Preliminary assessment of an alluvial aquifer system using airborne and ground-based geophysics: Upper Darling River Floodplain, New South Wales

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SUMMARY

Defining and characterising groundwater aquifers usually depends on the availability of data necessary to represent its spatial extent and hydrogeological properties, such as lithological information and aquifer pump test data. In regions where such data is of limited availability and/or variable quality, the characterisation of aquifers for the purposes of water resource assessment and management can be problematic. The Upper Darling River Floodplain region of western New South Wales, Australia, is an area where communities, natural ecosystems and cultural values are dependent on both surface and groundwater resources. Owing to a relative paucity of detailed geological and hydrogeological data across the region we apply two non-invasive geophysical techniques—airborne electromagnetics and surface magnetic resonance—to assist in mapping and characterising the regional alluvial aquifer system. The combination of these techniques in conjunction with limited groundwater quality data helps define an approximate extent for the low salinity alluvial aquifer in a key part of the Darling River valley system and provides insights into the relative water content and its variation within the aquifer materials. This work demonstrates the utility of these key geophysical data in developing a preliminary understanding of aquifer geometry and heterogeneity, thereby helping to prioritise targets for follow-up hydrogeological investigation.

Key words: Alluvium, aquifer, electrical conductivity, airborne electromagnetics, magnetic resonance

INTRODUCTION

As part of the Australian Government's Exploring for the Future (EFTF) program (https://www.ga.gov.au/eftf) several projects were conducted to improve the understanding of groundwater systems at regional to continental scales across Australia. The Upper Darling River Floodplain region of western New South Wales (Figure 1) is one such area where groundwater and surface water are critical resources supporting a range of users. Water resource management and community water security are key concerns in the region, and the limited hydrogeological information available makes the development of targeted management options more challenging for water managers.

Here we present aspects of an investigation into a key part of the Upper Darling River Floodplain near Wilcannia, where community water supply is a major water management issue. The key hydrogeological systems of interest are the fresh and saline groundwaters within Cenozoic alluvium deposited by the Darling River, which forms sedimentary sequences 30 m to 140 m thick beneath the floodplain. We apply two main non-invasive geophysical techniques—airborne electromagnetics and surface magnetic resonance—to assist in mapping and characterising the regional alluvial aquifer system with limited borehole constraint, including characterisation of the approximate extent, water content and heterogeneity of the low salinity alluvial aquifer.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The broader study area is characterised by bedrock terranes associated with the Lachlan and Thomson orogens (Glen, 2013), with the latter occurring in outcrop and subcrop to the southeast of the study area in the Byrock/Cobar region (beneath inset – Figure 1) and in the southwest near Wilcannia (Figure 1). Overlying these terranes are sediments of the Mesozoic Eromanga and Surat basins (Exon and Senior, 1976) and the Cenozoic Murray Basin (Brown and Stephenson, 1991) (Figure 1). The present low-relief landscape comprises a thin veneer of Cenozoic sediments with relatively limited bedrock outcrop (Pain et al., 2011). Beneath the surface within and upstream of the study area are several palaeovalleys, including that of the Darling River, that are associated with palaeodrainage from the Eastern Highlands. These palaeovalleys are 100–200 m deep, predominantly filled with Cenozoic sediments (Martin, 1997, 2014) and are important pathways for groundwater. In many instances the palaeovalley-fill sediments are compositionally and chronologically analogous to upper Murray Basin sequences (Brown & Stephenson, 1991; Lawrie et al., 2012; Martin, 1997, 2014).

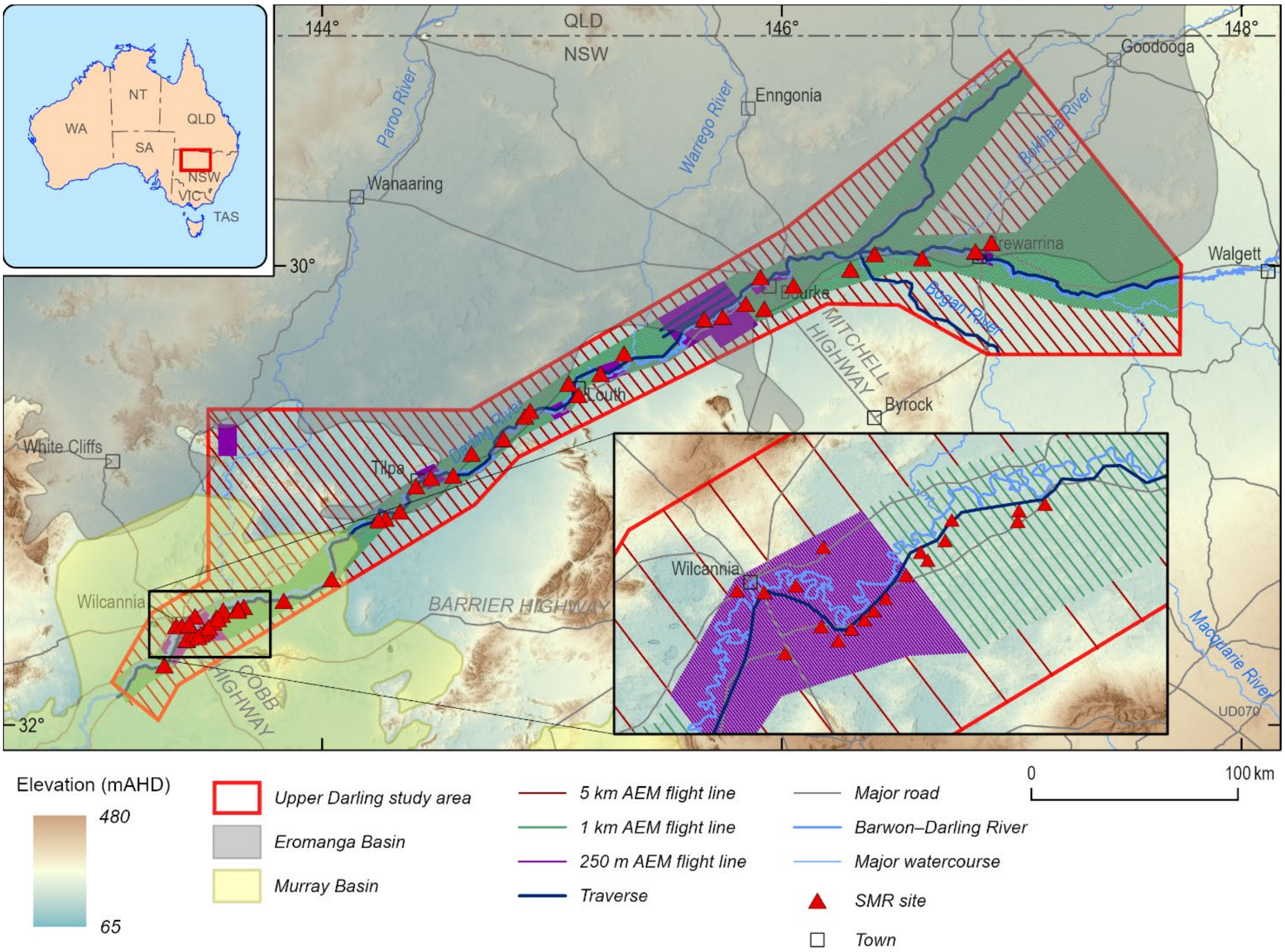

Figure 1. Map of Upper Darling River Floodplain study area in western New South Wales showing the location of airborne electromagnetic (AEM) survey flight lines colour-coded by acquisition density. Locations of surface magnetic resonance (SMR) profiles are marked. Inset shows details of data coverage in the Wilcannia area (see Figure 3). Basin extents from Raymond et al. (2018); background is hill-shaded 1 s SRTM DEM (Gallant et al., 2011).

Cenozoic stratigraphy is poorly constrained within the Upper Darling study area (refer to Brown and Stephenson, 1991 for regional stratigraphic detail), yet it is these sequences that comprise the Darling River valley alluvial aquifer system. Downstream of Wilcannia in the Lower Darling River (Menindee) region previous detailed work on these sequences identifies the Pliocene–Pleistocene Coonambidgal and Menindee formations as the dominant units within the upper part of the current river valley (Lawrie et al., 2012) (Figure 2). Owing to the apparent absence of the Blanchetown Clay within the present study area (cf. Brodie, 1998), the Coonambidgal and Menindee formations are likely to be in disconformable or unconformable contact with the underlying sequences, dominated by generally coarser-grained quartzose and lithic sediments of the Miocene–Pliocene Calivil Formation and Eocene–Miocene (upper) Renmark Group (Brown and Stephenson, 1991; Lawrie et al., 2012) (Figure 2). The hydrogeological setting is summarised as a deep, saline groundwater system associated with coarser-grained sediments of the Renmark Group/Calivil Formation overlain by generally finer-grained Plio–Pleistocene and younger (Martin, 1997) sediments representing the shallow aquifer system, with lithological variation influencing the degree of connectivity between them (Williams, 2002; d'Hautefeuille et al., 2004). The shallow groundwater system is characterised by a localised freshwater zone where exchange occurs between the Darling River and its alluvium, with sporadic overbank flooding being the key recharge mechanism for the alluvium at distances greater than ~500 m from the river (Meredith et al., 2009, 2015, 2016).

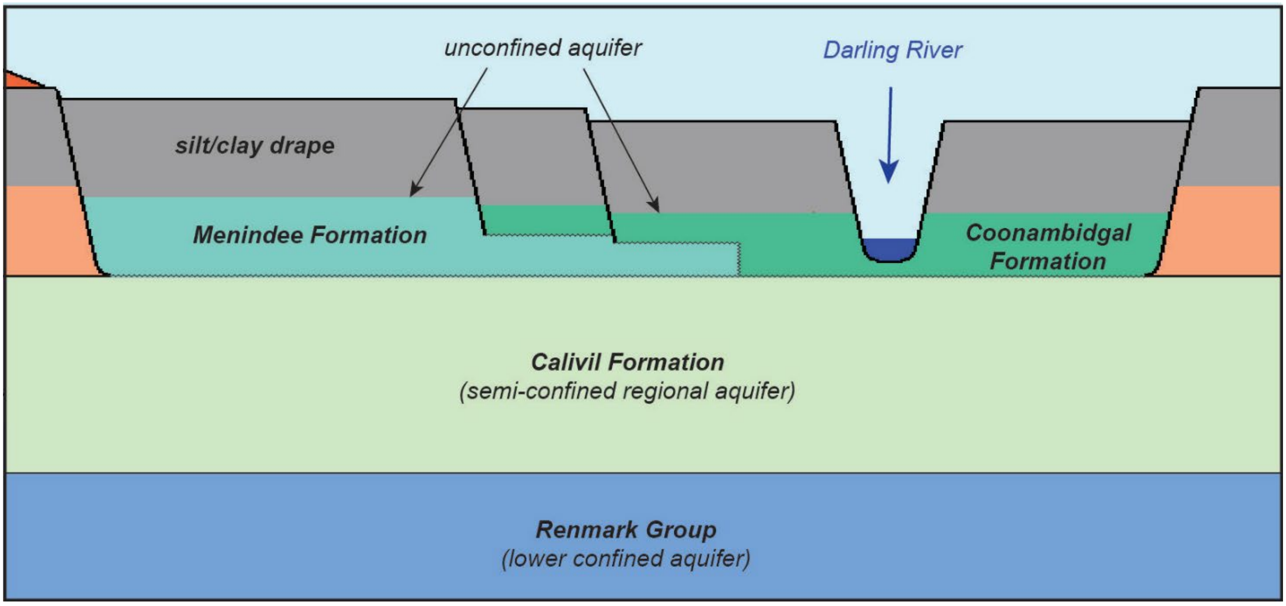

Figure 2. Schematic diagram illustrating the stratigraphic relationships between Cenozoic fluvial units in the study area based on detailed investigations from downstream in the Lower Darling (Menindee) region (adapted from Lawrie et al., 2012).

GEOPHYSICAL DATA ACQUISITION AND PROCESSING

The study acquired new airborne, downhole and ground-based geophysical data that were integrated with existing geoscientific data—full methodology, results and interpretation are reported in McPherson et al. (2024) while the more detailed assessment in the Wilcannia area is reported in Tan et al. (2024).

The Upper Darling Floodplain SkyTEM airborne electromagnetic (AEM) survey acquired 25,611 line-kilometres of helicopter-borne AEM data across the study area in March–July 2022 (Ray, 2022). The survey acquired time-domain transient electromagnetic (TEM) data at flight line spacing varying from 250 m up to 5 km, with tie lines acquired parallel to the major trunk streams (Figure 1). In addition to contractor-delivered products the data were also inverted using the HiQGA fast forward model and inversion framework (Ray & Myer, 2019; Geoscience Australia, 2022). The HiQGA inversion uses a 50-layer model, with thicknesses increasing geometrically with depth, also terminated by a half-space, with model resistivities potentially varying between 0.1 and 1000 Ωm. The inversion applies first differences regularisation and enforces a resistive background of 100 Ωm when sensitivity to the AEM signal is weak. Both contractor-delivered and HiQGA inversions generally produced a maximum depth of investigation of ~100–200 metres below ground level (mbgl) within the study area.

Surface (nuclear) magnetic resonance (SMR) soundings were acquired at 47 sites across the study area (Figure 1) and the data (Peljo et al., 2024) inverted using a HiQGA probabilistic (stochastic) inversion (Taylor et al., 2022). Measurement sites targeted areas of differing geological and AEM conductivity characteristics to assess the possible range of total water contents at different depths within the alluvium, including estimates of uncertainty for these models. Seventeen (17) sites were preferentially located where AEM models suggested the presence of thick (tens of metres) and broad (several kilometres wide) low conductivity zones that might represent the presence of low salinity groundwater. Downhole geophysical logging of 23 bores across the study area additionally acquired induction conductivity, natural gamma and borehole nuclear magnetic resonance data (Peljo et al., 2024), and groundwater salinity and chemistry data were collected from 26 boreholes (Walsh et al., 2024).

INTERPRETATION AND RESULTS

In the Menindee region downstream of the study area Lawrie et al. (2012) demonstrate that within the Calivil Formation aquifer AEM conductivity responses of <0.06 S/m has an 80% chance of containing good (<600 mg/L total dissolved solids; TDS) to acceptable (<1,200 mg/L TDS) quality groundwater. Owing to the continuity of key hydrostratigraphic units such as the Calivil Formation between the Menindee and Wilcannia–Tilpa areas, the methodology of Lawrie et al. (2012) is applied in the present study area.

Using the 0.06 S/m threshold, low conductivity signatures were mapped from the AEM and matched with high total water content in SMR profiles to identify potential groundwater resource areas beneath the floodplain (Figure 3). These low conductivity areas typically occur from 20 mbgl to 65 mbgl and denote a high probability of low salinity groundwater being present in the unconfined aquifers of the Coonambidgal and Menindee formations, and the semi-confined Calivil Formation aquifer (Figure 4). Low conductivity values in borehole geophysical logs, high sand content inferred from natural gamma logs, and groundwater salinity data from a limited number of locations provide high confidence in the presence of fresh groundwater resource areas.

In Figure 4 the AEM conductivity depth section (B–B' in Figure 3) shows shallow (<10 mbgl) variably conductive responses across much of the section interpreted as unsaturated, fine-grained floodplain deposits, underlain by a low conductivity layer—the potential groundwater resource—which in turn overlies a high conductivity interval sitting above resistive bedrock. SMR profiles across the section suggest a high probability of moderate to high water contents in the potential resource area, and in the underlying saline Renmark Formation aquifer. Borehole geophysical logs (e.g., GW036839, Figure 4) generally show a sharp increase in conductivity at the Calivil/Renmark interface, although gamma logs generally lack any large spike that might indicate the presence of low hydraulic conductivity, clay-rich sediment capable of acting as an aquitard. The generalised hydrostratigraphic relationships shown in Figure 4 are seen in each of the potential groundwater resource areas (Figure 3).

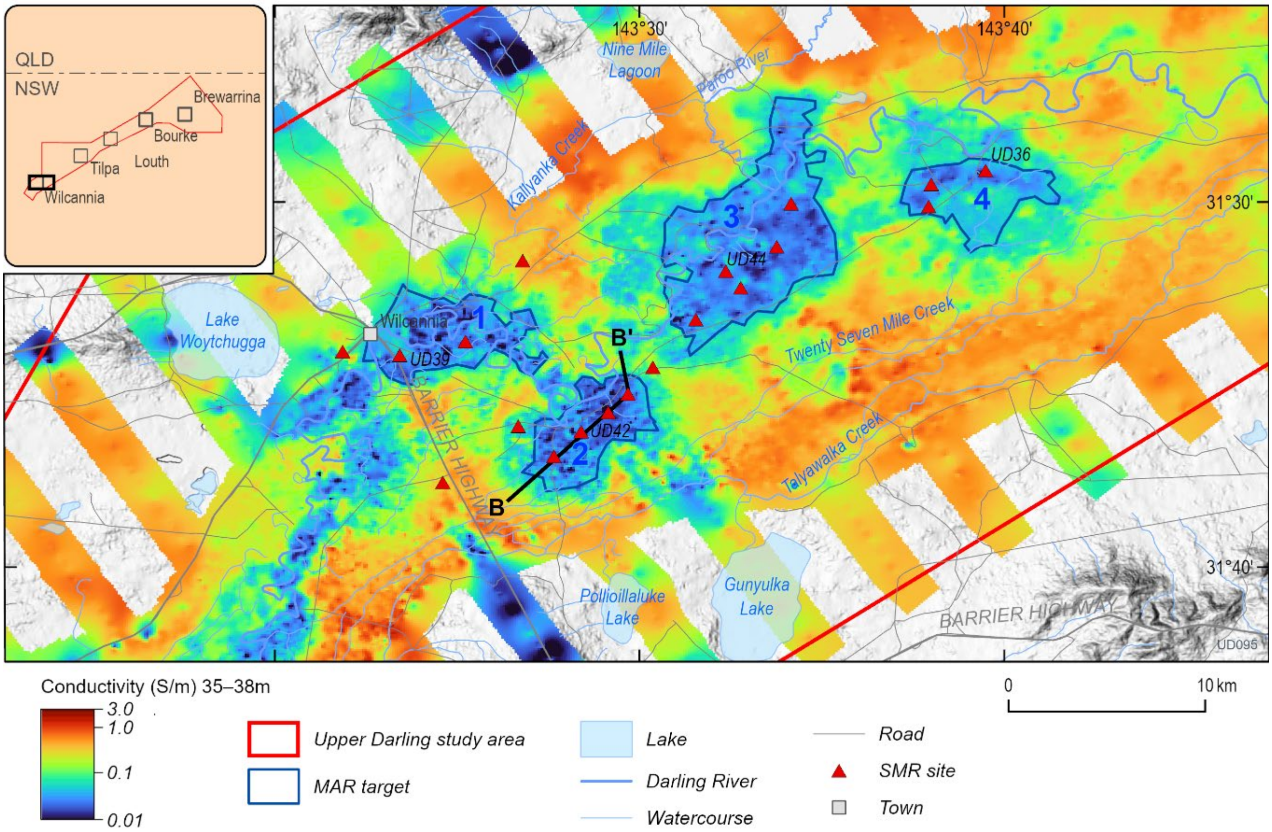

Figure 3. AEM conductivity grid for the depth interval 35–38 mbgl in the Wilcannia area showing the extent of four potential groundwater resource areas defined using a conductivity threshold of 0.06 S/m. Surface magnetic resonance (SMR) measurements sites are marked. Background is hill-shaded 1 s SRTM DEM (Gallant et al., 2011).

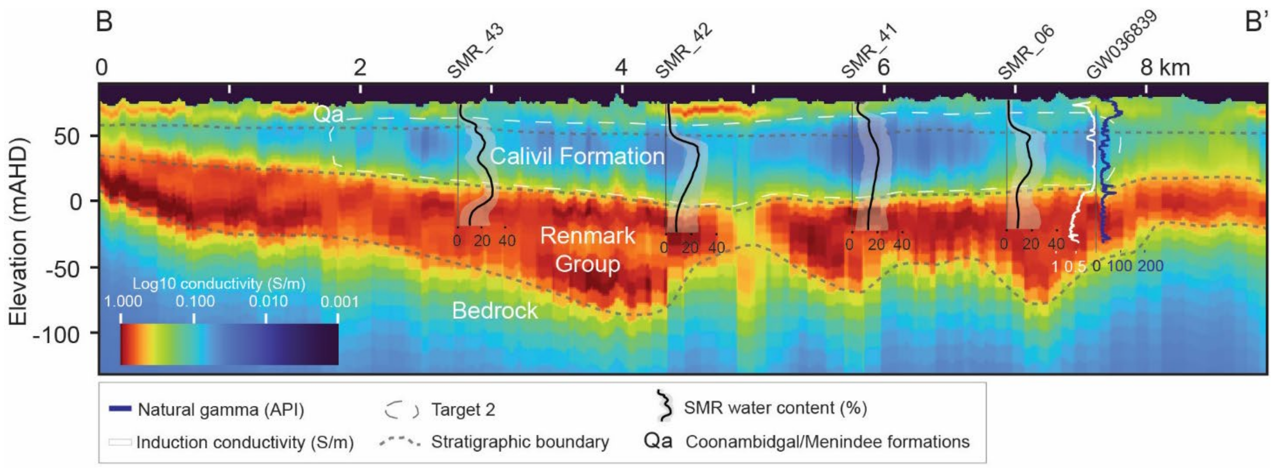

Figure 4. AEM conductivity depth section through potential groundwater resource area 2 (line B–B' in Figure 3) with stratigraphic unit interpretation, SMR total water content (%) profiles (line = median; shading = 90% credible interval), and conductivity and gamma logs for borehole GW036839. Approximate cross-sectional area through Target 2 is outlined and highlights the low conductivity, high water content area associated with the Calivil Formation and parts of the overlying units.

CONCLUSIONS

The integrated assessment presented here, which is underpinned by AEM and ground-based geophysical datasets, demonstrates the utility of these geophysical techniques in conjunction with existing geoscientific data for producing high-resolution mapping of the distribution of lower salinity groundwater resources in alluvial sequences, and enabling delineation of highly saline aquifers that may pose a salination risk to streams and/or fresher groundwater. Such information can be used by planners and water managers to assist in understanding future resource availability across a range of Cenozoic alluvial settings (e.g. Murray-Darling Basin), as well as being highly relevant to understanding and maintenance of cultural values and management of groundwater dependent ecosystems.

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