# Joining the dots: How airborne geophysics helps constrain hydrogeological models

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## SUMMARY

Hydrogeological models rely on accurate conceptualisations of groundwater flow in the sub-surface. For this we require an accurate interpretation of the sub-surface, regolith, architecture and definition of preferential lines, and obstacles to, movement of water. Traditionally, this information is acquired through judicious use of groundwater bores, combined with expert knowledge and assumptions based on the understanding of the regions hydrogeology. Flow nets are created from water level data and flow parameters determined from point determinations through pump tests.

Increasingly, geophysics is being used to help define the sub-surface architecture, identify preferential flow lines and constrain the extents of groundwater models. In particular, airborne geophysics (AG) can provide a contiguous image of subsurface features, defined by the technology being used. Thus, airborne magnetics can define pre-existing, buried river channels from the relict iron oxides on some river gravels; airborne electromagnetics (AEM) can define the preferential flow-lines from the higher conductivity of water saturated sediments.

Field mapping and careful calibration of signals is imperative, though this is often an iterative process requiring additional information from new bore holes or cross-comparisons with other technologies.

Examples of where AG technologies have greatly aided the development of groundwater models will be shown from regions in South Australia. Both simple (FLOWTUBE), and complex (MODFLOW), models have been enhanced by using AG data.

**Key words:** Airborne geophysics; hydrogeological modelling; hydrogeology; field calibration

## INTRODUCTION

While the surface hydrological systems can be observed and defined using topographic analysis, groundwater systems, due to their hidden nature, are harder to define. In high-relief fractured rock and in-filled-valley landscapes, groundwater systems usually mirror the surface hydrology. Thus, the surface watersheds are used to define the catchments for aquifers and the extent of these groundwater systems. In low-relief, alluvial landscapes, however, the present-day topography may not be a reflection of the sub-surface geology. Thus, the use of surface watersheds is problematic.

Airborne geophysics is routinely used to describe the sub-surface architecture of geological systems (*e.g.* Lawrie, et al., 2000; Street, et al., 2002), but this has generally been confined to the search for mineral deposits and to discern environmental impacts, such as salinisation. Here I use the spatial capabilities of airborne geophysical datasets to help define the extents of hydrogeological models, help determine the appropriate model to use and constrain the parameters used to define the model variables.

## METHOD AND RESULTS

Previously, we have defined and described the hydrogeological systems associated with salinisation in a number of locations across Australia (Cresswell, 2004; Cresswell & Liddicoat, 2004; Cresswell, et al., 2007). In each case a 3D framework could be developed that described the geophysical parameters on and beneath the surface. These contiguous sets of data allow us to define the vertical and horizontal extents of features and constrain the boundaries of groundwater flow within a system. Using these visualisations, one can then devise an appropriate ground-truthing program that includes drilling and sampling of materials and waters across the area flown with geophysics. The bores also allowed us to complete a series of pumping tests to determine local hydraulic properties of the shallow aquifers. This information is combined with pre-existing bore and pump-test data to consolidate the physical model of the area. From this, one can build a hydrogeological model of the region, populated with data that can be extrapolated between spot locations.

The nature of the subsurface can influence the type of model used. Hence in a region where groundwater flow is tightly constrained by geological features, a simple 2-D model can be employed. In regions where flow is more diffuse, or with stronger vertical and horizontal variability, a model with 3D capability may be preferred.

### JAMESTOWN REGION

In the Mid-north of South Australia, around the town of Jamestown, airborne geophysics (magnetics, radiometrics and electromagnetics) have defined the surface and sub-surface flow characteristics of water within strongly delineated valleys (Figure 1). The subsurface image from magnetics and electromagnetics, however, revealed a discrepancy between current surface flow and sub-surface groundwater flow directions to the NE of the area. This has been used to explain the occurrence and re-currence of salinity in the region, but also defines the true flow-lines when creating a flow-net for a hydrogeological model.

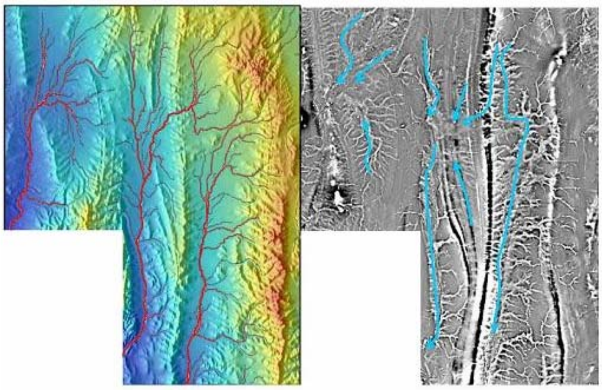

**Figure 1. Comparison of flow lines interpreted from the surface topography (left) and sub-surface magnetics (right). A slightly different drainage pattern is seen for the NE, where the surface drainage cuts through a pass in the ridge to meet with the central stream, while the sub-surface drainage continues south beneath the present-day divide. Note that the drainage patterns have been modelled from a DEM. Surface flow is intermittent and characterised by flooding of the valley floors. Incised channels exist, however, coincident with the modelled channels shown in the left image.**

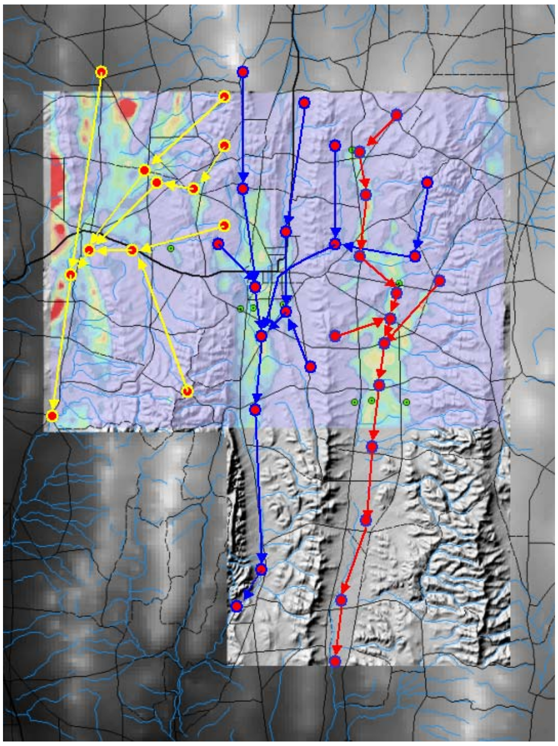

**Figure 2. FLOWTUBE conceptual framework for the area flown with airborne geophysics. Three distinct "tubes" were modelled, each with a series of tubes based on spatial data from the airborne geophysics. Nodes and modelled flow-lines are superimposed over the 15-20m AEM depth slice and the digital elevation model (DEM. Note that overlap of the central (blue) tube and the eastern (red) tube. Green circles mark location where hydraulic parameters were obtained from pump-test on bores. These were used to populate the model's variables.**

From the conceptualisation derived from the airborne geophysics, a series of flow segments can be established, and these become the cells of a hydrogeological model, with nodes marking the input and export points for each cell. Cell dimensions are defined using the extents of the magnetic images in the horizontal sense, and the depth patterns from the AEM for the vertical dimensions. This is illustrated in figure 2. Depth to basement were interpolated from bore data and matched to AEM depth boundaries (Figure 3 *from* Wilford, 2004).

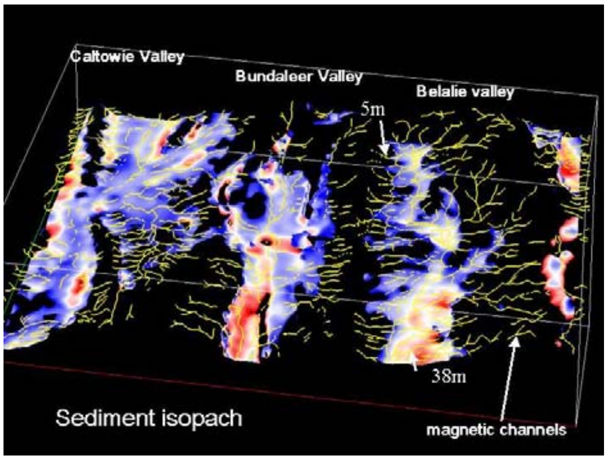


**Figure 3. High conductivity zones in the sub-surface delimit the extent of transmissive sediments, and hence groundwater flow, in the regolith. Sediment thickness is calibrated against drill-hole data (*from* Wilford, 2004).**

Three FLOWTUBE (Dawes, et al., 2000) models were constructed, each representing a single valley exit. Thus, from east to west, we defined the Belalie, Bundaleer and Caltowie tubes. As can be seen from figure 2, there is some commonality between the Belalie and Bundaleer tubes, with the easterly Bundaleer nodes overlying the Belalie nodes.

FLOWTUBE was run for each tube and assessed against existing water table height information, and the known occurrence of salinity outbreaks as indicators of waterlogging and hence where watertables have intersected the ground surface. The models were run under drought, moderate rainfall regime and high rainfall regime to simulate the extremes of climate experienced in the region. In all three valleys, high recharge during wet climatic periods is required to cause sufficient water table rise to induce waterlogging (and salinisation). For the Belalie valley, the system drains sufficiently fast that prolonged waterlogging does not occur at any part of the valley (Figure 4a). For the Bundaleer valley, high recharge will cause waterlogging through the mid-section of the valley (Figure 4b). The Caltowie valley will experience shallow water-tables upstream of a bed-rock high, which has expressed itself as rising damp in the town of Caltowie, and loss of productivity in the adjacent paddocks.

ANGAS BREMER REGION

To the west of the Murray mouth, the Angas and Bremer Rivers periodically drain into Lake Alexandrina, creating a fertile floodplain that has produced premium wine grapes, lucerne and other horticultural crops for over a century. A shift in water use from flood dominated, to groundwater dominated, to surface water dominated has followed

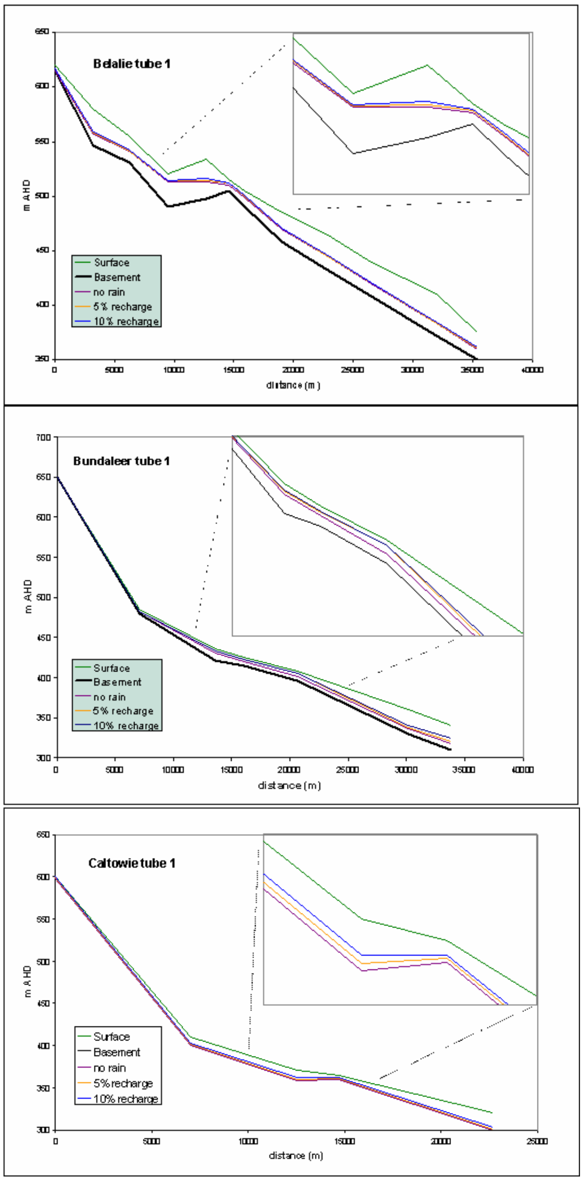


**Figure 4. FLOWTUBE simulations of groundwater heads during drought (no rain), moderate (5%) and high (10%) recharge conditions, for three valleys around Jamestown: Belalie (top), Bundaleer (middle) and Caltowie (bottom). Insets show regions most affected by rising watertables during wet climatic conditions. Only the tube that discharges from the valley is shown. Tributary tubes feed into this tube (figure 2).**

progressive management strategies as the balance of crop-type changed and water conditions dictated. For example, in the mid-1980s, over-extraction of the groundwater resource led to exchange of groundwater licences for surface water ones for many irrigators in the district and extraction from the lake. Accurate figures for the components of the regional water balance have never been satisfactorily derived, as the system is complex, with shallow and deep aquifers, surface-groundwater interaction and poorly-defined sub-surface boundaries. In addition, the region is surrounded by saline groundwaters as it lies at the end of the Murray-Darling Basin and receives input from saline groundwaters from the east.

Airborne electromagnetics have been used to define the extents of the non-saline aquifer beneath the Angas-Bremer Plains (Figure 5).

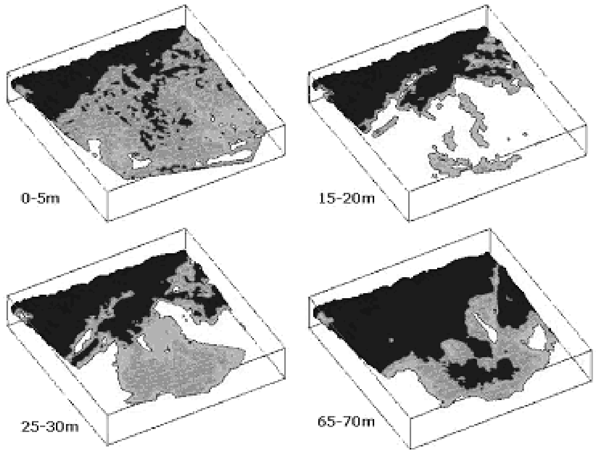


**Figure 5. AEM depth slices beneath the Angas-Bremer Plains. Black represents resistive basement in sub-surface slices and disturbed soils in the shallow slice. Grey represents regions of <200mS/m, which corresponds locally to groundwater below 2000mS/cm salinity. White is >200mS/m and represents both highly saline waters and/or clay-rich sediments.**

Combining this with geological data from existing and new bore holes (Gibson, 2004) allows us to define the groundwater system with a high degree of certainty and, particularly, locate sub-surface structural features that influence groundwater movement (Figure 6). In addition, geochemistry of the waters constrains mixing and surface-groundwater interactions, allowing us to further define the interaction between shallow and deep aquifers and the recharge mechanisms operating in the region.

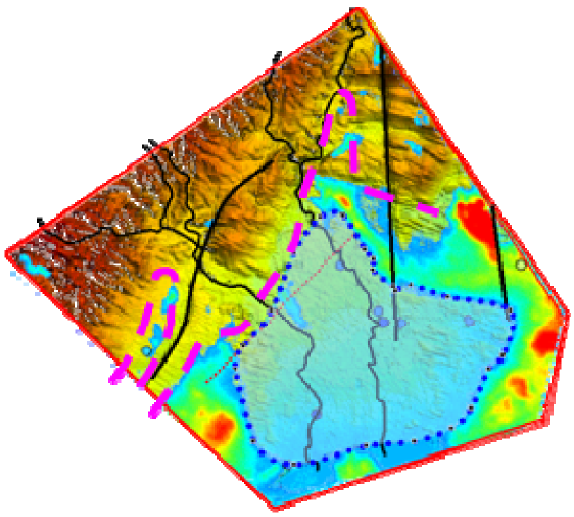

**Figure 6. Interpreted hydrogeological features of the Angas Bremer region. Pale blue marks the limits (at 30m depth) of good aquifer water. Pink dashed line marks the geological boundary of the deep aquifer sediments. Black lines indicate sub-surface faults that constrain water movement. More saline waters are shown as red. The DEM and river channels are also shown.**

The complexity of the region requires that a 3D model be developed. A MODFLOW model of the region has been developed using the parameters defined from the airborne geophysics, an is currently being calibrated.

## CONCLUSIONS

Airborne geophysics is a useful adjunct to traditional field techniques when developing groundwater models. The digital elevation model that is generated almost as a by-product of the airborne survey, is a critical layer for surface and groundwater models, and is often at a resolution better than existing DEMs. Magnetic data can help define both deep structural elements in the sub-surface, and also shallow features such as palaeochannels, which delineate preferential flow paths for groundwater. Airborne electromagnetics highlight regions of greater water content, but this requires accurate field checking as water content, pore space, salinity and clay content all contribute to the resistivity signal. The contiguous nature of airborne surveys, however, can indicate where groundwater flow is prevalent and can provide some depth information on water-bearing sediments.

Airborne geophysics helps determine the complexity required for a hydrogeological model. Thus, for the relatively simple system outlined by magnetics and AEM in the Mid-north or South Australia, a 2D block model satisfactorily modelled the groundwater system to provide the information needed to guide salinity management. In the more complex region of the Angas-Bremer Plains, near the Murray mouth, however, a 3D model was required, and airborne geophysics provided spatial context to develop a MODFLOW model for the region.

It should be stressed that targeted ground investigations were required in both cases to provide both confidence in the spatial patterns seen by the geophysics, and validation in terms of physical parameters relevant to hydrogeology, such as lithology, hydraulic conductivity and calibration of depth determinations.

## ACKNOWLEDGMENTS

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