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Salinity and groundwater mapping: a multi-scale, hierarchical approach to identify and map key functional elements in Australia's complex depositional regolith landscapes

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Research over the last few years has led to significant new insights into landscape evolution and 3D regolith architecture in many of Australia's catchments affected by dryland and irrigation-related salinity (Lawrie *et al*., 2002a). Integrated geoscience studies involving electromagnetic methods (AEM) studies have shown that many of the large catchment-scale groundwater flow systems are often compartmentalised, and may contain geomorphic units of significant geospatial distribution that have higher hydraulic conductivities and higher potential water yields (Lawrie *et al.*, 2003a; Munday, 2004). These flow systems may also be spatially nested, in effect containing local and intermediate types within the larger, slow moving regional flow systems (Fitzpatrick *et al.*, 2004). This is considered to be a common occurrence in areas of fluvial buried landscapes, which occur in two thirds of the Murray-Darling Basin (Lawrie *et al.*, 2003a).

The critical attributes required for assisting salinity mapping, modelling and management in Australia's depositional landscapes are (1) the connectivity of aquifers in different salt-water systems; (2) the existence and extent of by-pass flow (vertical and lateral); (3) the size of the salt store and its potential for mobilization; (4) the 3-D nature of the regolith (and adequate algorithms and models to depict this); (5) the need for a dynamic water balance (Lawrie *et al*., 2003a). In these landscapes, only geophysical techniques (e.g. airborne electromagnetics) can provide information on the spatial distribution of regolith materials and groundwaters (Spies & Woodgate, 2004).

Presently, airborne are viewed as considerably more expensive than other airborne geophysical techniques for salinity and groundwater mapping. However, recent investigations by the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) and Geoscience Australia suggest that substantial cost reductions in acquiring AEM datasets (up to an order of magnitude) may be achieved if the critical landscape elements that control salinity and groundwater in a target area can be identified prior to surveying (Lawrie *et al.*, 2003b) Savings can be made if the spatial and geo-electrical characteristics of the elements allow relatively wide line spacings to be used.

Preliminary work in the GILMORE Project area, NSW, has established many of the attributes listed above. The GILMORE survey area lies within a shallow inland basin, the Bland Creek palaeo-valley, a north-south-trending palaeo-valley system 60 km across, and 130 km long. The northern of two AEM surveys lies within the western flank of the palaeo-valley in an area of relatively flat alluvial plains with a few low hills (Lawrie *et al.*, 2000; Chan & Gibson, 2001). The latter consist of granites or silicified hydrothermal alteration zones associated with Au and Au-Cu deposits (Lawrie *et al.*, 2002b). NNW-trending, discontinuous topographic ridges consist of siliciclastic meta-sediments and/or granites. The streams flowing from the hills mostly disappear into alluvial fans or into the alluvium of the flood plains. The main north-flowing stream, Bland Creek, varies in salinity, receiving low salt waters from its left bank but, occasionally, very high salinity waters from the right bank (Lawrie *et al.*, 2000).

In the GILMORE project area a detailed picture of 3D regolith architecture has been established through analysis and interpretation of materials from several hundred boreholes, and integrating this analysis with airborne geophysics datasets and surface regolith landform mapping (Lawrie *et al.*, 2000, 2002a). The MDBC Groundwater Flow Systems Map for this area is derived largely from surficial datasets and older geology maps that denote the Quaternary materials largely as one regional flow system. There is no sub-surface data incorporated in this construct. It shows a large part of the area as a regional GFS system. However, a very different picture of the regolith architecture and contained groundwaters emerges from the AEM survey data. Significant complexity is observed at sub-catchment scales, with compartmentalisation evident within this same area. Drilling has validated this compartmentalisation. Up to 120 m of sediment infill are recorded in the northeast of the AEM survey area. However, sediment thickness is markedly variable on account of complex bedrock palaeo-topography (Lawrie *et al.*, 2000).

Within this complex landscape there is considerable vertical and horizontal variability in landscape and salinity elements (Lawrie *et al.*, 2003a). There are broadly four scales of features present:

1. First order features. At depth (>20 m), bedrock-influenced elements such as variably weathered saprolith, and limited fresh bedrock (eg resistive silicified ridges). The structural dominance in the bedrock has partitioned the bedrock and its weathered equivalent into NNW-trending landscape elements that are between 1 and 6 km in width, and 10-50 km in strike length. These landscape elements provide the large scale controls on regolith architecture and have considerable influence on salt store and groundwater flow. In this landscape it is important to recognise and map these features for catchment and sub-catchment scale salinity mapping and management. Nearer surface (<20 m), the bedrock influence is less, and Cainozoic sediments predominate. At these depths landscape elements of similar scale include a clay-dominated palaeo-lake that contains significant volumes of saline groundwater within clays of low hydraulic conductivity (salt store);

2. Second Order Features. Sedimentary basins developed through preferential erosion of weathered bedrock and subsequent infill. These form discrete basins at depth (15-60 m), and are between 1.5 and 6km in width, and 3-20 km in length. These features are important elements as they contain significant stores of saline groundwaters, and it is important to map these features at sub-catchment scales. At all depths colluvial fan deposits are important at different scales. However, at shallow depths (<20 m) a colluvial fan apron around the Barmedman Granite is an important element, as significant recharge appears to occur within this unit. It is present as an apron around the exposed granite, extending up to 6 km from it;

3. Third Order Features. The sedimentary basins inter-connected downstream. They are sinuous features that represent palaeo-channel fill materials (not a single channel, but many stacked, small scale channels). They contain higher proportions of sand-sized materials than adjacent sediments, and in general appear to have higher hydraulic conductivities and water yields than adjacent finer grained sediments. These features form palaeo-gorges that cut through linear bedrock ridges that otherwise act as barriers to groundwater flow in this area. The palaeo-channels are generally less than 300 m in width, and can be traced for between 2 and 20 km. It is important to recognize and map these features at sub-catchment scales;

4. Fourth Order Features. Small-scale features are evident in the highest resolution AEM datasets. These features are mainly narrow (<100 m wide, 500 m long) tributary palaeo-channels. These are probably of some significance at paddock (farm) scale only.

These features are the key functional elements of the landscape that should enable targeted engineering and/or biological interventions in the landscape for salinity management at a range of scales. Pump tests in the different regolith materials in the survey area have demonstrated significant (>5 orders of magnitude) differences in hydraulic conductivities in regolith materials in the GILMORE Project area (Grant Jones, pers com., 2002). Work is on-going to derive a hydrogeological model for the area.

Analysis of the key functional elements of the landscapes in the GILMORE (New South Wales), Lower Balonne (Queensland) and Honeysuckle Creek (Victoria) TEMPEST AEM survey areas, suggest that 1km line spacing is adequate to map most landscape and salinity elements in these depositional landscapes (Lawrie *et al.*, 2003b). Even 2 km-line spaced data provides catchment and sub-catchment scale salt store data, and this may be useful for broad scale planning and national audit purposes. For 1 km and 2 km line spacing, this means that significantly larger areas could be flow for the same cost, reducing the cost of AEM data per hectare as follows:

1 km line-spacing <$0.7/ha for acquisition

2 km line-spacing <$0.4/ha for acquisition

This represents a very substantial cost saving, and could make AEM data affordable for many more NRM applications. The assumptions in the above calculations are that the total number of line km from the original surveys are maintained, that the line km costs are similar to those from recent surveys, and that all other survey mobilisation and operational costs remain similar to the original surveys (Lawrie *et al.*, 2003b).

Salinity and groundwater mapping in Australia's complex regolith landscapes is greatly assisted by using an integrated geoscience approach that utilises a multi-scale, hierarchical approach to identify and map key functional elements. An approach that involves consideration of present landforms and buried landscapes can greatly assist with the design of cost-effective surveys for salinity mapping and broader NRM applications. This approach should also utilise GFS conceptual models and frameworks where possible.

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