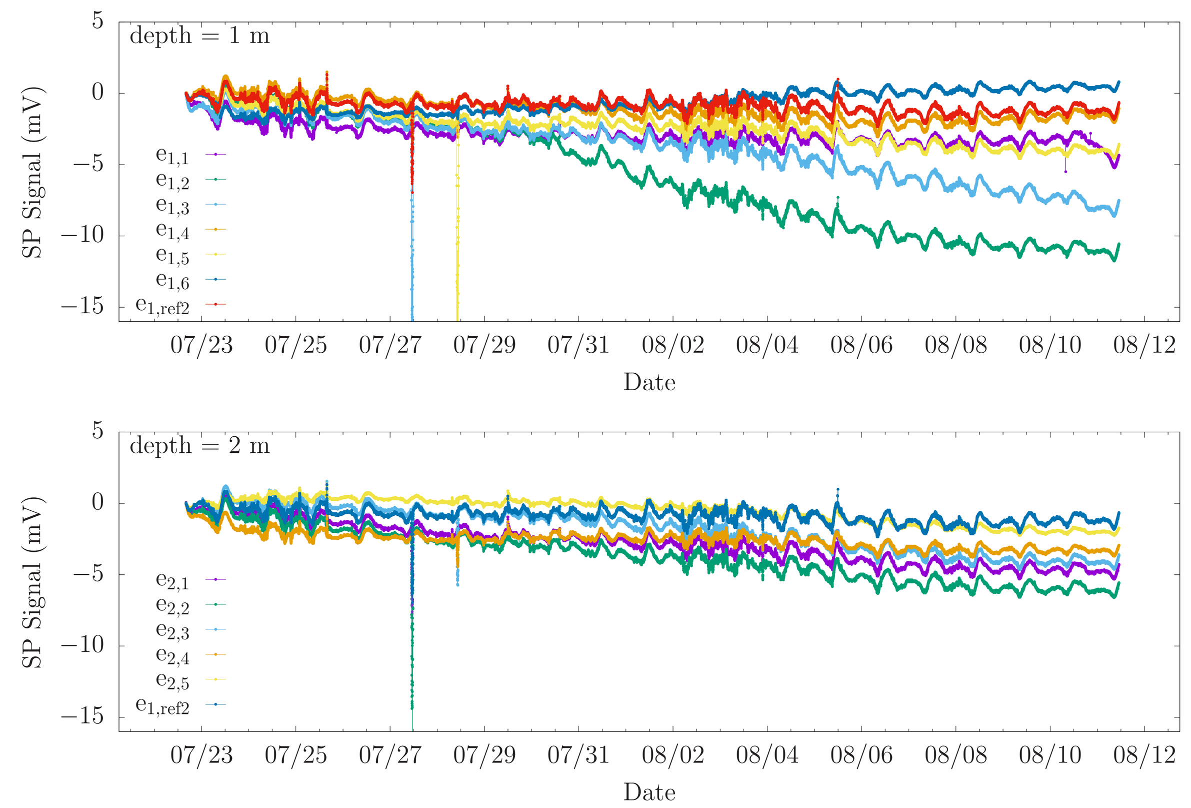

Figure 2: Periodic background SP time series data.

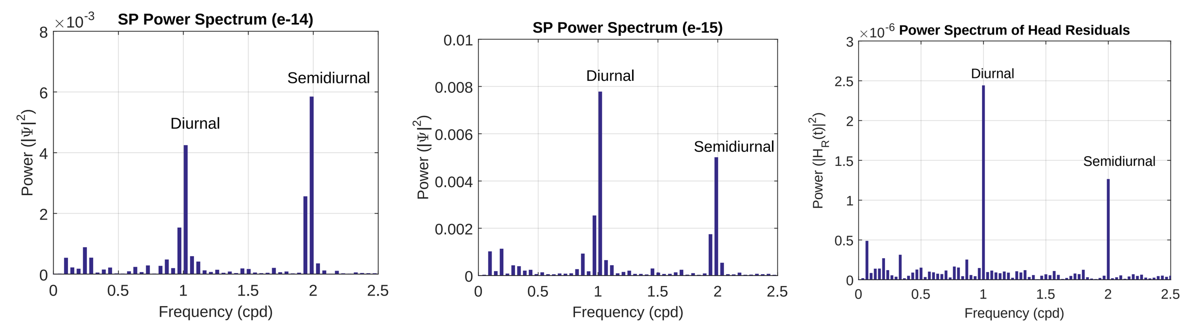

Figure 3: Spectral densities of SP and head data.

Drawdown response indicate confined aquifer, and confirms findings from pneumatic slug tests. Background SP data show periodic fluctuations at all depths. Spectral decomposition of SP time series show dominant diurnal and semi-diurnal frequency components indicative of earth-tide effects. Same basic spectral structure as observed in water-level data in test site vicinity.

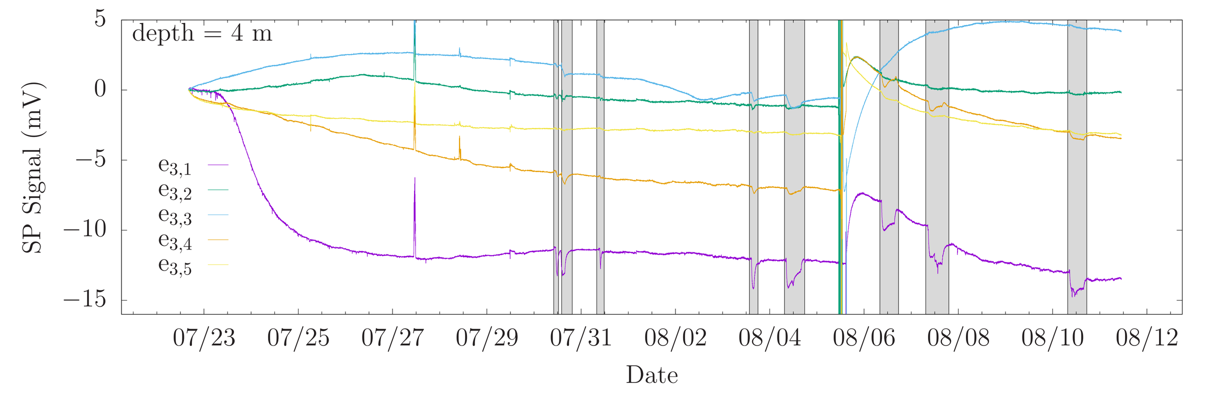

Figure 4: SP time series of deep (4 m) electrodes during background monitoring and 8 aquifer testing periods.

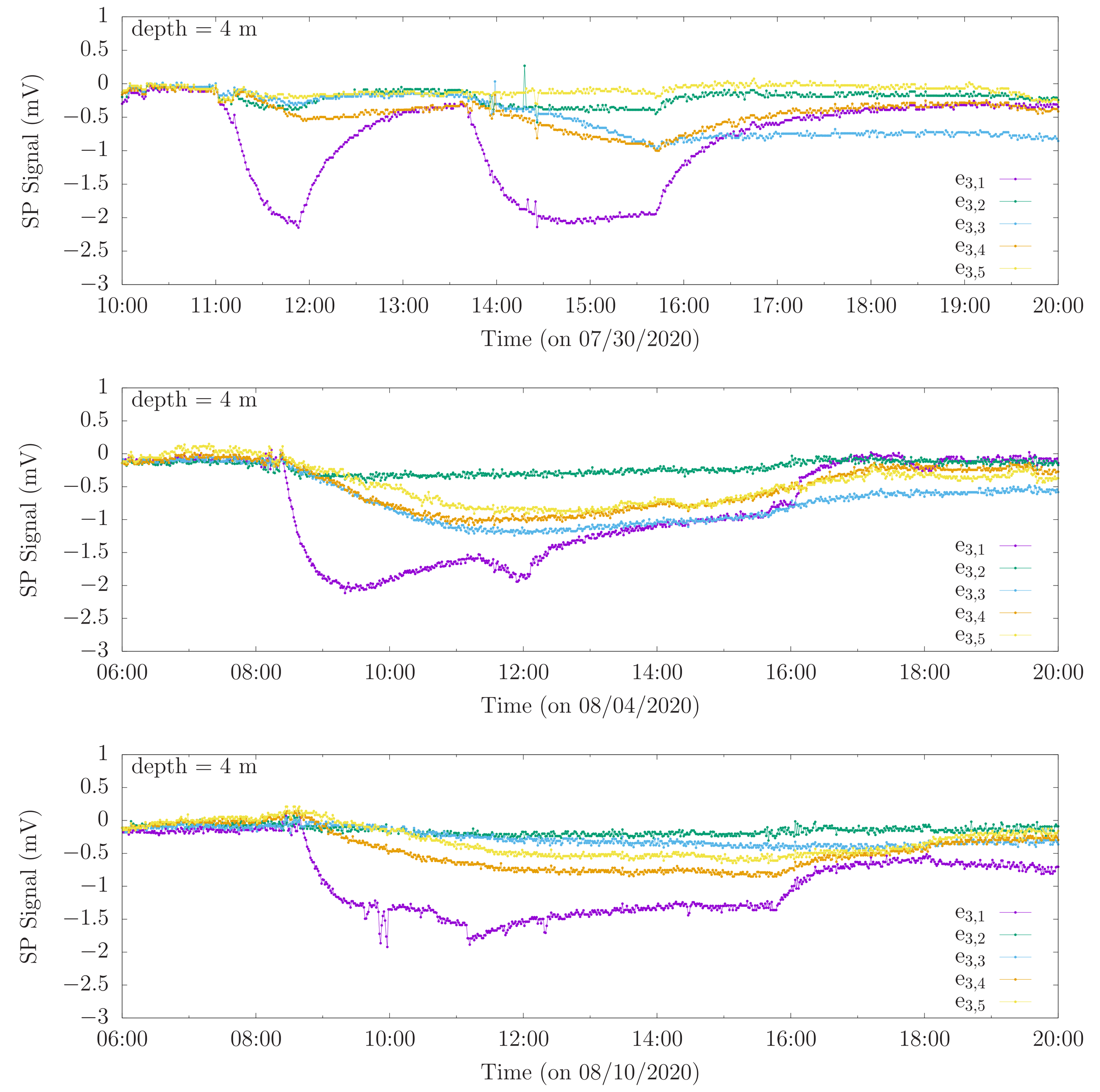

Figure 5: Transient SP responses of deep electrodes recorded during pumping tests 1, 4, & 8.

Minimal SP response at 1 & 2 m depths; Unambiguous response in deep electrodes; Data denoising by (a) removing dominant frequencies or (b) subtracting signal at non-responsive electrode; Signal strongest nearest to well; Generally decays radial distance from well; SP data show response to pumping and recovery following pumping cessation; Corrupted by surface effluent discharge.

Conclusions

Spectral analysis of water-level & SP time series indicates earth tide effects. High resistivity surface layer reduces signal strength near the surface even at 2 m depth. Deep seated electrodes (4 m) show transient responses in general agreement with drawdown data in observation wells. Analysis of SP data is ongoing using model of [1].

References

[1] Malama, B., Revil, B., Kuhlman, K. L., 2009. *A semi-analytical solution for transient streaming potentials associated with confined aquifer pumping tests*. Geophys. J. Int. 176, 1007–1016.

[2] Malama, B., 2014. *Theory of transient streaming potentials in coupled unconfined aquifer-unsaturated zone flow to a well*. Tree Physiology 3 (4), 309–320.

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