MULTIDISCIPLINARY APPROACH TO SALINITY MANAGEMENT IN THE LOWER BALONNE, SOUTHERN QUEENSLAND

Andrew Fitzpatrick, Jonathan D.A. Clarke & Ken Lawrie

CRC LEME, Geoscience Australia, GPO Box 378, Canberra, ACT, 2601

INTRODUCTION

The Lower Balonne Airborne Geophysics Evaluation Project is the largest time domain airborne electromagnetic (TEMPEST) survey acquired in Australia for natural resource management purposes. 28,912 line km of data were acquired in 2001 under the auspices of the National Action Plan for Salinity and Water Quality, in a project undertaken by the Queensland Department of Natural Resources and Mines (QNR&M), the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME), and the Bureau of Rural Sciences (BRS).

The survey area is approximately 18,000 km^2 covering a section of the Lower Balonne catchment in southern Queensland. AEM line spacing varied between 250 and 400 m over the survey area. The study area is categorised as a high potential salinity risk consequent of intensive cotton irrigation, large land clearing and signs of dryland salinity in the region (Hansen *et al*. 2004). The survey was flown to assess the use of airborne geophysics as part of a multi-disciplinary systems approach to mapping and understanding salinity and groundwater systems. Prior to this study, dryland salinity was known to occur in adjacent areas, however, there was a poor understanding of groundwater and salinity processes in the study area itself. The area was selected to provide greater insights into salinity risk in a region where there has been significant clearing of native vegetation and a substantial increase in surface water diversion for cotton irrigation.

In the Australian context, an assessment of salinity hazard requires an appreciation of how land use changes have impacted upon complex biophysical systems. Compared with other trend-based and composite index approaches (Walker *et al.* 1999), an integrated geoscience approach has the potential to provide a more complete understanding of salinity and groundwater systems in Australia's complex regolith landscapes (Lawrie *et al*. 2000, Lawrie *et al*. 2003). This approach involves mapping regolith architecture, salt stores and groundwater. The regolith architecture provides a framework for understanding aquifer distribution and connectivity, groundwater flow systems, and the controls on the distribution of salt and preferential movement of groundwaters in the sub-surface. When integrated with hydrogeochemical and hydrogeological data, this provides a 4D picture of salinity and groundwater dynamics, and enables salinity hazard to be assessed with greater reliability (Lawrie *et al.* 2003).

This approach also value-adds to our understanding of groundwater flow systems. In particular, it enables zones of higher hydraulic conductivity to be identified and mapped, and this may lead to redefinition of existing groundwater flow system constructs (Lawrie *et al*. 2004).

METHODS AND RESULTS

An integrated geoscience approach was applied to project design and implementation. AEM conductivity data and borehole lithology information provide a basis to interpret the 3D regolith architecture of the area.

3D regolith architecture was constructed using lithogical borehole data and extrapolated in 3D using correlations with the AEM conductivity volume. AEM conductivity data was predicted and assessed using a layered earth inversion model in conjunction with electrical borehole measurements (Lane *et al.* 2003, Lane *et al.* 2004). The resulting architecture can be divided into four vertical stages, each with a distinct fabric in the AEM depth slices (Table 1, Figure 1).

Particularly noteworthy in this architecture is the fabric discordance between stages 4, 3 and 2. The fault-controlled basins and deeply incised valley fills in stage 2 have not been obviously reflected in the fabric of stage 3. Also, the broad valley filling fluvial systems of stage 3 are not reflected in the inset fan systems of stage 4.

In the near-surface slices (0-5 metres), high conductivity anomalies are associated with high salt loads. Three main salt stores are identified in the near-surface: saline/sodic soils occurring in the floodplain, west of the river (anomaly 1); a natural saline disposal basin—Goondoola Basin (anomaly 2); and, topographic lows surrounding the Noodoo Rises in the south. With increasing depth, areas of very shallow or exposed bedrock are revealed by moderate conductivity. Highly weathered Cretaceous bedrock is characterised by a strong conductive signature associated with ferruginisation. Other geomorphic features can be distinguished by subtle changes in conductivity. Highly resistive areas, such as the Maranoa surface, correlate well with large, thick sand bodies. Such bodies have significant recharge potential, especially when connected to the near-surface. The large resistive bodies observed at depth (stage 2) reflect the spatial position of the lower confined aquifer running parallel to the northwest survey boundary, which has a major tributary palaeo-valley running perpendicular to the southeast.

Table 1: Four stages of regolith architecture interpreted from the AEM conductivity depth slices, and lithological logging.

AEM layer	Stage	Interpretation
0-5 5-10 10-15	4	Fabric of this stage is dominated by surface architecture, including areas of shallow bedrock and the sediments of the Balonne Fan and Maranoa surface. Pattern closely resembles that of gamma-ray spectrometry and regolith-landform mapping.
15-20 20-30 30-40	3	Fabric of this stage is dominated by broad valley fills in central and north eastern regions; broad valleys separated by bedrock highs; and first and second order dendritic valley fills in shallow bedrock areas.
40-60 60-80 80-160	2	Fabric of this stage is dominated by deeply incised trunk valleys and the Dirranbandi Palaeovalley
160-200 >200	1	This stage lacks distinct fabric apart from 'ghosts' or shadows of shallower features

Subsurface salt stores were also identified from conductive anomalies and verified by ground validation (surface and borehole geophysics and laboratory analysis of borehole materials). Interpretation of hydrogeochemical data (major cations and anions and stable isotope compositions in pore waters) indicates that there are four main hydrostratigraphic groups in the study area. These are: weathered Cretaceous rock aquifers (characterised by the highest salts stores); Quaternary near-surface zones and clay-dominated zones (both characterized by high salt stores); and, Quaternary sand-dominated zones (characterised by low salt stores). Both the upper unconfined and lower confined aquifer were spatially mapped using the AEM conductivity volume data. The connectivity of the aquifers was determined by geochemical analysis of respective water samples.

Drilling identified watertable surfaces and these surfaces could be mapped in 3D by a correlation of these surfaces with a marked change in AEM conductivity as a function of water saturation. For example, the upper aquifer is divided into two distinct zones: Quaternary alluvial sands; and, Cretaceous shallow bedrock (Griman Creek Formation). Standing water levels for the alluvial material typically lie within 15 to 30 metres of the surface and 5 to 10 metres for the Cretaceous bedrock (Figure 2).

The distinct contrast between the hydrochemistry of pore waters in these zones indicates that different processes control salt concentrations and mobilisation. Higher concentration salt stores appear to have been derived from evaporative concentration, whereas the lower concentration salts are likely to have been derived from rainwater that has undergone minimal evaporative concentration of salts and has had some input from mineral weathering.

Preferential flow paths are identified by combining hydrogeochemistry with 3D regolith interpretations. Hydrogeochemical analysis of pore fluid data suggests the complex groundwater movements, with different flow paths within disconnected aquifers, the geospatial extent of which can be mapped using AEM data. Contrasts in hydrogeochemical compositions of salts and pore waters in the different hydrostratigraphic zones suggest that lateral flow processes dominate over vertical flow processes in alluvial aquifers. Lateral flow predominates in the lower alluvial confined aquifer, whereas lateral and vertical movement are identified in the nearer-surface, upper Quaternary aquifers. The homogeneity of chemical compositions in pore waters from the weathered Cretaceous rocks suggests this aquifer is dominated by vertical flow, with groundwater mixing throughout the aquifer.

Overall, it is likely that the longer-term salinity risk in the area is linked to rising regional groundwater surfaces within unconfined aquifers within the alluvial aquifers. More locally, salinity risks are identified within the Cretaceous weathered rock aquifers and the Quaternary alluvium clay-dominated zones (within the unsaturated zone and upper aquifer). Despite limited evidence for diffusion and subsequent removal of salts out of these zones, the few cases where diffusion of high salt concentrations does occur suggests that hydraulic re-equilibration may be the driving process (e.g., Goondoola Basin; Wilkinson 2003). This is of potential concern for future water resources and highlights the need to manage recharge to the clay dominated zones and the Cretaceous aquifers. Although salts appear to be relatively immobile in these relatively low hydraulic conductivity aquifers, once sufficiently pressurised, these aquifers have the potential to act as salt reservoirs and deliver saline waters to more hydraulically conductive aquifers that currently transmit low EC waters.

CONCLUSIONS

An integrated geoscience approach has revealed a complex regolith architecture with stacked, disconnected aquifers present in 'nested' groundwater flow systems concealed beneath a low relief regolith landscape. Borehole data, including sedimentological and regolith analysis, and hydrogeological and hydrogeochemical data have been used to identify aquifers, assess their connectivity, and identify groundwater flow paths. These data provide new constraints on groundwater and salinity processes and models. These data are integrated with geophysical data to construct 3-D regolith, salt store and hydrogeological models that enable salinity risk to be assessed.

The highlights of the project for environmental management include:

- Integration of geophysics and other biophysical datasets to gain an understanding of the 3D nature of the regolith (to inform models of surface-groundwater interaction and groundwater movement);
- Identification of separate aquifer systems, their connectivity and identification of 'nested' groundwater flow systems with different salinities;
- The size of the salt stores and the potential for mobilisation;
- The mapping of groundwater surfaces and preferential flow paths; and,
- Contributions to a dynamic water balance model.

These data are being used to better understand the salinity risk and water security issues in this area.

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REFERENCES

HANSEN J.W., JACKSON J.A., LEE R.B., PEARCE B.R., STGELER J.P., VOKE S.J. & VOWLES. C.M. 2004. Report on compliation of a hydrogeological conceptual model for the Lower Balonne Region. *QDNRM* Unpublished Draft Report.

LANE R.L., BRODIE R.B. & FITZPATRICK A.D. 2004. A revised inversion model parameter formulation for fixed wing transmitter loop-towed bird receiver coil time-domain airborne electromagnetic data. **Extended abstract**, *ASEG 17th Geophysical Conference and Exhibition*, Sydney.

LANE R.L., BRODIE R.B. & FITZPATRICK A.D. 2003. Constrained inversion of AEM data, St.George, Queensland, Australia. *CRCLEME* unpublished report.

LAWRIE K.C., MUNDAY T.J., DENT D.L., GIBSON D.L., BRODIE R.C., WILFORD J., REILLY N.S, CHAN R.A. & BAKER P. 2000. A ‘Geological Systems’ approach to understanding the processes involved in land and water salinisation in areas of complex regolith - the Gilmore Project, central-west NSW. *AGSO Research Newsletter* **32**, p. 13-32, May 2000.

LAWRIE K.C., PLEASE P. & CORAM J. 2003. Groundwater quality (salinity) and distribution in Australia., 2003. *In: Water, the Australian Dilema*. Proceedings of the Annual Symposium of the Academy of Technological Sciences and Engineering, 17-18th Nov., Melbourne (Abs. & Invited paper).

LAWRIE K.C., PLEASE P., CORAM J., PAIN C., GRUNDY M., & WALKER G. 2004. An integrated geoscience approach to re-assessing regional groundwater flow systems for salinity mitigation in the Murray-Darling Basin. *9th PURSL (Productive Use of Saline Land) Conference*, Yepoon, Qld (Abs. & paper).

WALKER G.R., GILFEDDER M. & DOWLING T. 1999. Regional scale dryland salinity risk prediction - a review. *In: Proceedings of the Murray-Darling Basin Groundwater Workshop,* September 14-16, Griffith, NSW, p. 255-261.

WILKINSON K. 2003. *Investigation into the salinisation of the Goondoola Basin, Southern Queensland* Masters Thesis, University of New South Wales, unpublished.

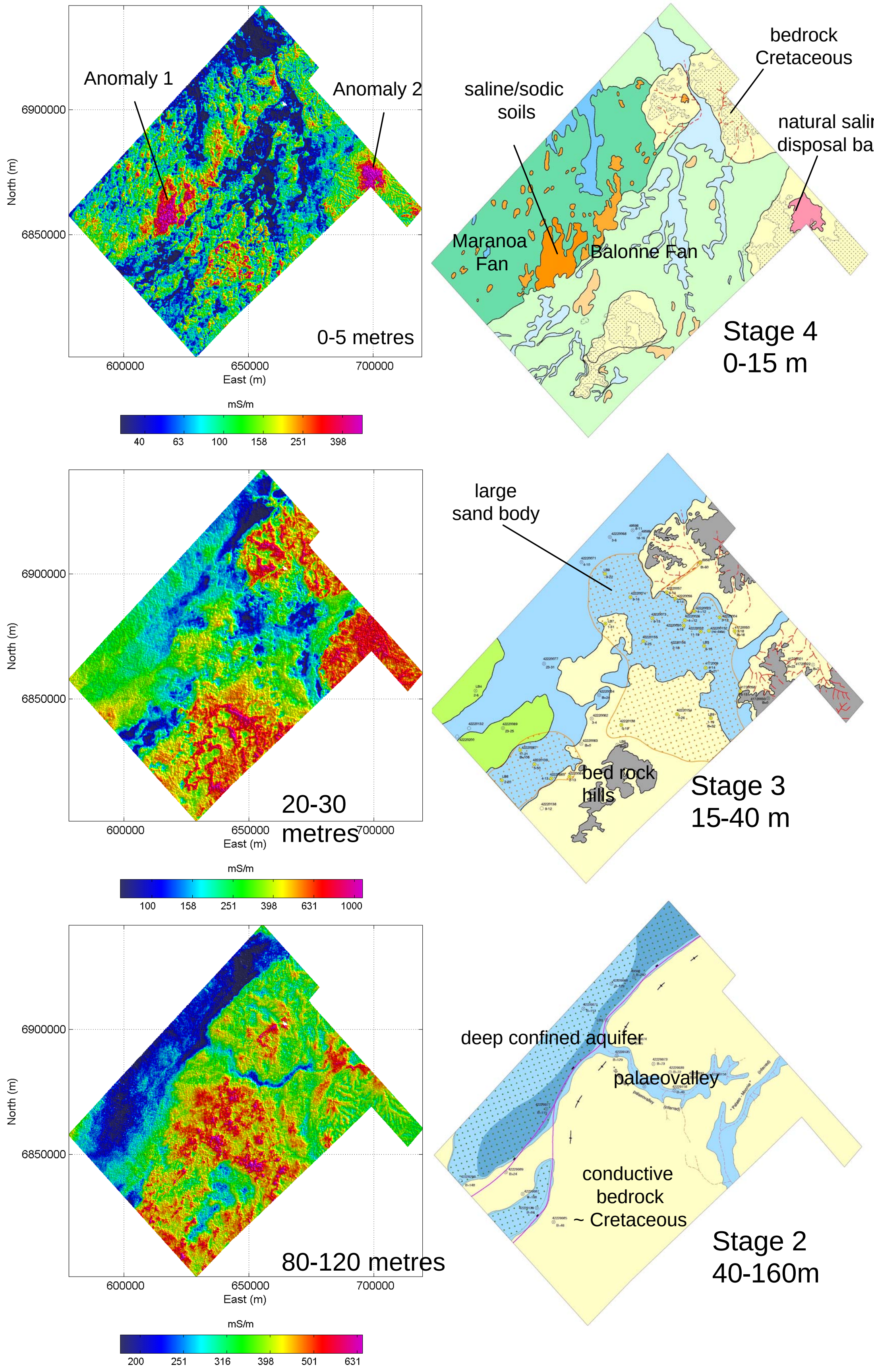

Figure 1: Three of four distinct sedimentological stages (right side) interpreted from the AEM conductivity slices (left side). Note that different colour scaling limits have been applied. Shallow conductive highs correlate to salt stores, moderate conductivity is indicative of the conductive Cretaceous bedrock. The large palaeo-trough and valleys, which form the deep confined aquifer are evident in the deeper slice (Stage 2).