An airborne electromagnetic survey used to address salinity and land management issues in the River Murray corridor, SE Australia

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Introduction

An airborne electromagnetic (AEM) survey recently acquired under the auspices of the Australian Government's Community Stream Sampling and Salinity Mapping Project and managed by the Bureau of Rural Sciences, is providing information vital for addressing salinity, land management and groundwater resource issues along a 450 km reach of the River Murray Corridor (RMC) in SE Australia. The study area stretches from the South Australian border eastwards to Gunbower in Victoria (Figure 1). A total of 24,000 line km of AEM data were acquired.

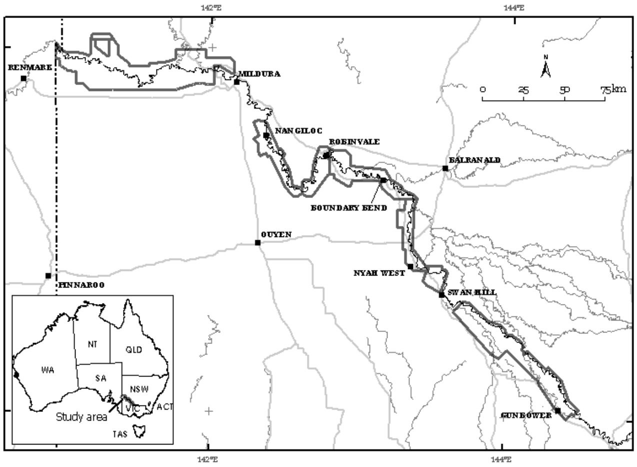

Figure 1 Map of River Murray Corridor AEM survey areas (outlined)

The survey area encompasses iconic wetland areas, national and State forest parks, and irrigation and dryland farming. Within the RMC project area key land management issues (Lawrie, 2007) include (1) the impact of irrigation on the floodplain, river and groundwater system; (2) the distribution of saline groundwaters where these have the potential to impact on the floodplain and river; (3) the location of salt stores in the unsaturated zone within the floodplain; (4) the potential for salt mobilisation during Living Murray inundation actions and natural flood events; (5) the drivers for floodplain health with respect to groundwater processes; (6) the potential for leakage from salt disposal infrastructure; and (7) the extent of losing and gaining effects along different reaches of the river system.

In this project, a new approach to the interpretation of AEM data has been applied using a 4D landscape analysis approach to complement more traditional hydrogeological analytical techniques. The approach builds on earlier multi-disciplinary systems approaches to mapping salinity recommended by the joint Academies Salinity Mapping Review (Spies & Woodgate, 2005). The approach uses modern investigative approaches to the conceptualisation of aquifer systems, seeks to map and characterise key biophysical components of the hydrogeological system critical to the movement of water and salts in the landscape, and incorporates data on landscape, water, salinity and vegetation dynamics. These data provide key constraints on interpretation of both near-surface AEM responses and floodplain hydrostratigraphy, while the 3D spatial mapping of key elements of the aquifer systems (e.g. water quality and lithologies) reduces the uncertainty in predicted salinity impacts and enables management actions to be targeted more effectively.

Recently, this approach has been greatly facilitated by the development of a holistic inversion method (Brodie & Sambridge, 2006). The holistic method inverts all of the airborne samples in one large inversion, thus allowing it to capitalise upon the spatial coherency in the data to produce a spatially continuous conductivity model. The superior spatial continuity of the holistic model allowed us to interpret more subtle features (eg palaeo-strand line patterns) in the data than we could from the conventional sample by sample stitched inversions, which were also used in the project. This method also obviates the need for the iterative, time-consuming calibration-processing-recalibration paradigm, and allows for more rapid turn-around in developing interpretation products.

In the RMC project, integration of the AEM data with new surface geomorphic and surface salt mapping (using SPOT5, Landsat, and LIDAR datasets; Clarke *et al.,* 2007), borehole hydrogeological data, and spatio-temporal analysis of vegetation health, has allowed development of a broader range of interpretation products. These include 3D maps of the extent and thickness of particular geological formations (e.g. Coonambidgal Fm, Blanchetown Clay), river flush zone maps, recharge maps, and maps of near-surface salt stores, near-surface freshwater distribution, irrigation-related anomalies, the extent of groundwater conductive zones, and salt store and salt load maps.

These AEM-based products provide important new information on the spatial distribution of key elements of the hydrogeology, notably the extent and thickness of aquitards such as the Blanchetown Clay, as well as important data on the depth to the top of the Loxton Parilla Sands aquifer and the distribution of zones with higher hydraulic conductivity within this aquifer. Combined with new products showing the spatial distribution of groundwater salinity and salt stores within the unsaturated zone, these datasets provide important new inputs to hydrogeological models and provide the spatial context to salinity impact modelling.

Preliminary work has resulted in a number of important new findings: (1) ‘flush’ zones (laterally and vertically) associated with the losing reaches of the Murray River appear to be much more extensive than previously thought; (2) near surface salt stores have been identified on the margins of and beneath the floodplain at points adjacent to some irrigation areas; (3) there are extensive ‘flush’ zones beneath some of the irrigation areas on the floodplain; (4) overall, there is a strong correlation between land use and AEM response in many areas. Examples of information products are documented below.

River flush zone maps

The river flush zones include fresh water (up to 1000 μS/cm) and slightly brackish water (1000 to 3000 μS/cm) suitable for desalinisation. Brackish water with EC up to 5000 μS/cm may be suitable for desalinisation in the future but at this stage is not included in the flush zone maps. Taking porosity of fine to medium sand to be approximately 35 vol %, the apparent conductivity of the saturated sediment can be calculated as:

$$EC_a = [EC_{water}\ (\mu S/cm) / 10 \times 0.35\ ]\ mS/m$$

The table below shows the range of apparent conductivity used to map the extent of river flush zones.

Table 1. Range of apparent conductivity

Water quality	Fresh	Slightly Brackish	Brackish	Saline
Water EC μS/cm	< 1000	1000 - 3000	3000 - 5000	>5000
ECa mS/m	< 35	35 - 105	105 - 175	>175

Customized AEM conductivity depth slices, tilted with respect to the Australian Height Datum (AHD) to utilise the surface of modern floodplain unit as a local datum, were constructed. The flush zone maps were produced on depth slices starting 2 m below the floodplain in the saturated zone.

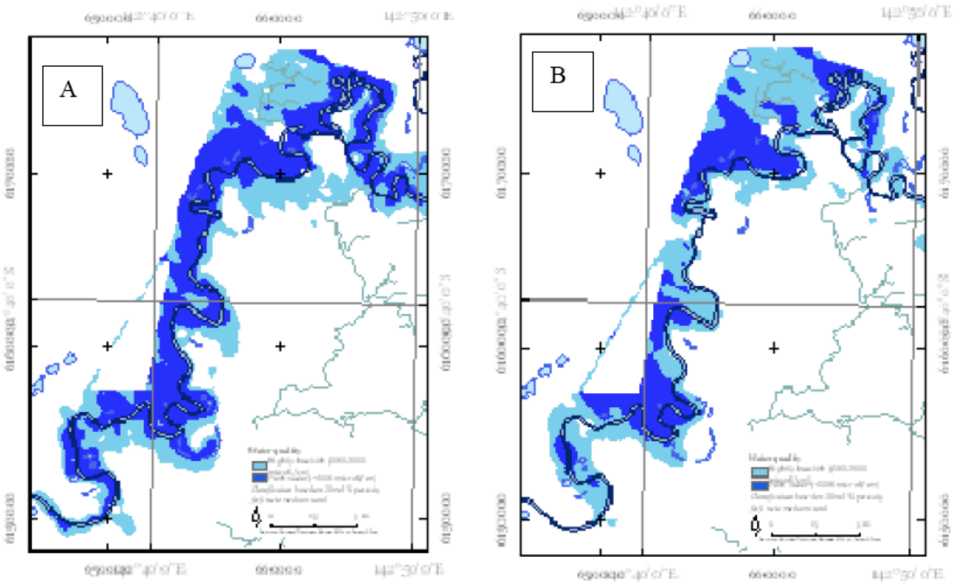

Figure 2 **River flush zone maps for the Liparoo-Robinvale sub-area from different depth slices below the floodplain surface (A) -10 to -15 m and (b) -25 -30m below floodplain surface). The flush zones (dark blue) in the shallower depth slices are within the Coonambidgal Fm and essentially follow the course of the main river channel, while the fresh groundwater in the deeper slices is more compartmentalised within the Parilla Sands.**

Near surface salt stores

Apparent conductivity (ECa) is a response to the amount of salt in the regolith. Previous studies have demonstrated that the causal relationship between ECa and salt can be expressed as a linear function (Tan *et al.*, 2005). On average, the bulk density of sediments is approximately 1.6 g/cm3 (or t/m3). Because the ArcGIS calculates the total-salt as voxel (*i.e.* 40 x 40 x 1 m3), the conversion of mass of sediments into voxel and finally to tonnes/hectare is carried out as follows:

EC_a = 0.1073 x Total-Salt mS/m
Total-Salt = EC_a / 0.1073 g/tonne
1 voxel = 40 x 40 x 1 = 1600 m^3
Taking the bulk density of sediments to be 1.6 t/m^3,
1 voxel will contain 2560 tonnes (i.e. 1600 x 1.6) of sediments.
Thus, to convert g/tonne to tonnes/voxel Total-Salt (where EC_a is in S/m instead of mS/m)
Total-Salt = ((EC_a x 1000) / 0.1073)/1000000 x 2560 *t / voxel*
Since 1 hectare consists 6.25 voxels (*i.e.* 10000/1600),
Total-Salt = ((EC_a x 1000) / 0.1073)/1000000 x 2560 x 6.25 *t / hectare*
Total-Salt = EC_a x 149.11 *t / hectare*

The average conductivity in the material between surface and groundwater is used to produce the near-surface salt store map (Figure 3.). The average ECa is translated into total salt as tonnes per hectare. The spatial distribution of fine textured materials (mud and clay of Coonambidgal Formation of the floodplain, and Blanchetown Clay of the shallow pre-alluvial succession) are overlain onto the total salt image. The salt in these areas of fine textured material is unlikely to be mobilised as it is held A B within these low permeable clays. The salt hosted in permeable sand (*i.e.* remaining areas) is considered to have a higher degree of mobility, and represents the highest salinity risk to the River Murray and the floodplain.

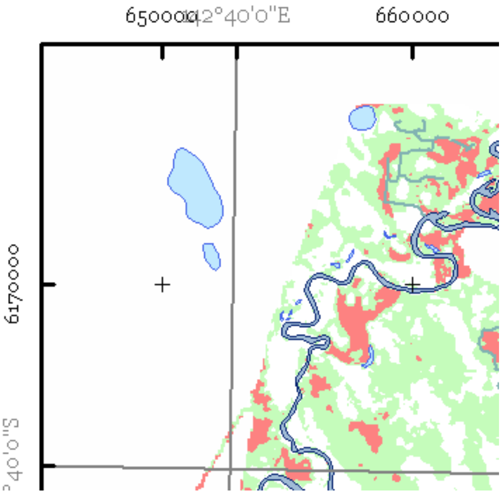

Figure 3 **Near-surface salt store map for the Liparoo-Robinvale sub-area. The variability shown in the Parilla Sands (light green) reflects the patterning of palaeo-strand lines, and most likely reflects differences in clay:sand ratios, and permeability.**

Conclusions

In this project, new holistic inversion methods combined with a 4D landscape analysis approach to interpreting AEM data map spatial variability in key elements of the hydrogeological system. This approach has been used to predict major changes in AEM responses and hydrostratigraphy related to the avulsion of the Murray – Wakool –Edwards River systems (Wong *et al.* 2008). The interpretation products produced in this study provide key inputs to further hydrogeological modelling, and should assist with improving irrigation planning and salinity impact modelling in the River Murray Corridor.

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