Resistivity imaging across native vegetation and irrigated Vertosols of the Condamine catchment—a snapshot of changing regolith water storage

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Abstract
Over use of one of Queensland's most productive groundwater systems, the Condamine River alluvium, has led to substantial depletion in groundwater levels. Most use is for irrigation (mainly furrow), which is known to increase deep drainage below the root zone. Thus irrigation should create greater groundwater recharge, but this is not generally detected in groundwater levels. The enhanced deep drainage may be filling a moisture deficit in the unsaturated zone and is therefore not yet causing greater recharge. Geophysical 2D resistivity imaging and soil coring was used to look at changes in stored regolith water in the alluvium. Transects were imaged across naturally vegetated landscapes (as a reference) into irrigated paddocks. All soils under native vegetation were found to be very dry (low conductivity) even when only sparsely populated by trees. In contrast, significant long-term migration of water has occurred to deep within the regolith (up to 15 m) in most irrigated paddocks. A wet (close to saturated) zone was found in the upper 6 m of soil in the irrigated paddocks. Deeper regolith (20-60 m) was resistive, both above and below the water Table, due to low salinities in the groundwater and coarser textures.

Key Words
Deep drainage, groundwater, geophysical survey, recharge, unsaturated zone.

Introduction
The Condamine River Alluvium and its tributaries is one of the most productive and utilized groundwater resources in Queensland. The main system is over 150 km long, up to 30 km wide, and over 120 m deep in places, with multiple sand and gravel aquifers in a matrix of clayey sediments. An estimated 95 000 ML/yr are used for agriculture (90%) on Vertosols, and some urban purposes. Groundwater levels have fallen substantially because of over use, particularly in the Central Condamine where ~70% of all usage occurs (Murphy, 2008). This decline has been particularly evident over the last decade as the system has been in a virtual 'recharge drought'. There is also increasing evidence of water quality deterioration, both in shallow groundwater as a result of increased salt leaching, and in deep systems as a result of the migration of poor quality groundwater from adjacent areas and from bedrocks (Murphy, 2008).

Irrigation alters the surface water balance. Water not used for plant growth or lost to evaporation, drains below the root zone (deep drainage). Deep drainage of 100-200 mm/yr has typically been measured under furrow irrigation in a large number of sites on Vertosols and Sodosols in Australia (Silburn and Montgomery, 2004; Smith *et al.* 2005; Gunawardena *et al.* 2008). There is some evidence, from bore monitoring, of rises in groundwater level in shallower aquifers in the alluvium (DERM groundwater database), likely due to recharge from deep drainage, but many shallower bores have been dry for many years. Diffuse recharge (i.e. through the soil) in the alluvium is considered to be small, with the aquifers mainly recharged by river leakage (Lane, 1979). Thus there is a disparity—deep drainage below the root zone is seen to be high but recharge from this source is thought to be low. This would be explained, in part, if deep drainage was being stored in an unsaturated zone left dry by the previous native vegetation, creating a time lag between deep drainage and recharge.

Little is known about the moisture capacity and status of the regolith (unsaturated zone) or how this has changed as a result of changes in the soil water balance. To examine the moisture status of the regolith, electrical resistivity tomography and soil coring was applied to transects in the central alluvium. Soil resistivity is related to soil water content, salinity and clay (content and type). Data can be interpreted qualitatively with the aid of lithology from bore logs and measures of salt and clay content. Contrasts in regolith under native vegetation and under irrigated agriculture were examined, to assess the impacts from land use changes.

Methods

Two dimensional resistivity images were taken using an ABEM SAS4000 Terrameter and LUND ES464, across transects (200–600 m long and 60 or 21.5 m deep) in the Central Condamine alluvia, in SE Queensland. Where possible, transects running through native vegetation and adjoining irrigated paddocks were imaged to look at differences in water and salt due to the irrigation. Sites imaged were:

1. Dalby, Black Vertosol—a) 400 m transect down an irrigation furrow with 2.5 m wide spacing of electrodes, measuring to 60 m depth, b) 600 m transect through native vegetation (*Acacia harpophylla, A. homalophylla, Casuarina cristata, Eucalyptus populnea*) into irrigated sorghum (stubble present) to 60 m
2. Pampas, Black Vertosol—480 m transect running down a furrow in irrigated paddock to 21.5 m depth
3. Brookstead, Black Vertosol—400 m transect from one irrigated field (sorghum stubble) through native vegetation (*Eucalyptus camaldulensis*) and into another irrigated paddock (fallow) to 60 m depth.

Soil volumetric water content was sampled with a soil coring rig. Soil samples were collected and analysed for electrical conductivity (EC), chloride (Cl) and dispersed particle sizes, along the transects to assess the influence of salt and clay content on resistivity. Two dimensional resistivity images were inverted using the RES2DINV software. Data was converted to conductivity (reciprocal of resistivity) with high conductivity generally indicating high water contents.

Results and discussion

All the images are deeper than—or close to, in the case of Pampas—groundwater levels. The saturated zone and the deeper unsaturated zone are generally resistive, due to the low salinity of the groundwater (Pampas and Brookstead 400, Dalby 1200 µS/cm) and sands and sometimes gravels interbedded in the clays. Thus the less resistive deeper material at the Dalby site (Figure 1) is consistent with the higher groundwater salinity.

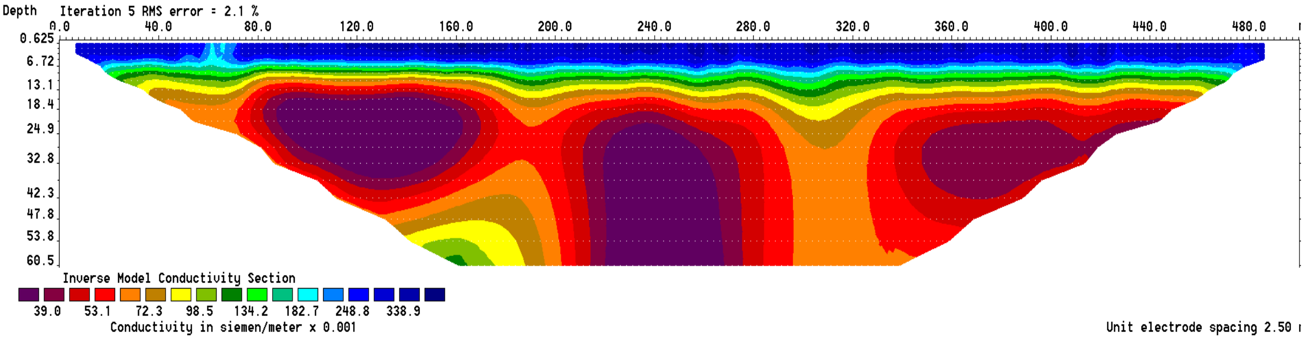

Figure 1. Dalby transect L to R, furrow irrigated paddock, head ditch (L) to past mid point in paddock.

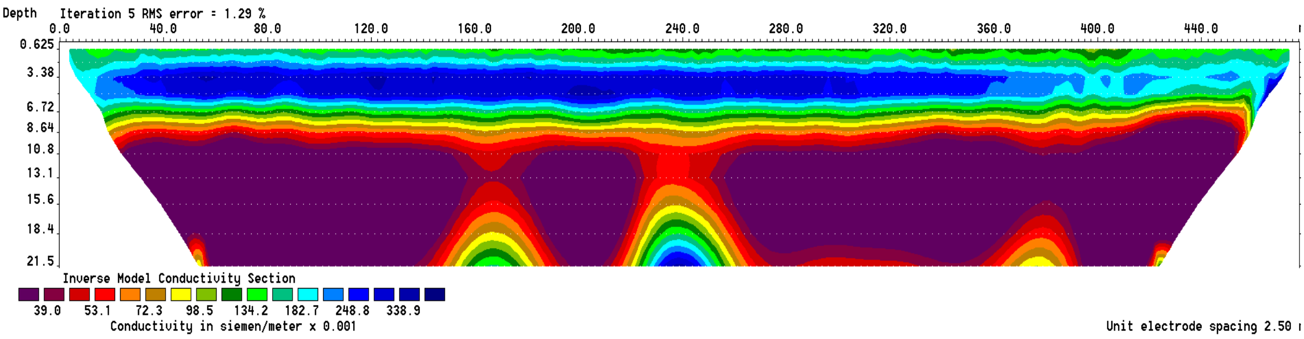

Figure 2. Pampas transect: L to R, furrow irrigated paddock, head ditch (L) to past mid point in paddock.

The first two transects were measured down typical irrigation furrows at Dalby and Pampas. Images show highly conductive zones of soil (very wet, with medium salinity typical of soils in the region), along the entire length of the transects in the upper 6 m of the profile (Figures 1, 2). Soil volumetric water sampling revealed, on average, these areas had >550 mm of water above that stored under native vegetation and up to 250 mm above drained upper limit in the top 6 m of soil. This is 'new' water added by irrigation.

Water in this near-saturated layer is not static. It is draining into the deeper regolith at a rate proportional to the hydraulic conductivity of the deeper clay and sand layers. The soil profile changes at around 5–6 m, with increasing sandy, sandy clay and occasionally gravel layers. These often create confining zones. Once saturated clay layers become interspersed with sand layers, the soil will remain saturated in the clay but not in the sand, due to hydraulic relationships. Water will continue to move deeper in the regolith, but these zones will not show up on the image as having a high conductivity due to the increasing presence of unsaturated sand. Also, salinity will be a mixture of that in the leachate (i.e. higher, due to salt from the soil) and the lower salinity in groundwater discussed above. Groundwater levels were at 10–20 m before 1965, so some of the current unsaturated zone once held groundwater of low salinity.

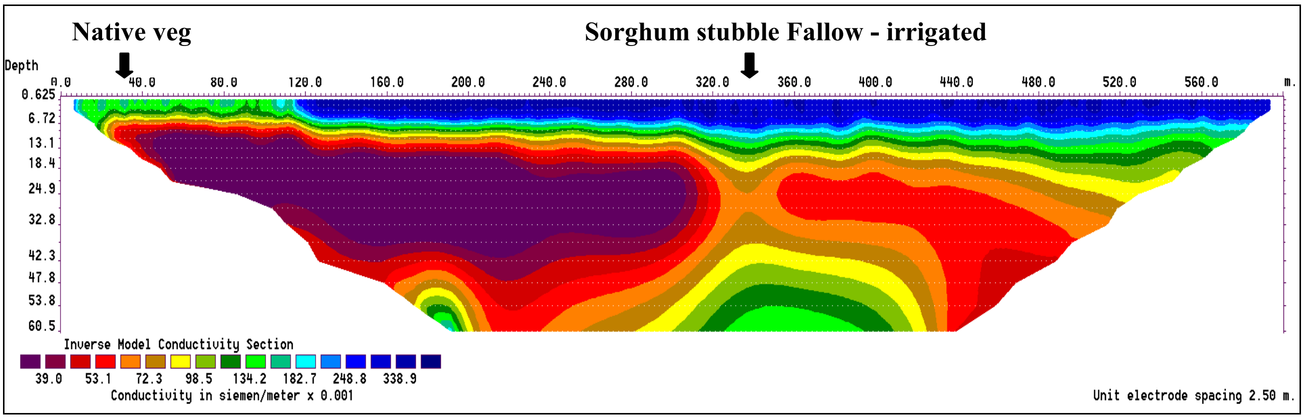

Figure 3. Dalby transect: L to R, native vegetation into sorghum stubble (irrigated).

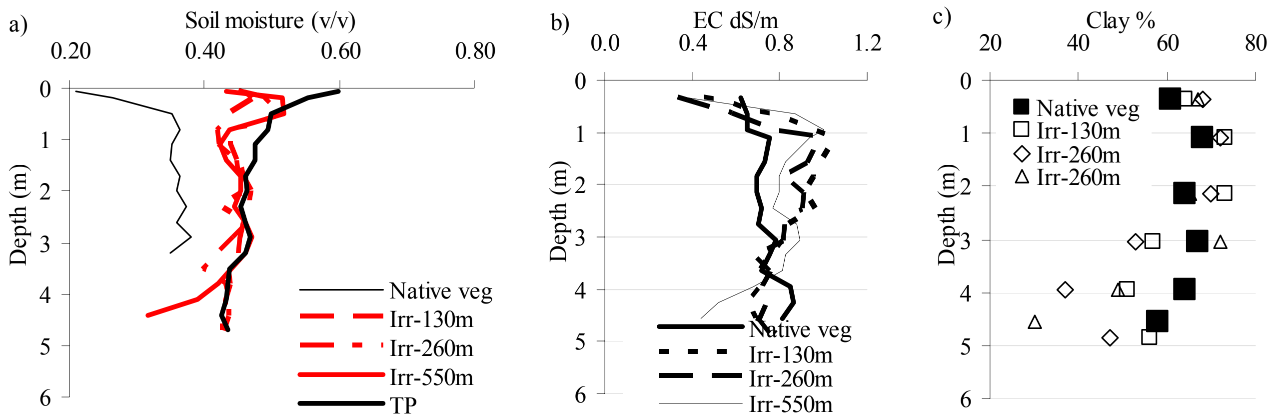

Figure 4. Dalby transect a) soil volumetric water contents, b) EC and c) clay contents, taken in native vegetation and at 130, 260 and 550 m (refers to distances along transect in Figure 3).

The image at Dalby (Figure 3) shows a clear increase in conductivity in the upper layers at 120 m, where native vegetation ends and the irrigated paddock starts. Soil under native vegetation had lower conductivity, half that in the irrigated paddock, and was dry (Figure 4a). Soil was extremely wet under irrigation to the depth measured (Figure 4a). Water contents were close to total porosity (TP); the soil was near-saturated and had little air content. EC profiles show a salt bulge higher in the irrigated paddock, consistent with salt added in irrigation water (Figure 4b). However by 3 m depth, EC was reasonably uniform along the entire transect. Similarly, % clay was consistent along the transect to 4 m (Figure 4c). Deeper that this, some sandy layers begin to emerge, creating variability in particle size analysis. Overall, these results indicate changes in conductivity in the upper profile are predominately due to differences in soil water. The depth of the highly conductive zone is shallower at the tail drain (near the native vegetation) than towards the head ditch, consistent with less drainage occurring along furrow irrigated fields (Gunawardena *et al.* 2008).

As with the Dalby transect, a clear delineation is seen when moving from irrigation to native vegetation at Brookstead (Figure 5). The wet zone extends considerably further down (to 15 m), under irrigation. Soil EC and clay contents are very uniform along the transect (Figures 6b, 6c), and so it can be assumed that conductivity changes along the transect (at shallow depths) are due to changes in soil water.

Conclusion

2-D resistivity imaging and soil coring showed that irrigated fields in the Condamine alluvium were consistently near-saturated in the upper regolith to depths of about 10 m, whereas under native vegetation the regolith was dry. Thus considerable deep drainage from irrigation has been stored in regolith previously kept dry by native vegetation, preventing it from contributing to recharge. It is not possible to determine from resistivity imaging whether deeper layers (e.g. >15m) are also wet because they are resistive in the unsaturated zone and below the water Table, due to low salinity of the groundwater. Deeper coring is required to determine the moisture status and confirm the salinity of these deeper materials.

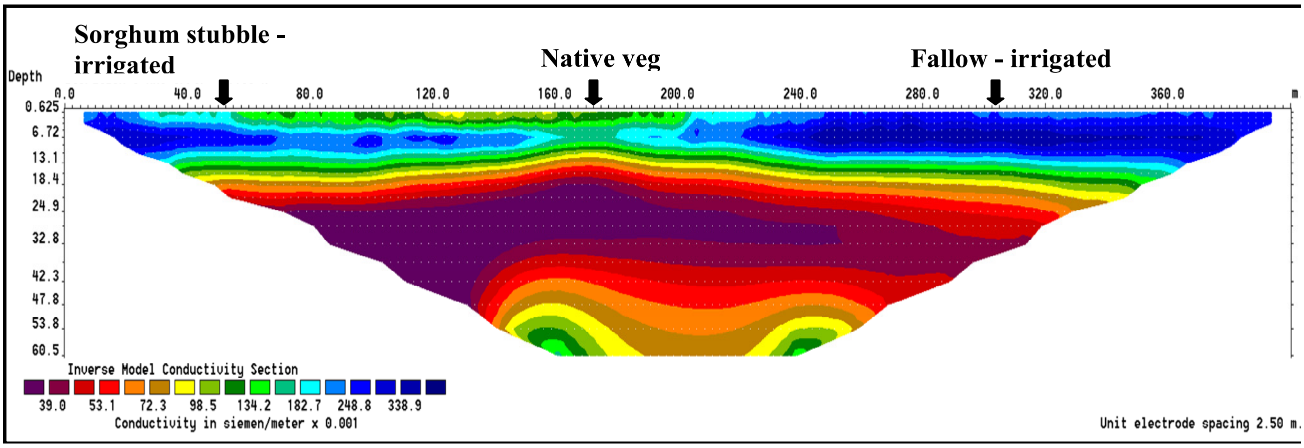

Figure 5. Brookstead transect: L to R, sorghum stubble (irrigated) into native vegetation, into fallow irrigated.

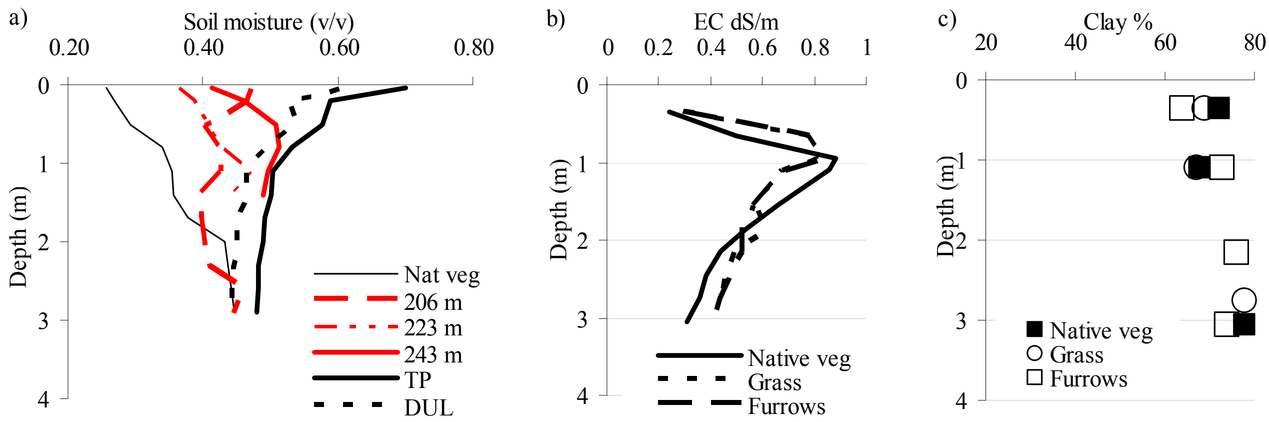

Figure 6. Brookstead transect a) soil volumetric water contents, b) EC and c) clay contents taken at 196 m (native veg), 203 m (grassed) 206 m (furrow start), and 223 and 243 m (refers to distances along transect in Figure 5).

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