Electrokinetic monitoring groundwater flow in fractured rock media

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SUMMARY

When investigating an anthropogenic fluid migration event within a given hydrogeological setting, information relating to hydraulic transmissivity is typically evaluated using a set of observation wells. Due to high production costs observation wells are often scant in numbers; additionally their intrusive nature bares further disturbances to natural aquifer conditions. Now more than ever, there is an indisputable need for low-cost, non-intrusive and reliable geophysical methods sensitive to these groundwater flows.

Ground water flows are known to generate electrokinetic signals that can be measured passively at the ground surface, and these 'self-potential' signals generated can be used to measure and estimate patterns of groundwater flow.

Two pump programs were conducted in fractured rock aquifer systems in the Adelaide Hills Region, South Australia. The predominant purpose of these programs was to quantitatively investigate the self-potential responses of these systems, this included gathering of complimentary geophysical data to support conclusions.

Key words:
Self-potential, electrokinetic, fractured rock aquifer, groundwater.

INTRODUCTION

Monitoring groundwater flow is typically determined through the use of observation boreholes in the area of interest. This methodology requires expensive drilling, disturbs the hydrogeological environment, and gives point measurements at typically large spacing. In laterally-uniform clastic sedimentary environments, singular point measurements are sufficient, as the media can be generalised in all directions with some confidence when extrapolating observations.

Fractured rock aquifers, by contrast, are heterogeneous, with high permeability fault, fractures and bedding planes in otherwise low-permeability matrix. Here, flow is almost exclusively through the faults, fractures and bedding planes as they represent a path of hydraulic conductivity that maybe orders of magnitude higher than the matrix. Monitoring of flow in fractured rock is becoming increasing important to understand the dynamics and long-term sustainability for both domestic and industrial uses.

A prospective means for monitoring groundwater flow is through measurement of surface voltages, known as the self-potentials (SP). Voltages occurring at the Earth surface are the direct result of the generation of electrical current associated with the advective transport of negatively charged ions in solution. Such advective potentials are often known as electrokinetic, and can be measured by an array of electrodes that measure the surface voltages relative to a distant reference point. Electrokinetic methods are cheap to undertake, can cover a wide spatial area and can be used to monitor change in almost real time.

This paper presents two programs of electrokinetic monitoring of groundwater flow in a fractured rock aquifer system: at Watervale in the Clare Valley, SA; and at Balhannah, Adelaide Hills, SA. At each site, controlled and repeated pump tests were carried out, and groundwater was monitored by both an array of 48 electrodes and multiple observation wells. Additionally, at each site, we have acquired complementary geophysical data including cross-hole electrical resistivity tomography, borehole to surface electrical mapping, DC resistivity and time-domain EM, downhole geophysical logs, and salinity measurements.

Finally, we will show a new 3D tomographic image method used to model the surface potentials in terms of a probability of source depth; such tomography is the first step towards quantifying the electrokinetic method.

METHOD AND RESULTS

Field methodology is based around former field works outlined by Rizzo et al., (2004), however was slightly adapted for the purposes of industry usability and overall cost effectiveness. At the Watervale site, electrodes were located along four straight line transects between the pumping well and available observation wells. A rectangular gridded electrode formation was used in Balhannah as it was best suited to the terrain and locations of observation wells.

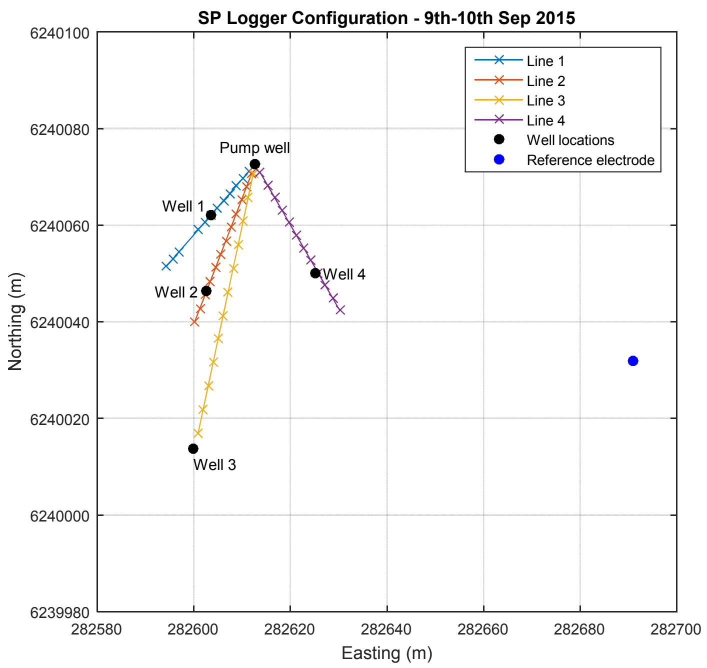


Figure 1: The straight line transect (Line 1-4) configuration used for the Watervale Pump Test. Each of the transect lines contained 12 electrodes, for a total of 48 electrodes (and one reference).

To process raw data, a steady pre-pumping temporal reference was chosen for each electrode in attempt to set the electrical potential as close to zero as possible, thus removing great amounts of static noise. High frequency spikes were apparent in the data, which were likely caused by telluric currents and induction effects in the cables. These spikes were dealt with using a Fourier transform and low-pass filter. These filtering processes allowed us to retain the whole amplitude of the low-frequency self-potential variations.

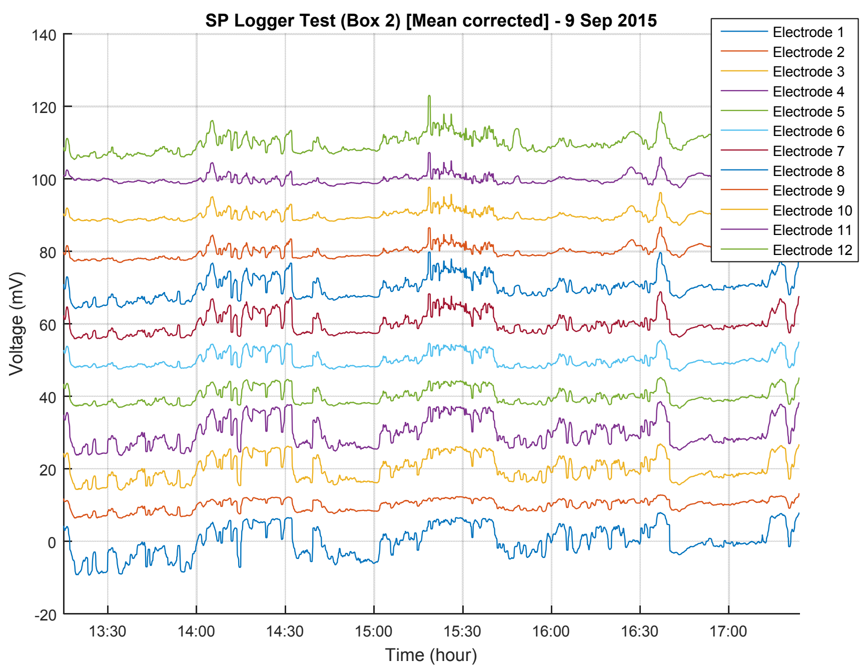
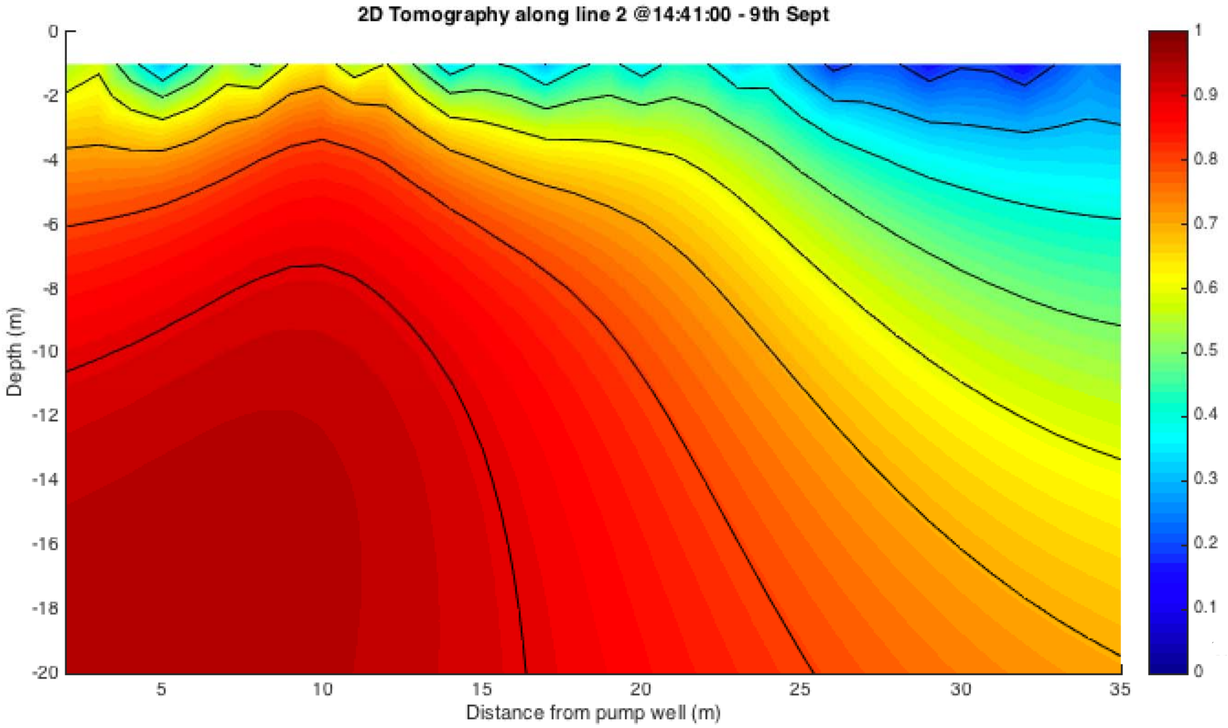


Figure 2: An example of corrected self-potential data acquired on SP Line 2 (Well 2 transect) at Watervale Pump Test. Noticeably, all electrodes are responding to the same events in varying degrees of amplitude, with amplitude based largely on distance from source of signal. Note electrode lines are artificially spaced by +10mV for ease of electrode inspection and response comparison.

A method of reconstructing images of the most probable locations for self-potential sources is outlined by Hammann et al. (1997). Since his work, similar techniques have also been developed by others (Patella, 1997; Gibert and Pessel, 2001; Revil, 2003b; Jardani et al., 2006b; Alaia et al., 2009). The method measures the extent to which a potential source at some given location correlates to the actual measured response.



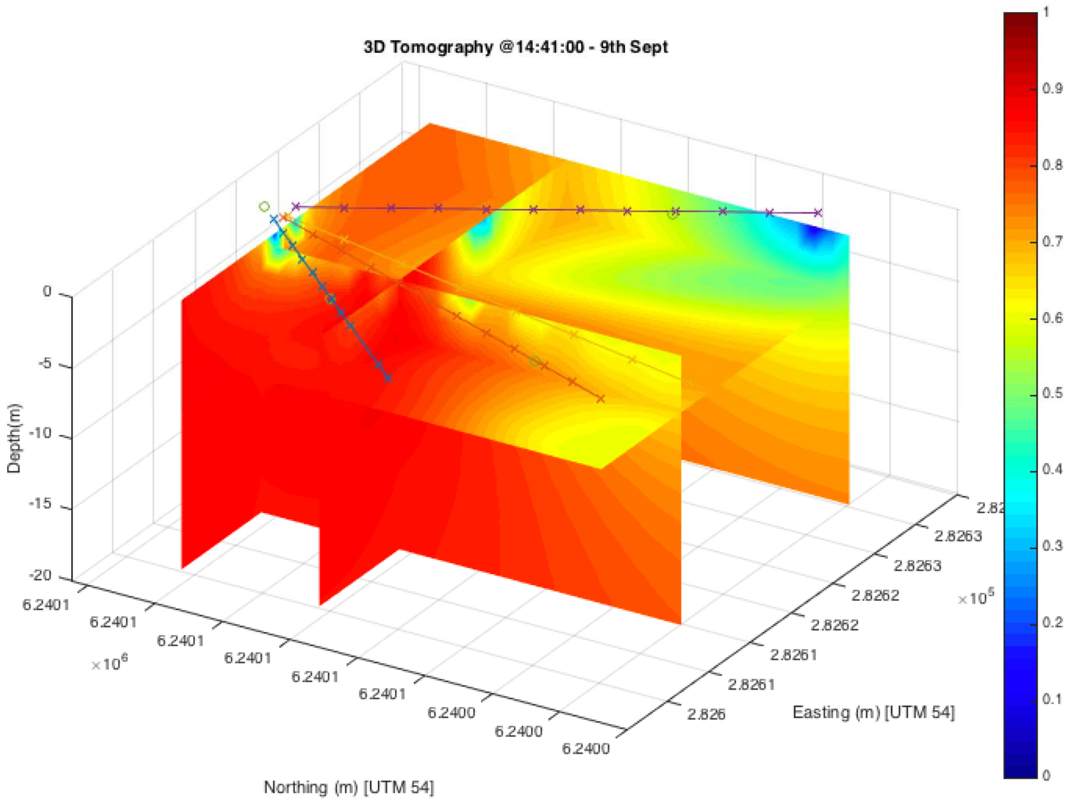


Figure 3 and 4: The figures shown are based on formulations by Hammann et al., 1999, and recreated by Inverarity K., 2013, illustrating the most probable locations of self-potential response at a given point/period in time. Figure 3 is a 2D inversion along transect Line 2, Watervale Pump Test. Figure 4 represents slices of a 3D inversion of Watervale Pump Test

CONCLUSIONS

We present initial results from the electrokinetic observations that show strong spatial patterns of voltage changes (of order of a few millivolts) that are aligned with the strike of the bedding planes. However, the observed voltage changes are not always consistent across the array and did not show consistent behaviour between repeated pump tests. We attribute some of the ambiguity to the complex heterogeneity of flow (and variable recharge rates) in these fractured rock environments, but further work is required.

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