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## **Extended Abstracts**

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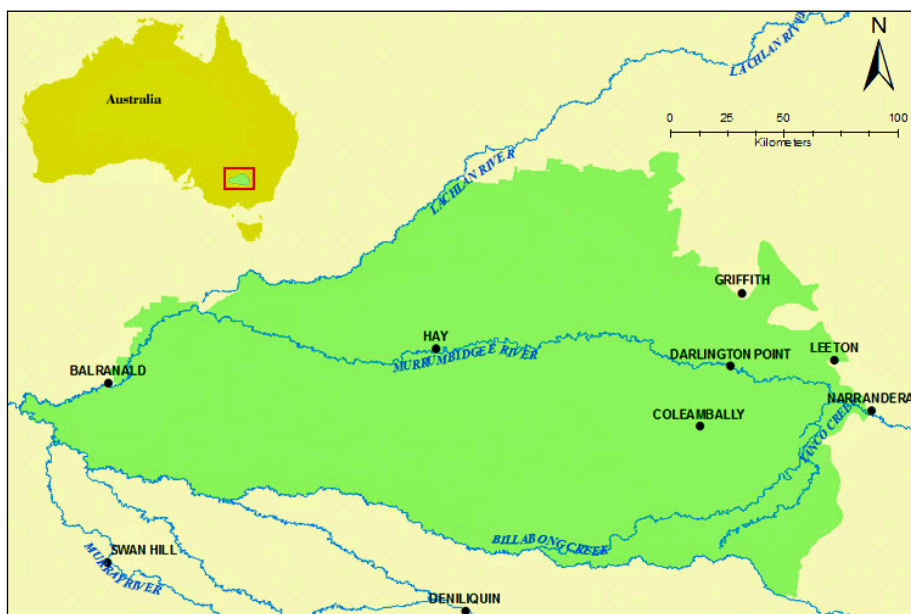
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## INTRODUCTION

The semi-arid Lower Murrumbidgee region of Australia's Murray Basin (Figure 1) comprises unconsolidated, flat-lying, fluvio-lacustrine, regolith aquifers produced during Cenozoic weathering of the Lachlan Fold Belt, with the shallow and deep aquifer systems separated by a clay aquitard (Brown, 1989). Over the last century the Lower Murrumbidgee has been subject to extensive agricultural development, with irrigation water sourced from both the Murrumbidgee River and regional aquifers.

Historically, vertical gradients between aquifers were small, limiting the flux of salt from the saline shallow aquifer into the fresher deep aquifer. However, changes in the vertical gradient ( $dh/dz$  up to 0.2 m/m) attributed to irrigation, groundwater extraction, and the recent period of below-average precipitation present a potential for saline water intrusion into the deep aquifer system.

This paper summarizes the results from the first part of a three-year study of groundwater dynamics in the 33,000 km<sup>2</sup> Lower Murrumbidgee region. Bore hydrographs and environmental tracer concentrations measured in over 250 surface water and groundwater samples are reviewed for evidence that the altered hydraulic gradients have enhanced leakage of saline groundwater into the deep aquifer and to assess if regional salt fluxes are influenced by the presence of the aquitard windows identified by Timms and Ackworth (2002).



**Figure 1.** The Lower Murrumbidgee groundwater management area within Australia.

## METHODOLOGY

Field work was conducted during several field trips between March 2009 and May 2010. Samples were collected from surface water bodies and aquifers across the region, with sampling concentrated around the two major irrigation areas: the 6,600 km<sup>2</sup> Murrumbidgee Irrigation

Area (MIA) located near Leeton and Griffith; and the 790 km<sup>2</sup> Coleambally Irrigation Area (CIA) located near Coleambally.

Groundwater samples were collected from discrete, aquifer-specific monitoring bore nests. Agricultural production bores (data not presented) screened across multiple units were also sampled in the MIA and CIA. Monitoring bores were sampled using a submersible pump set at the mid-point of the bore screen. Groundwater temperature, pH, EC, dissolved oxygen, and redox potential were measured in the field using calibrated Orion Three-Star meters and electrodes and, prior to sampling, monitoring bores were pumped at a constant flow rate until measured parameters stabilized. Samples from production bores were collected from the bore discharge point following a minimum of 30 minutes of operation. Initial grab samples of surface waters were collected adjacent to the channel bank in March 2009, followed by a ten-site river transect from Balranald to Narrandera in January 2010. During the 2010 event samples were collected from multiple depths in the channel thalweg, including a grab sample from the top 20-40 cm and 1-2 additional samples collected at depth using a 2 L Niskin bottle. An aliquot of water from each production bore and surface water sample was analysed for field parameters.

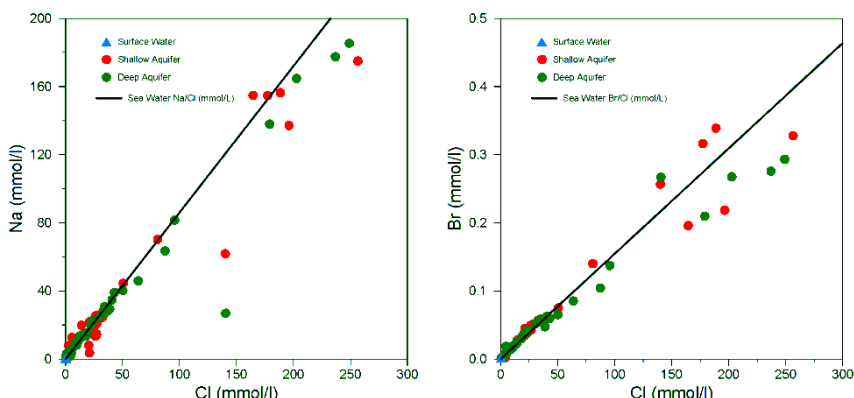
All water samples were field-filtered using 0.45 µm cellulose nitrate filters, and field analysis of alkalinity was conducted by acid titration using a Hach digital titrator and methyl-orange indicator. Select samples were field analysed for ferrous iron and sulphide using a Hach portable spectrophotometer. Samples for cations, anions, and <sup>2</sup>H/<sup>18</sup>O analysis were collected in HDPE bottles filled to minimize headspace and refrigerated until analysis, with duplicates collected every ten samples. Cation samples were preserved to pH < 2 using 50% HNO<sub>3</sub>.

Major, minor and trace cation and anion concentrations were measured at the Research School of Earth Sciences at the Australian National University, Canberra. Cations were analysed using a Varian ICP-AES and Varian ICP-MS, and anions were analysed using a Dionex ion chromatograph. Uncertainties in ion concentrations are estimated to be ±5%.

Oxygen and hydrogen stable isotopic ratios were measured by isotope mass spectrometry at GNS Science, New Zealand. <sup>18</sup>O analyses were conducted on CO<sub>2</sub> equilibrated with water at a constant temperature, and <sup>2</sup>H analyses were conducted on H<sub>2</sub> produced via reduction of water samples in a chromium injection furnace. Stable isotope ratios are expressed as deviation from Vienna Standard Mean Ocean Water (VSMOW) in parts per thousand (‰). Uncertainties are estimated to be ±0.1 ‰ for <sup>18</sup>O and ±1 ‰ for <sup>2</sup>H.

## RESULTS AND DISCUSSION

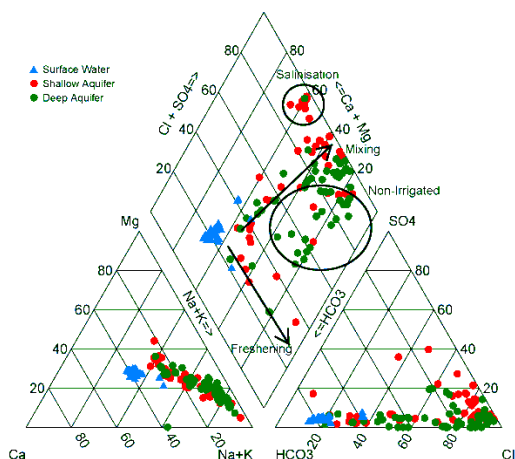
The results show a strong correlation between chloride and the other major ions (Figure 2) in surface water and groundwater samples, following a marine-like trend. However, the terrigenous sedimentary aquifers were deposited in a freshwater environment and modern groundwater recharge is via leakage from the Murrumbidgee River and lateral inflows from adjacent catchments, with irrigation return flow substantially contributing to recharge of the shallow aquifer in cultivated regions. Given the fresh water environment, combined with regional groundwater ages (Drury et al., 1984) which indicate that several pore volumes have been flushed from the aquifers since their deposition, it is unlikely that connate sea water accounts for the observed groundwater composition.



**Figure 2.** Scatter plots of sodium and bromide versus chloride in surface water and groundwater samples showing a marine-like signature in ion ratios for Cl concentrations less than 100 mmol/L.

The marine-like ratios are consistent with other catchments within the Murray Basin (Herczeg et al., 2001; Cartwright, Weaver, 2005; Petrides et al., 2006), which have resulted from mixing of evapoconcentrated meteoric and irrigation water with regional groundwater, modified by ion exchange, water/rock interaction, and precipitation of silicate clays, with the linear Br/Cl relationship (Figure 2) indicating that dissolution of halite (NaCl) is not a significant source of dissolved solutes.

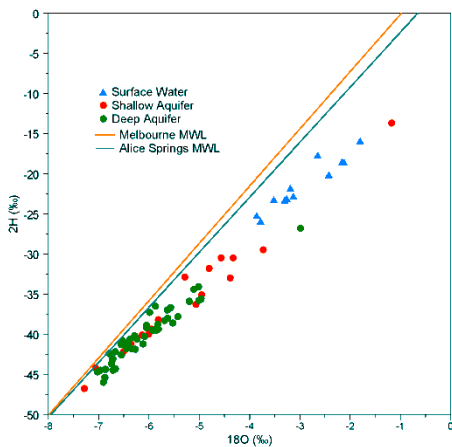
Major ion proportions for groundwater samples collected from monitoring bores follow a few constrained trends (Figure 3). In irrigation areas, groundwater compositions reflect a trend of mixing between fresh Ca-Mg-HCO<sub>3</sub> type groundwater with more saline Na-Mg-Cl type groundwater, whereas samples collected outside of the irrigation areas plot below the mixing line indicating water rock interaction and ion exchange are the dominant processes controlling groundwater composition.



**Figure 3.** Piper plot of surface water and groundwater samples. Groundwater samples collected from depth-specific monitoring bores.

A few groundwater samples collected adjacent to surface water channels show ionic ratios consistent with aquifer freshening, indicative of groundwater recharge from the Murrumbidgee River and major irrigation canals, while evidence of aquifer salinisation is seen in groundwater samples collected from a region with historically pronounced groundwater mounding where the water table was less than 2 m below grade.

A groundwater mixing trend is also apparent in a plot of  $^2\text{H}$  vs.  $^{18}\text{O}$  (Figure 4). Groundwater samples plot along a trend line (slope  $\sim 4.3$ ) parallel to, but displaced from, summer surface water samples (slope  $\sim 4.7$ ). Neither the surface water nor the groundwater trends are consistent with meteoric water lines measured for coastal (Melbourne) or inland (Alice Springs) locations in Australia which reflects either a markedly different local meteoric water line or the effects of evapoconcentration, the latter of which is most likely given the positive correlation between total dissolved solids and  $^{18}\text{O}$  (not illustrated).



**Figure 4.**  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  values (VSMOW) in surface water and groundwater samples. Meteoric water lines for Melbourne and Alice Springs plotted for comparison.

## SUMMARY AND FUTURE RESEARCH

Outside of the major irrigation areas, groundwater compositions indicate that there is a gradual regional prograde hydrogeochemical evolution from  $\text{Ca-Mg-HCO}_3$  to  $\text{Na-Cl}$ , resulting in deep groundwater with a relatively light  $^2\text{H}/^{18}\text{O}$  signature. In the irrigation areas, however, this gradual evolution is punctuated by mixing of fresh regional water and more saline, isotopically heavier waters, indicating the recent enhancement of vertical gradients has increased the flow of saline groundwater from the shallow aquifer into the deep aquifer.

The difference in salinity between the irrigation areas and non-irrigated areas can be used to estimate the additional salt loading occurring as a result of the modified hydraulic gradients. Future research will include high-frequency sampling of select monitoring bores to identify seasonal trends in leakage, as well as isotopic measurements (e.g.  $^{14}\text{C}$ ) to further constrain leakage rates across the aquitard and to refine historical groundwater age estimates.

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