Non-Seismic Geophysics for CSG Monitoring

Initial results from the pilot field trial

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ABSTRACT

- A pilot time-lapse field survey was carried out near Dalby using **microgravity** (MG), **electrical resistivity tomography** (ERT) and **self potential** (SP) during irrigation pumping, from 23 Sept to 13 Oct 2015.

- Changes in the subsurface due to pumping are related to changes in mass (MG), changes in resistivity (ERT) and changes in fluid flow (SP). Measurements are surface-based and could provide a cost-effective alternative to well-bore monitoring for the resource industry.

- This pilot study evaluated the applicability of the various methods to approximately evaluate shallow aquifer characteristics. Modelling results indicated that certain combinations of non-seismic methods, at certain geological conditions, can result in sufficient imaging fidelity to provide a lower cost monitoring alternative to well-based approaches.

	groundwater integrity *(~depth range: 0-150 m)*	stimulation effectiveness *(~depth range: 0-1000 m)*	reservoir performance *(~depth range: 0-1000 m)*
Microgravity *Depth (m): ~0-1000*	✓ *(density)*	✓ *(density)*	✓ *(density)*
Self-Potential *Depth (m): ~0-100*	✓ *(fluid flow)*	✗ *(fluid flow)*	✗ *(fluid flow)*
DC Resistivity *Depth (m): ~0-300*	✓ *(resistivity)*	✗ *(resistivity)*	✗ *(resistivity)*

Table 1 Applicability of various non-seismic methods for CSG activity monitoring. The detectability of the geophysical signals are depending on property contrast, volume and survey parameters. Microgravity can provide results from larger depths; whereas surface-based measurements of Self-Potential and DC Resistivity are only applicable for shallow systems.

COMBINED MODFLOW/GRAVITY MODELLING

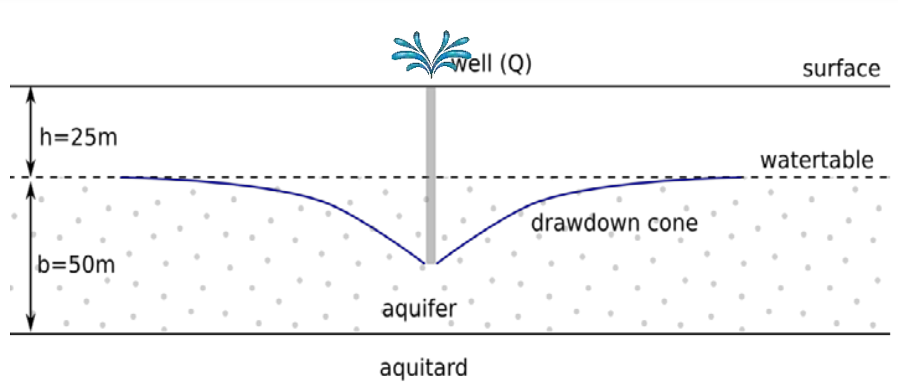

Fig 1 Conceptual hydrological model to estimate the gravitational response of the drawdown cone. The model consists of a water table aquifer of 50m thickness overlain by an unsaturated layer of 25m thickness. A discharge well pumps out water from the aquifer, causing a cone-shaped depression of the water table in the vicinity of the well.

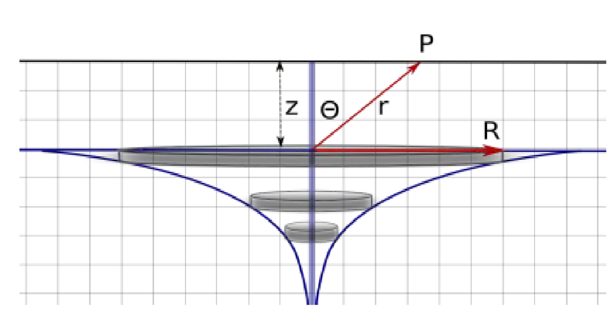

Fig 2 Schematic illustrating the calculation of the gravitational response. A closed pack of finite cylindrical shells approximately fills out the drawdown cone. The vertical extent of a shell is calculated by the difference in hydraulic head of two neighbouring cells; the radius is determined by the number of cells the shell spans.

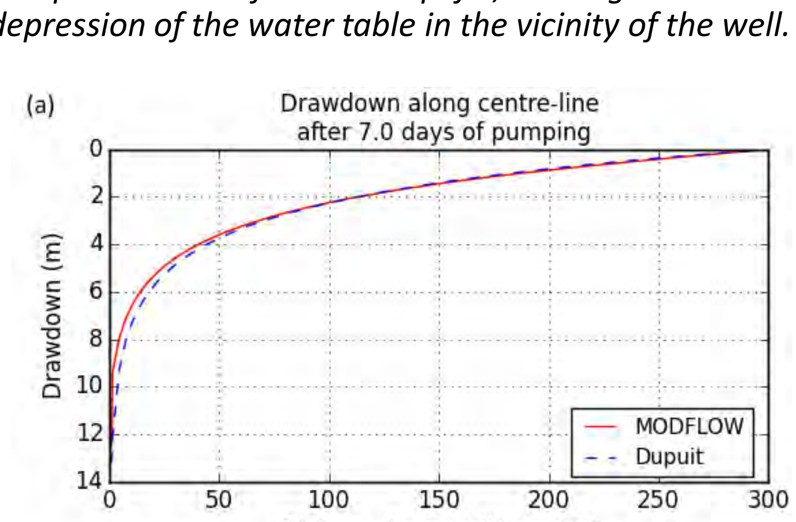

Fig 3 Cone-shaped spatial variation of the hydraulic head along the centre of the model after 7 days of pumping. The MODFLOW response is compared with the analytical Dupuit solution for steady-state conditions..

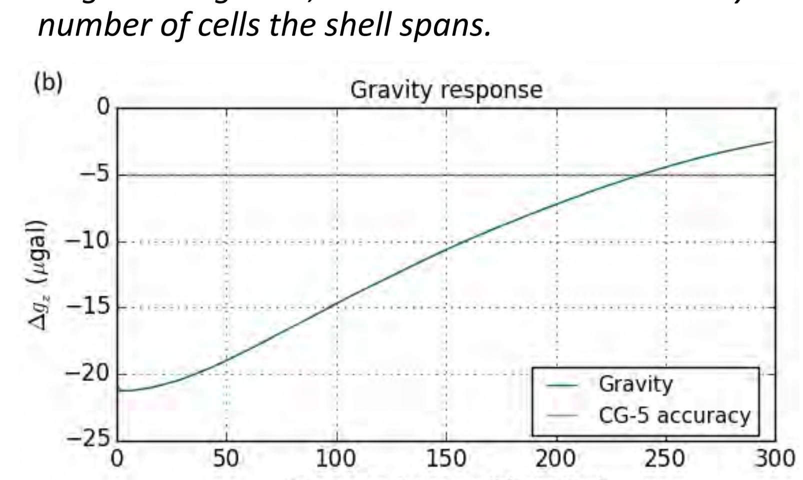

Fig 4 Gravitational response due to the change in the water table elevation and the associated mass change after seven days of pumping. Superimposed is the accuracy of the Scintrex CG-5 relative gravimeter. .

FIELD SITE & GEOLOGY

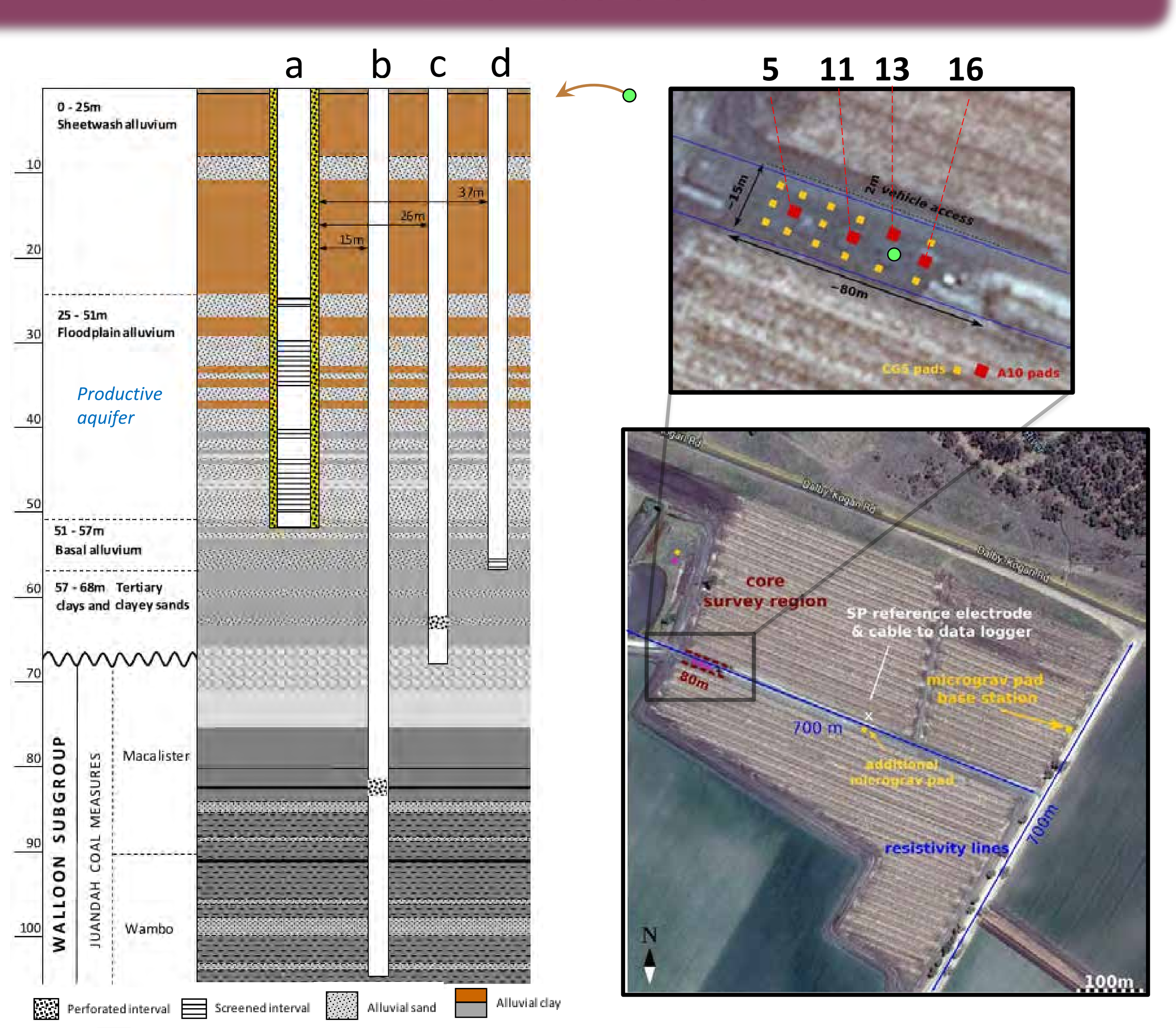

Fig 5 Survey site and geology. The stratigraphic map (modified, original by Anderson & Rahman, 2013) is based on core analyses and logging of monitoring-well 'b', denoted with a green dot in the map (●). The farmer's irrigation bore is denoted 'a'; 'c' and 'd' are monitoring wells screening different depths. The survey site was prepared for MG and SP. ERT measurements were made in the 'core-region' with 200m cables, 3m electrode takeout (~40m depth) and along two roads with 700m cables, 11m takeout (140m depth).

PILOT SURVEY

Fig 6 (a) 180° image of survey site with the farmer's diesel engine and tank for the irrigation pump on the left; enclosed monitoring wells and geophysical field equipment to the right. (b) relative gravity measurements using a CG-5 instrument; (c) absolute gravimeter A-10, on loan from Geoscience Australia and GPS base station; (d) field site; (e) resistivity cable and electrode; (f) irrigation channel and tubes to flood the paddocks; (g) landscape view of field site with irrigation channels and paddocks; (h) water pumping from the Condamine Alluvial Aquifer and Molly, the farmer's dog, taking a bath.

FIELD DATA INITIAL RESULTS

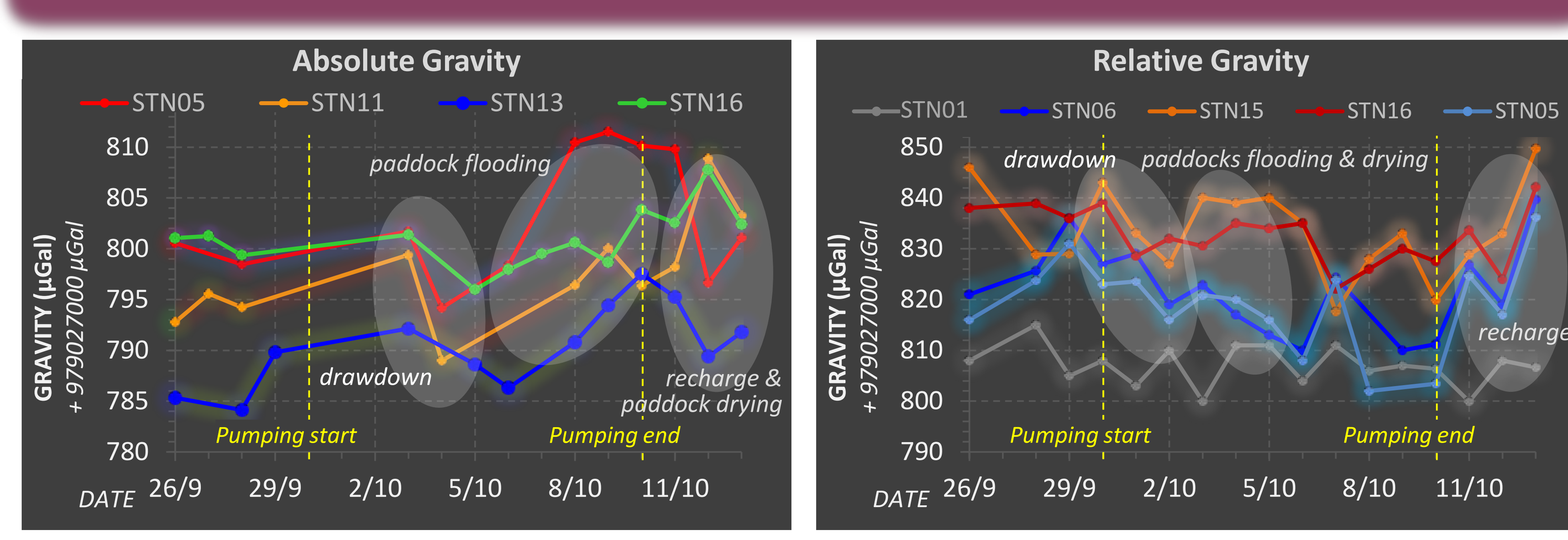

Fig 7 Microgravity measurements for absolute (A-10) and relative (CG-5) gravimeters. The absolute gravity data shows a sharp decline on the 3rd day after pumping associated with the drawdown of the aquifer. A slow rise from the 5th Oct is understood to be due to flooding of irrigation channels and the paddocks, where the southern paddock and channel were closest to STN05. After pumping stopped various responses might be attributed to paddock drying and aquifer recovery. The relative gravity data on the right shows analogous but more complicated behaviour due to a higher noise level and higher sensitivity of the instrument.

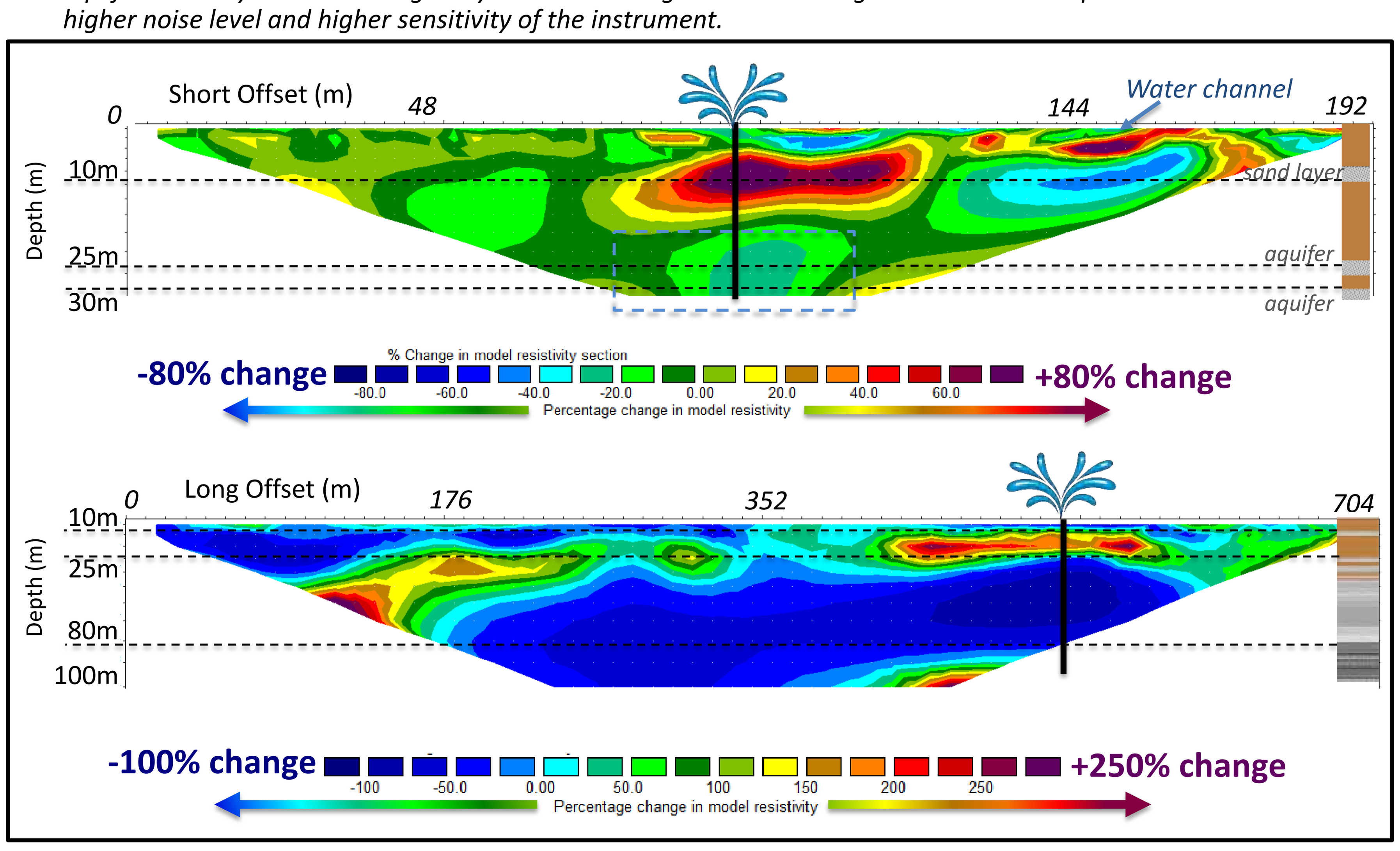

Fig 8 Result of Time-Lapse inversion of electrical resistivity data acquired in the core region (top) and along the access road (c.f. figure 5) using a Wenner layout. The images show the relative change in resistivity during 10 days of pumping with respect to a baseline measurement which was done before pumping commenced where all data sets are inverted simultaneously. In both images the main changes are centred around the well bore and in 10m depth coinciding with the sand layer. (Thanks to Msc student Taruna Fadillah)

SUMMARY & OUTLOOK

- A pilot field survey was carried out to assess the applicability of various non-seismic potential field techniques for aquifer characterisation.

- A hybrid microgravity survey was completed using a CG-5 relative and an A-10 absolute gravimeter. The data from the A-10 looks cleaner, but the data from the CG-5 exhibits more features due to higher sensitivity. In both datasets, the aquifer drawdown is observed.

- Time-lapse ERT could demonstrate the change in electrical resistivity associated with irrigation pumping from the Alluvial Aquifer.

- Based on the microgravity datasets, specific yield (**effective porosity**) can be estimated and based on the ERT datasets, hydraulic conductivity (**effective permeability**) can be estimated.