DEVELOPMENTS IN HYDROGEOPHYSICAL RESEARCH

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SUMMARY

Measurement of groundwater physical properties of porosity and hydraulic conductivity in porous or fractured rock environments, and assessing water quality generally requires drilling a borehole. Boreholes provide accurate information at a point source, and a combination of boreholes can be used to infer regional-scale (i.e. 2 to1500 km) characteristics. However, is there a better way to fill in the gaps?

Electrical and electromagnetic geophysical techniques are sensitive to electrical properties of the subsurface. Movement of electrical charges (usually in the form of charged chloride and sodium ions) can provide an analogue for amount of water contained in pores, and to a lesser extent, to the movement of water through the environment. In addition, the interaction of electrical charges with porous sediment grains and within fractures can be used to determine fluid flow without ever drilling a hole.

APPROACH

The primary challenge for geophysicists is to link observations of electrical properties uniquely with hydraulic properties. Such geophysical methods must be fast, repeatable, and cover large spatial areas to make them a practical alternative to traditional hydrogeological approaches. The Hydrogeophysics Group at the University of Adelaide are developing the following approaches, tools and techniques to do this in a number of ways:

(a) By measuring spatial heterogeneity, we can relate the fractal dimension of electrical properties to the fractal dimension of pores or fractures. It is known that hydraulic conductivity has a fractal spatial-dimension; that is, the bulk hydraulic conductivity varies with the scale over which it is measured (eg. Neuman & Di Federico 2003). Our approach is to measure the fractal dimension of electrical resistivity from airborne, ground and river-based electromagnetic systems as a rapid and non-invasive approach to determining hydraulic conductivity (Everett & Weiss 2002).

(b) One of the current central research questions in hydrogeology is in the emerging area of assessing temporal response of a near-surface aquifer system to external intermittent water movement (i.e. drought and flooding cycles, or changes in water levels above locks, etc; Figure 1). An obvious corollary that goes with this is what do solutes (specifically salt) do in this near-surface zone as water levels change? There is an obvious need for geophysical data that can be acquired at a suitable density, economically and repeatably (Figure 2).

Figure 1. Geophysical methods are being applied to floodplains along the River Murray to assess temporal effects of flooding on salt in the top 5-10 m. The geophysical data will be integrated with ecological and hydrological data to develop a model of floodplain groundwater dynamics. Photograph taken in the Chowilla floodplain, South Australia of a saline billabong and die back of the River Red Gums.

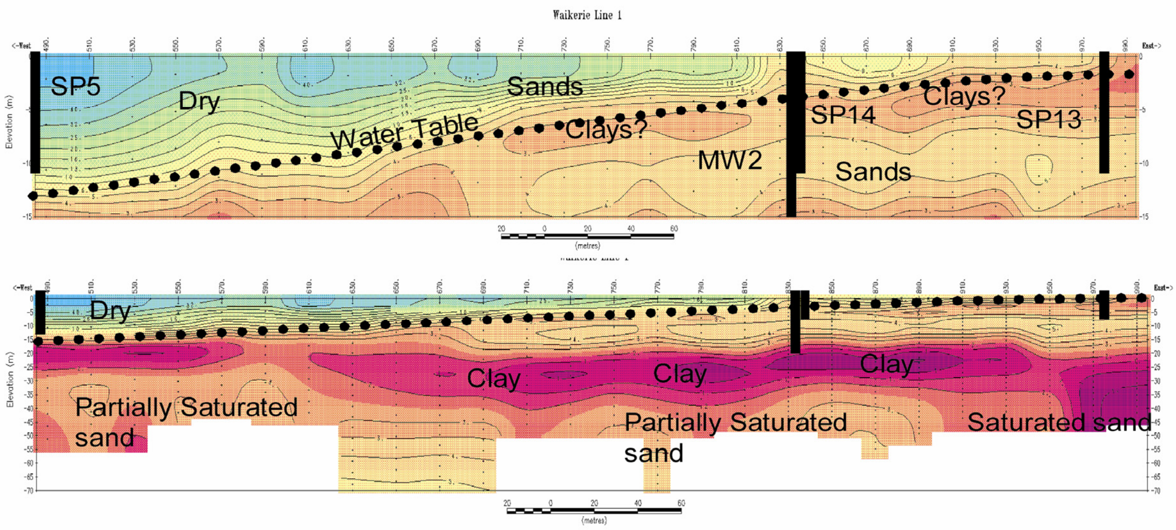

Figure 2. Two electrical resistivity sections of length 500 m obtained in a morning with a ground-based NanoTEM electromagnetic system, adjacent to a saline disposal basin near Waikerie. The upper plot shows the top 15 m, while the lower plot extends to a depth of 70 m. Blue colours show high resistivity regions that have low saturation; red regions show low resistivity, illustrating areas of clay and groundwater. The black lines SP5, SP13, SP14 and MW2 are boreholes used as calibration (Figure adapted from Barrett et al. 2002)

(c) By measuring the frequency-dependence of electrical properties, we can determine physical properties of the porous rock media, and its permeability (Binley et al. 2005). Movement of solute ions through a porous media is dependent on the shape of voids between grains, the amount of water present, the salinity of the fluid, and the frequency of the applied current (Revil & Cathles 1999). Our aim is to develop new field geophysical instrumentation to characterise the mean grain size, porosity and saturation using a wide range of applied frequencies.

(d) The movement of chloride ions with fluid-flow in porous or fractured rock media also generates an electrokinetic potential, sometimes known as streaming potential (Revil et al. 1999). This research project aims to establish a new technology to directly measure fluid-flow and hydraulic conductivity from the electrokinetic voltages at the surface. By surrounding a pump-test borehole with electrodes, we can characterize the radial fluid flow towards the hole and identify preferential pathways of fluid flow without having to drill observations wells (Fagerlund & Heinson 2003).

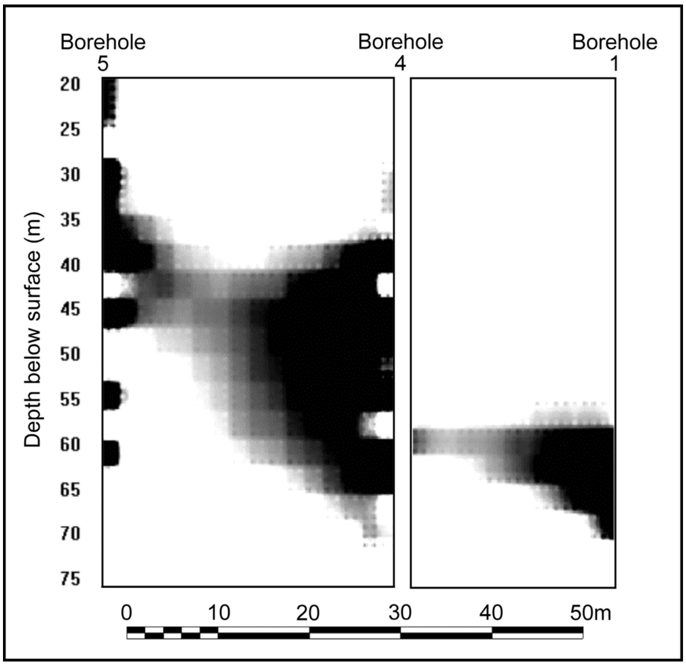

Figure 3. Electrical resistivity tomography between two pairs of boreholes near the town Watervale, in the Clare Valley. Low-resistivity fracture paths (shown as dark colours) indicate hydraulically connected pathways (adapted from Skinner & Heinson 2004).

(e) Within fractured rock, the irregular and often unpredictable distribution and geometry of hydraulically conductive fractures produces large spatial variations in bore yield and groundwater quality (Skinner & Heinson 2004). As fractures act as conduits for flow of groundwater and electrical charge, methods that can efficiently detect the distribution of electrical pathways can be used to infer characteristics of significant hydrological parameters. We have been using borehole-to-surface and cross-borehole electrical tomography methods to reconstruct the spatial distribution of sub-horizontal, laterally extensive, electrically conductive fractures (Figure 3).

CONCLUSION

The Hydrogeophysics Group is approaching the problems of characterising sub-surface groundwater resource evaluation using a mixture of: (i) laboratory-scale measurement on synthetic systems involving a range of grain sizes using quartz/rock gravel and fixed salinity involving NaCl solutions, (ii) numerical modelling and inversion to link geophysical measurement with hydraulic properties, and (iii) field-scale deployment of new instrumentation.

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