INTERPRETING AIRBORNE ELECTROMAGNETIC DATA AS AN ADJUNCT TO HYDROGEOLOGICAL INVESTIGATIONS: HONEYSUCKLE CREEK CATCHMENT, VICTORIA

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INTRODUCTION

An interpretation of airborne geophysical datasets for Honeysuckle Creek catchment in north central Victoria (Figure 1a and b), has been carried out in conjunction with the application of conventional hydrogeological techniques. Integration of existing bore data and substantial fieldwork with airborne geophysical coverages has been directed towards understanding groundwater and salinity processes in the region.

STUDY AREA

The airborne geophysical survey area encompasses the edge of the Riverine Plain of the Murray-Darling Basin and fringing uplands. This includes the northern flanks of the Strathbogie Ranges, composed of the Violet Town Volcanics and the Strathbogie Granite, and outliers of weathered fractured Silurian metasedimentary bedrock which make up the arcuate range of the Caniambo Hills. The Riverine Plain within the study area is composed of Quaternary Shepparton Formation fluvial and lacustrine alluvium. These sediments onlap the gentle northern slopes of the Caniambo Hills and also infill a deep structural trough that underlies the Violet Town Plain—the Honeysuckle Graben—located between the Strathbogie Ranges and the Caniambo Hills (Figures 2 and 3).

The distribution of Groundwater Flow Systems (GFS) in the area conforms to the geologic and topographic elements. The respective bedrock and associated colluvial GFS are local to intermediate in scale (green and blue GFS in Figure 2). The Riverine Plain here is part of the large regional alluvial GFS (yellow GFS in Figure 2). A considerable degree of interconnectedness is indicated between adjacent bedrock and alluvial aquifers (English *et al.* 2004). Saline outbreaks are common in the break-of-slope zone at the base of the Strathbogie Ranges and in topographically low-lying areas where the Riverine Plain abuts the Caniambo Hills in Sheep Pen Creek, Earlston and Kialla East sub-catchments (Figures 2 & 3). Saline discharges to streams and swamps are also a concern.

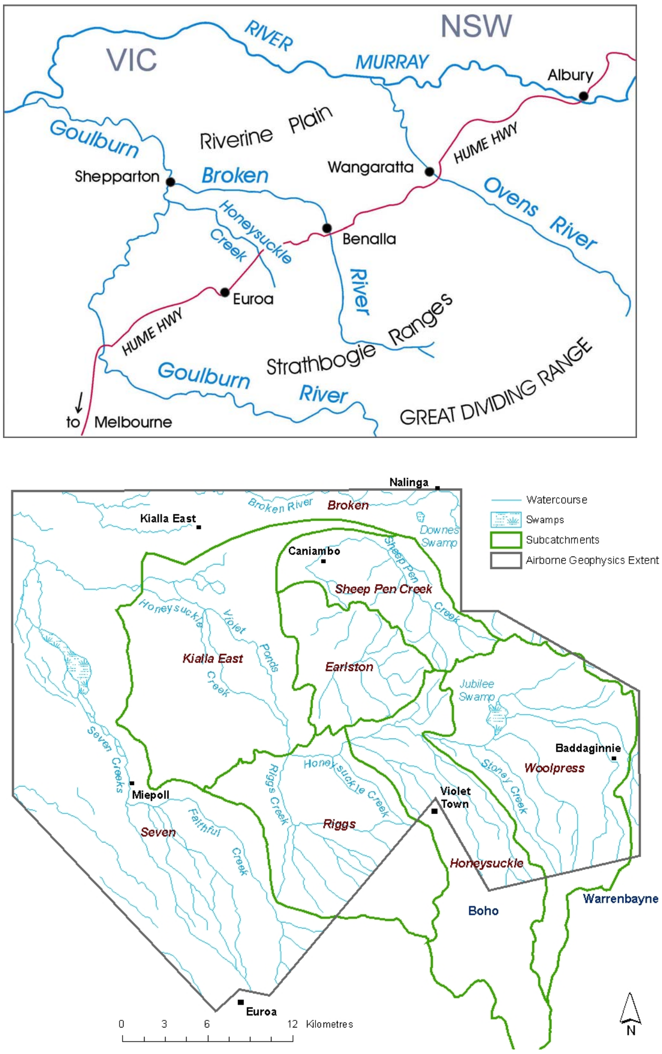

Figure 1a (top): Location of Honeysuckle Creek in northern Victoria; and, **b (bottom)** a map of sub-catchments in Honeysuckle Creek catchment and the extent of the airborne geophysics survey.

AIRBORNE GEOPHYSICAL DATASETS

High-resolution airborne magnetic, gamma-ray spectrometry (radiometric) and airborne electromagnetic

(AEM) data were utilised for the investigation. The AEM was flown with the TEMPEST system (Lane *et al*. 2000, Brodie, 2002). Prior to interpretation, the AEM data were calibrated against down-hole conductivity measurements and reprocessed to provide imagery of the distribution of the range of bulk conductivities of the substrate in *x*, *y* and *z*-space (Christensen 2004a, 2004b). Previous interpretations of the Honeysuckle AEM data utilised the original, uncalibrated datasets (Dent 2002, Dent *et al*. 2002). The radiometric and magnetic coverages for the area were previously interpreted by Gibson & Wilford (2002), Dent (2002) and Dent *et al*. (2002). Integration of groundwater data was limited in these initial interpretations. Figure 4 shows the AEM conductivity depth image (CDI) for the 0-5 m depth slice of the survey area.

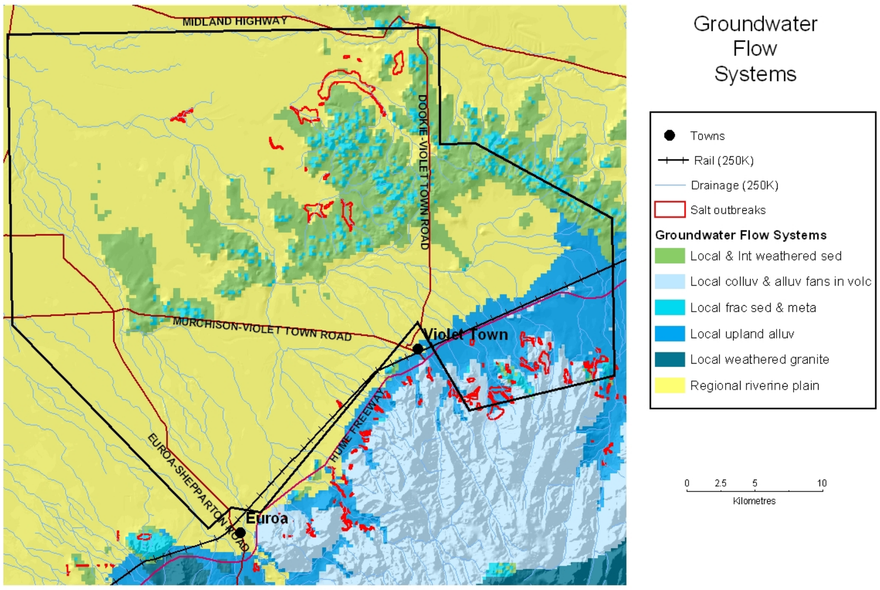

Figure 2: Groundwater Flow Systems (GFS) of the Honeysuckle Creek study area [Primary Industries Research Victoria, PIRVic, DPI]. Mapped saline discharge areas are shown as red outlines.

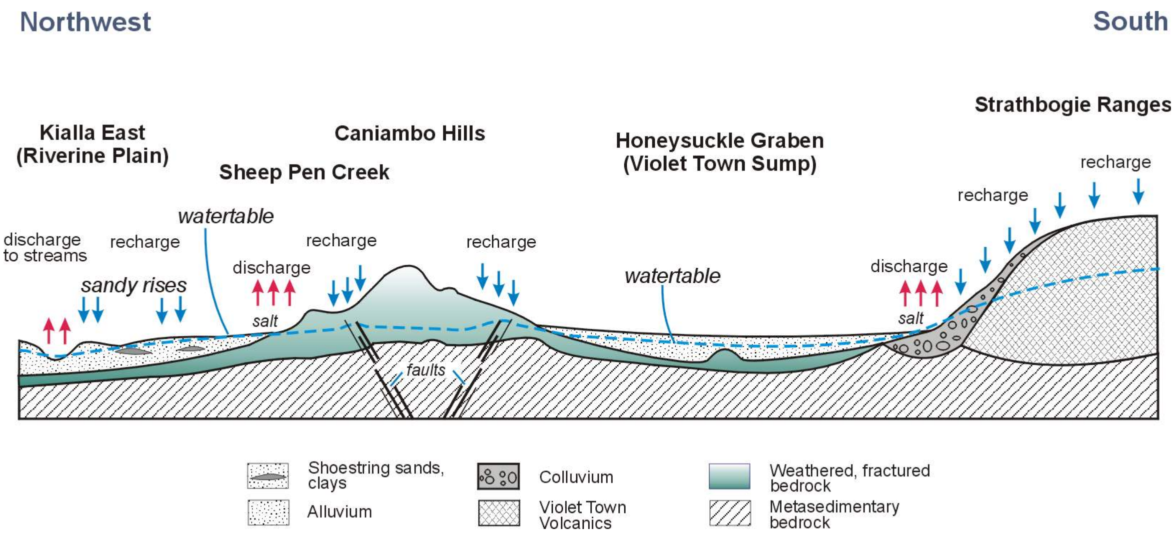

Figure 3: Schematic representation of the main groundwater processes in the Honeysuckle Creek catchment, modified after Cheng & Reid (2001).

KEY FINDINGS

Substantial salt stores are present in the unsaturated and saturated zones of the weathered, fractured metasedimentary rocks and associated regolith of the Caniambo Hills. Groundwaters throughout the fractured bedrock GFS are very saline (typically half seawater salinity). The magnitude of stored salt in the unsaturated zone has been assessed through drilling, field measurements (down-hole EM-39 conductivity profiles) and laboratory analysis (Electrical Conductivity ($EC_{1:5}$) measurements on drill-hole samples). Moderate to high salt stores are present in alluvium/colluvium that fills subtle valleys incised into the metasedimentary bedrock (e.g., small valleys in the western Caniambo Hills depicted as red in Figure 3). These are proximally derived clays sourced from the eroded bedrock hills. In contrast, salt stores in fractured bedrock beneath erosionally scoured hill-crests tend to be low compared to the intervening valleys.

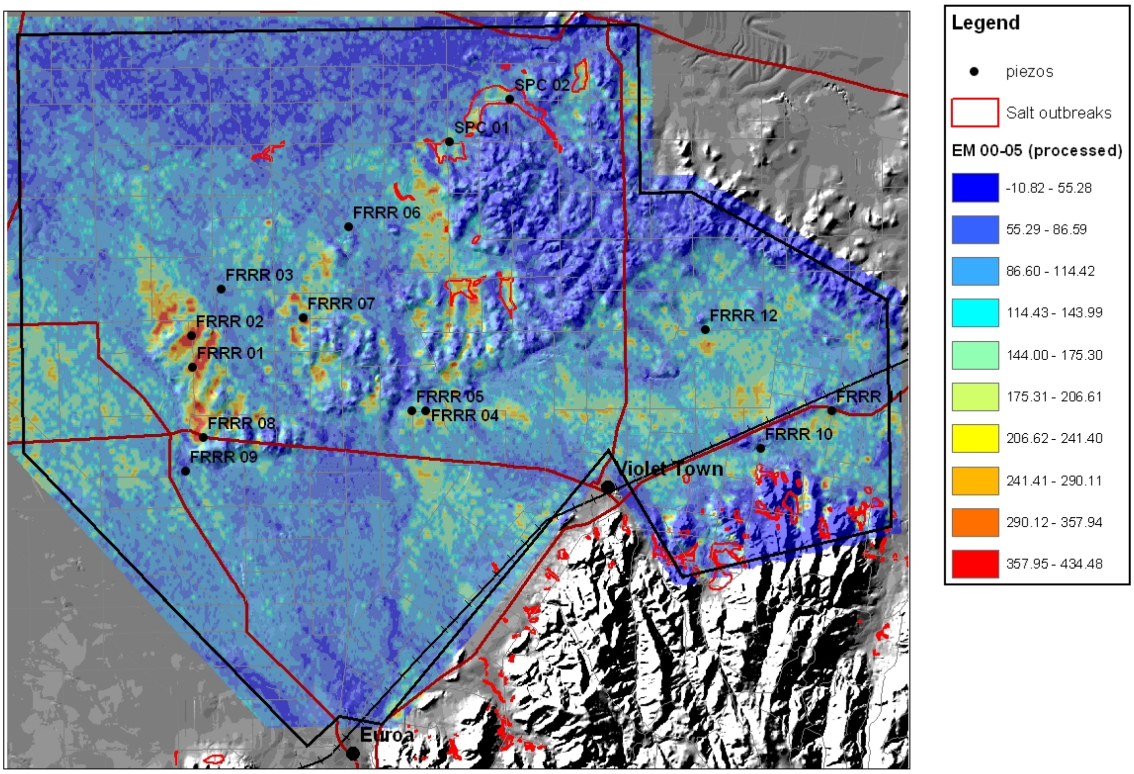

Figure 4: AEM image (calibrated, reprocessed, 2003) for the 0-5 m CDI, draped on a greyscale Digital Elevation Model (DEM) of the survey area. High conductivity = red = >350 mS/m; low conductivity = blue = <150 mS/m. Mapped salt exposures are indicated as red outlines. The Strathbogie Ranges are to the south of the survey area, the arcuate Caniambo Hills stretch east-west across the centre of the area. Also shown are drill-holes sunk by CSIRO in 2002-2003: SPC01 & 02 (Sheep Pen Creek) and FRRR01-12 (Foundation for Rural and Regional Renewal), documented in English *et al*. (2004).

The extent and severity of groundwater salinity is indicated in a groundwater salinity contour map (Figure 5a) and groundwater flow directions (Figure 5b) constructed from data for approximately 100 bores in the study area. These data strongly correlate highly saline groundwater with the fractured bedrock GFS of the Caniambo Hills. High salt levels in the groundwater originate from high salt stores in the unsaturated or previously unsaturated zone. These salts largely accumulated through transpiration processes over very long periods and were flushed from the unsaturated zone to the watertable via fracture and fault networks or other permeable pathways in the bedrock (English *et al*. 2004).

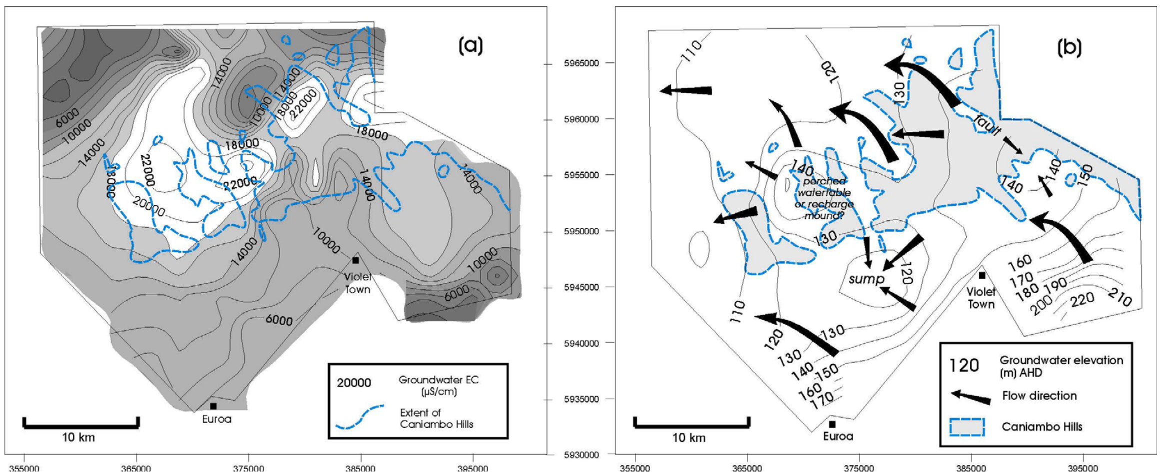

Figure 5a (left): Groundwater Electrical Conductivity (EC) contours showing a strong correlation of saline groundwater with the Caniambo Hills fractured bedrock GFS; **b (right).** Elevation of the watertable (m AHD) and interpreted groundwater flow directions.

Resident salts in the unsaturated zone of the Caniambo Hills are variably identified in the AEM. Highly conductive alluvium is well-expressed but pervasive highly saline groundwater in the fractured bedrock GFS is poorly represented (Figures 3 and 6). Magnetic channels and buried palaeochannels (defined by magnetic gravels) are clearly depicted in the airborne magnetics data (e.g., Total Magnetic Intensity, TMI, underlay in Figure 6). There is a correspondence in *x-y* space between these channels and high bulk conductivity; the latter, however, relates to clay-rich saline alluvium in the channels, rather than to the magnetic gravels which make up only a few percent of the sediments of the valley infill.

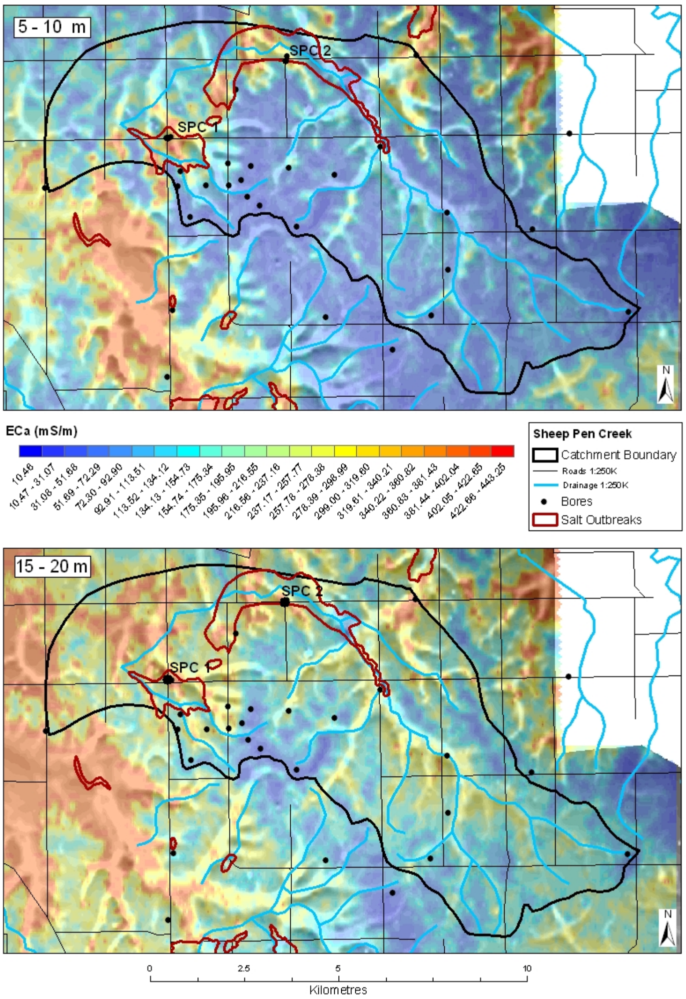

Figure 6: AEM images for the 5-10 m and 15-20 m CDIs for Sheep Pen Creek sub-catchment (outlined in black) and the adjacent Earlston sub-catchment to the south, overlain on the greyscale airborne magnetic (TMI) image. Mapped salt outbreaks are shown as red outlines. Pervasive, highly saline groundwater in fractured bedrock of the Caniambo Hills in the main upstream and headwater (southern and eastern) parts of the sub-catchments—green GFS in Figure 2—is not well-identified in the AEM data (blue areas). Onlapping highly conductive alluvium of the Shepparton Formation in the lower reaches of the main creeks (Riverine Plain sediments—yellow GFS in Figure 2) is well-represented in the AEM images (red anomalies in the northern and western parts of the displayed area).

Poor representation in the AEM of widespread saline groundwater in the fractured rock GFS is most likely attributable to a low water/rock ratio and to the fine-scale of the fracture networks and low inter-granular porosities in the bedrock. Isotopic analysis of the groundwaters sampled from the bedrock GFS of the Caniambo Hills and the base of the Honeysuckle Graben indicates considerable antiquity and long residence times, up to many thousands of years (English *et al.* 2004). Prolonged pre-settlement periods of salt accumulation in the regolith via transpiration processes are also indicated. Elsewhere in the study area—the break-of-slope salinity sites at the base of the Strathbogie Ranges and in topographically low-lying areas of the Riverine Plain—salt accumulation is attributable to contemporary evaporative concentration of solutes in the capillary fringe of the very shallow watertables as well as to the legacy of past and currently active transpiration processes accumulating salt in the unsaturated zone.

Poor detection by the AEM of pervasive saline groundwater in fractured bedrock aquifers has previously been noted for the Kamarooka area near Bendigo by Edwards & Webb (2003). In both cases—Honeysuckle Creek and Kamarooka catchments—conductive alluvium of the Quaternary Riverine Plain is well represented in the AEM data but not highly saline groundwater in subjacent and adjacent Palaeozoic bedrock. This finding may have implications for salinity investigations involving airborne geophysical surveys in other fractured Palaeozoic bedrock provinces around the edges of the Murray Darling Basin.

The overall research findings underscore the importance of integrating the use of all remotely sensed datasets with drilling and field and laboratory analysis, and with as many supporting datasets as can be acquired for a given area under investigation. *System understanding* (of given catchments) and *process understanding* (of the underlying causes and mechanisms of landscape and waterway salinisation in wider regions) are equally important. The need to establish the relationships between landscape and hydrology in three dimensions is emphasised. This framework needs to incorporate knowledge about temporal behaviour (the fourth dimension), including the antiquity of salt stores and groundwater residence times. The latter requirement includes an appreciation of the magnitudes of hydrologic disequilibrium (surface water inputs/outputs and groundwater recharge/discharge) and salt disequilibrium (salt inputs/exports) in given systems, and spatial and temporal variations that relate to climatic drivers.

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