Salt and Water Flux in an Arid Zone Intermittent River: The Role of the Floodplain Environment

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Abstract: Exchange between the surface water and local groundwater systems in intermittent rivers is not well understood, however the ecological functioning of these riverine environments can be dependent on the degree of interaction between the two domains. Spatial and temporal changes in the isotopic ($\delta^{18}O/\delta^{2}H$) and major ion composition of the floodplain aquifers in the lower reaches of the intermittent Diamantina River, South Australia, along with hydrologic data and sedimentary analysis, are used to identify localized groundwater recharge following flow events. The approximately synchronous response of groundwater levels to surface water events over two years (encompassing the recession of one major flood involving substantial floodplain inundation and two smaller events) particularly in near channel locations, indicates connectivity between surface water and local groundwater systems. The increase in $\delta^{18}O/\delta^{2}H$ values and decrease in the salinity of groundwater <100m from the river subsequent to major flooding indicates event recharge of the shallow alluvial aquifers. Over time, groundwater compositions return to more saline and isotopically depleted values, considered here to be base conditions. Groundwater salinity and isotopic compositions of the mid and outer floodplains varied little over the course of the study period despite flood inundation and change in groundwater head. Sedimentary analysis of the predominantly silt and clay floodplain surface indicates the potential of these soils to develop seals and thus limit infiltration of flood waters. Thus event recharge was limited to near bank areas or zones of preferential infiltration over the course of the study period. CFC dating and isotopic data give some indication that sustained recharge to the floodplain groundwater system occurs during successive large flood events or wet years.

Keywords: infiltration loss, arid rivers, groundwater recharge, chemistry, isotopes.

1. INTRODUCTION

The exchange between the surface water and floodplain groundwater systems in the intermittent rivers of central Australia is not well understood. The ecological functioning of these river systems can, however, be dependent on the degree of interaction between these two domains. For example, the health of riparian vegetation can rely on the degree of floodplain inundation and unsaturated zone infiltration. Where shorter periods of floodplain inundation can encourage the germination of annual vegetation and continued health of deeper rooted vegetation, prolonged flooding and deep drainage can result in high rates of shrub mortality due to anoxia [Capon 2002]. Similarly, groundwater to surface water exchange can be either beneficial to an aquatic ecosystems by contributing to the hydrological persistence of a water body or be detrimental if the groundwater input is of an unsuitable salinity. In salinity studies, understanding the degree of surface water recharge to the groundwater system forms an important water and salt balance component.

Generally, the exchange between surface water and groundwater can be described by hydrologically based transmission loss models that partition surface water losses into groundwater recharge, return flow and unsaturated zone storage and other processes (terminal surface storage, transpiration and evaporation). However, in areas where only minimal data are available, such models are difficult to develop with a high degree of confidence [Costelloe et al. 2003; Sharma and Murthy 1995; Sorman and Abdulrazzak 1993]. Under these conditions, examination of water chemistry dynamics can greatly improve understanding of exchange processes. Here, chemical and isotopic tracers are used to identify river flow contribution to floodplain groundwater in an intermittent arid zone river system. Specifically, the mechanisms that lead to recharge during flow events (i.e. bank recharge or vertical infiltration following floodplain inundation) and the temporal and spatial variability of these mechanisms are investigated. Recharge to groundwater is identified by changing groundwater levels and commensurate changes in groundwater salinity following surface flow events. The major source of groundwater in the area is also investigated.

1.1 Study site

In this study water chemistry tracers are used to identify localised groundwater recharge during flood events in an intermittent river in the Lake Eyre Basin, central Australia (Figure 1, inset). The study focuses on the floodplain aquifers near two semi-permanent waterbodies, Ultoomurra and Yelpawaralinna Waterholes in the lower reaches of the Diamantina River, which is known locally as Warburton Creek (Figure 1).

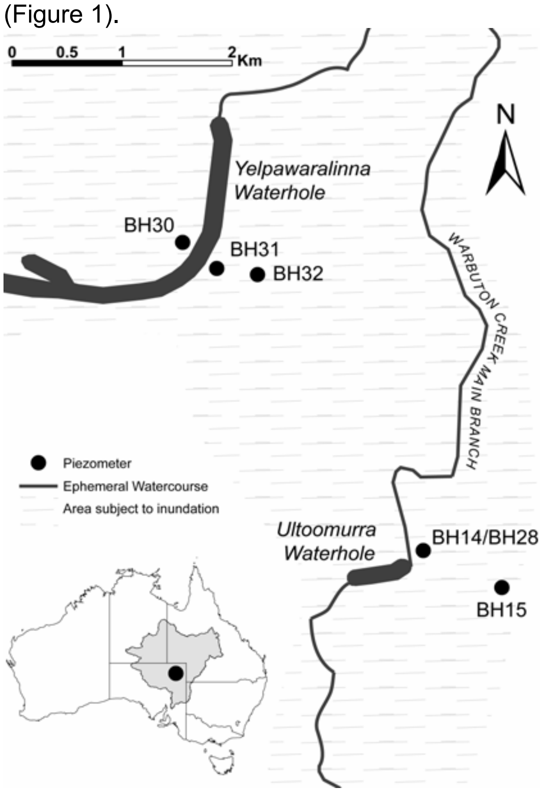

Figure 1: The groundwater monitoring network at the Warburton Creek study area and locality diagram (inset). BH28 has the same depth as BH14 (BH14 decommissioned late 2004).

Ultoomurra Waterhole is located on the main river channel and following flow events this waterhole can increase in salinity to hypersaline levels >100g/L TDS [Costelloe et al. 2005]. The floodplains flanking the waterhole are characterised by a thin cracking clay surface underlain by fine-grained sands. Yelpawaralinna Waterhole is located at the toe of a sand dune (on the north-west bank) on an anabranch of the river and receives flow only from large events. This dune is surrounded by the floodplain sediments. Despite the lower frequency of flushing, Yelpawaralinna Waterhole remains relatively fresh (salinity <2g/L TDS) [Costelloe et al. 2005]. Shallow groundwater in this area is previously unstudied.

2 METHODS

To monitor the response of groundwater to flood events in the study area, shallow piezometers (<12m) were installed at near bank and outer floodplain locations, along a section through the river channels and floodplain (Figure 1). Surface water and groundwater levels and salinity were monitored using capacitance probes or combined pressure-temperature-conductivity loggers. Water samples for major ion (Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, alkalinity) and isotopic (δ^2H, $\delta^{18}O$) analysis were taken at six monthly intervals over the two-year study period (2004-2006). Opportunistic sampling of bank seeps was also undertaken. Salinity results are reported here as g/L total dissolved salts (TDS), ionic concentrations as milli molar per litre (mmol/L) and isotopic values are reported as permille (‰) relative to Vienna Standard Mean Ocean Water (V-SMOW).

To confirm recent (post CFC production circa 1950) recharge of groundwater, groundwater dating, using chlorofluorocarbons (CFCs) was undertaken at selected locations. The result given refers to the date that the tested water was sealed from further atmospheric interaction (i.e. reached the saturated zone, not the date of rainfall generation).

Examination of floodplain sediments is used to examine any textural controls on recharge. Observations of surface sediment features were made to identify any preferred infiltration pathways (macropores) and sedimentary analysis from drill cuttings were undertaken to examine the potential for clogging or seal development that could inhibit infiltration on the floodplain.

3. RESULTS

3.1 Groundwater and surface water hydrology

The study period captured one major (early 2004) and two smaller (late 2005) surface water events (Figure 2a). The large flood event inundated the floodplain but occurred prior to the installation of piezometers in the study area. Two smaller sub-bankfull events flowed in the main channel only (i.e. not Yelpawaralinna Waterhole) and were captured by both the surface water and groundwater monitoring network. The groundwater response to these events (Figure 2b) is dominated by the initial large event, illustrated by falling head levels in all piezometers. Watertable level response to the smaller sub-bankfull events is identified only in near bank locations (BH14/BH28) and the peak response in the groundwater system occurs 1-2 weeks after the peak of the surface water event.

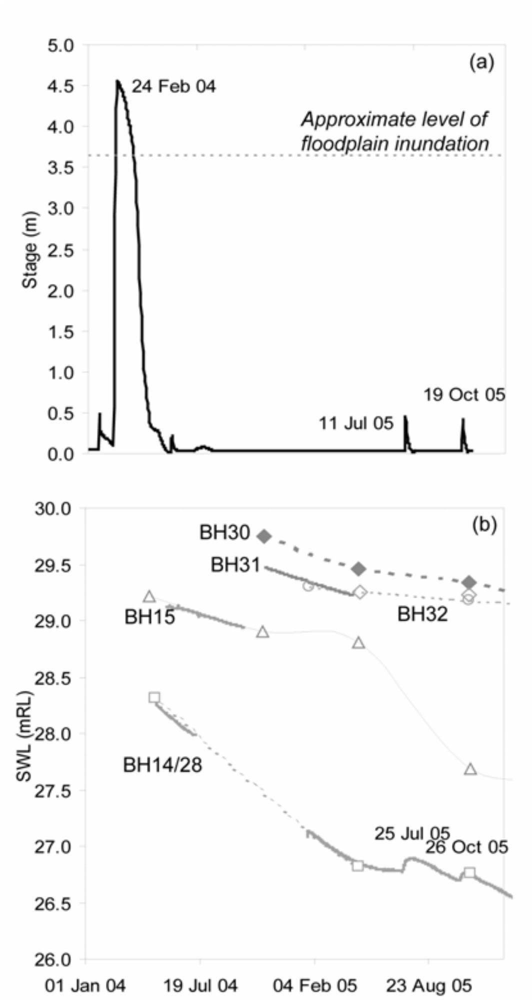

Figure 2: (a) flood and **(b)** groundwater hydrographs for the study period. Solid lines represent continuous logger data, data points represent manual measurement.

Outside these surface flow events, the dominant condition throughout the study period was low or no flow conditions. During these times hydraulic gradients toward Ultoomurra Waterhole prevailed. In contrast, during periods of high flow where the floodplain was inundated, the potential for vertical recharge through the floodplain and flow from the channel to the local groundwater system existed. The near synchronous response of groundwater levels in near channel locations following sub-bankfull events indicates that flow from the river channel to the groundwater occurred during these periods also (Figure 2b).

3.2 Groundwater chemistry

Representative ionic compositions of floodwater and groundwater in the study area are presented in Figure 3a. For clarity, the mean composition for each location is shown. Surface water samples from the recession flow of the large flood event were fresh (<1g/L TDS) and Na-HCO_3 dominated, with a high Na/Cl molar ratio (>1). In contrast, the chemical composition of groundwater across the floodplain is saline (35-50g/L TDS) with a Na-Cl dominated composition and low Na/Cl molar ratio (<1). Although floodplain groundwater compositions and salinities are similar, a slight groundwater salinity gradient (increasing salinity with increasing distance from the surface water system) was maintained over the study period (Table 1).

During the recession flow of the large flood event, bank seepage at Ultoomurra Waterhole was sampled. Ionic data shows the composition of this seep to be fresh and with a high Na/Cl ratio, more similar in composition to floodwater than groundwater. The large contrast in salinity between the bank seep and inner floodplain groundwater suggests the seep is an expression of return flow from bank stores. Bank seepage was not observed on subsequent sampling dates. The only evidence of a sustained fresh water lens associated with the river system was identified at BH30, drilled into the sandy sediments at the toe of the Yelpawaralinna dune. Groundwater at this location is substantially fresher than the floodplain groundwater (1-3g/L TDS), with a Na-HCO_3-Cl dominated composition similar to floodwater.

Isotopic data is presented in Figure 3b. The position of all groundwater samples in $\delta^{18}O/\delta^{2}H$ space is typical of recharging water that is evaporated in the soil zone from a depleted isotopic source, such as rainfall or isotopically depleted floodwater (Figure 3b). Provided that the recession floodwater sampled is typical of floodwater, the isotopic data suggest that floodwater is not the major groundwater source. However, the position of the fresh groundwater at the Yelpawaralinna dune site, relative to sampled floodwater, shows considerable floodwater influence (see figure 3b, inset). The similarity in chemical composition of BH30 to floodwater (<1g/L TDS and Na-HCO_3

dominated), supports the assertion that groundwater at the dune site is at least partially flood derived.

Despite groundwater head response following the large flood event and floodplain inundation, no significant temporal change in salinity or groundwater ionic composition (indicated here by Na/Cl ratios) at the mid and floodplain locations was detected. Changes in groundwater chemistry and isotopic composition occurred only at the near channel locations; the Ultoomurra levee location (BH14/BH28) and Yelpawaralinna dune site (BH30).

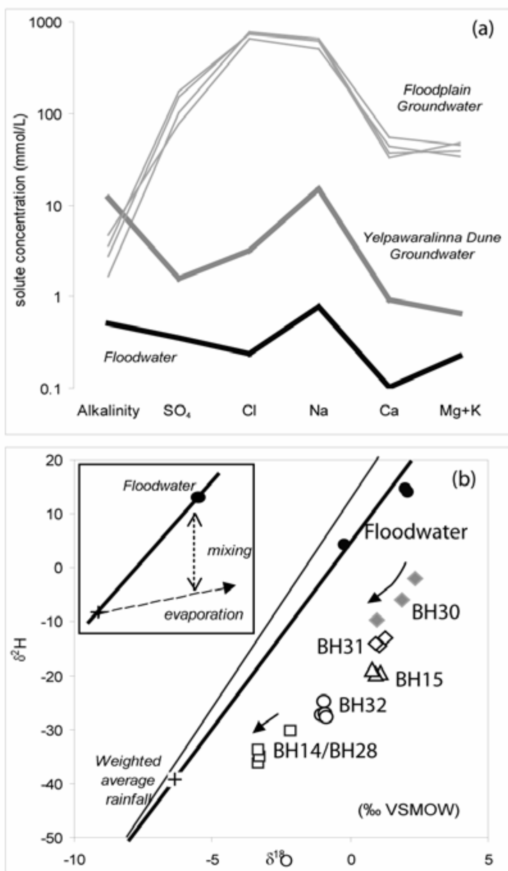

Figure 3: (a) chemical composition of groundwater and floodwater; (b) isotopic composition of floodplain groundwater (thick line Alice Springs local meteoric waterline (LMWL), thin line Brisbane LMWL). Arrows indicate temporal change in groundwater composition. Inset describes process that lead to the position in which samples plot in δ18O/δ2H space.

At the Ultoomurra near-bank site (BH14/28), groundwater following the large flood event of 2004 was isotopically enriched and of lower salinity in comparison to subsequent samples (taken to be background levels). In addition, the Na/Cl ratios of groundwater following the large flood at this location were also initially higher. These temporal changes are consistent with return to background conditions following recharge by event water. Following the sub-bankfull events, no change in the groundwater salinity and isotopic composition of groundwater was observed. Thus, from the bulk salinity and isotope data there is little evidence of recharge at this near stream location following smaller events.

At the Yelpawaralinna Dune site a prolonged response to the large flood event is apparent in the continued change in groundwater chemistry (note this anabranch site did not receive flow from the two smaller events in 2005). Following the event, the groundwater salinity at BH30 continually increases and the isotopic composition becomes increasingly negative. Again, these trends are consistent with a return to base conditions following event recharge. However, the changes in the chemical composition (illustrated by Na/Cl ratios) are contradictory to this assertion, as the ratio continually increases to levels far exceeding floodwater. Possibly these temporal trends could be explained by the intersection of a groundwater lens that is dominated by a fresh soil water input.

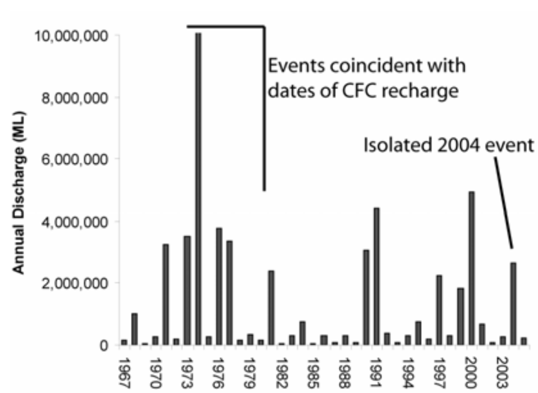

Figure 4: Annual discharge from the Diamantinna River, gauged at Birdsville QLD, 1967-2006.

The chemical and isotopic data presented so far illustrates that following a large flood event, substantial recharge to groundwater, resulting in salinity changes was restricted to near bank locations. CFC dating from both inner and mid floodplain locations however provides evidence of recent recharge across the floodplain at dates consistent with a series of large flood events between 1970 and 1977 (Figure 4, Table 2) indicating that larger flood events, or more consistent flood conditions may result in flood recharge.

Table 1: Selected water chemistry results. TDS results in g/L unless otherwise specified, Na/Cl ratios are molar, - indicates not analysed.

		Apr-May 04	Oct-Nov 05	Apr-May 05	Oct-Nov 05
Floodwater (Ultoomurra)	TDS	261mg/L	-	-	-
	Na/Cl	3	-	-	-
Bank Seepage (Ultoomurra)	TDS	254mg/L	-	-	-
	Na/Cl	2.9	-	-	-
Groundwater					
BH14/ BH28	TDS	36	38	40	41
	Na/Cl	0.85	0.77	0.79	0.80
BH15	TDS	45	-	49	49
	Na/Cl	0.87	-	0.80	0.82
BH30	TDS	-	910mg/L	1.4	1.5
	Na/Cl	-	3.4	4.7	7.2
BH31	TDS	-	41	49	51
	Na/Cl	-	0.84	0.86	0.89
BH32	TDS	-	48	49	49
	Na/Cl	-	0.83	0.86	0.88

Table 2: CFC dating results. Range indicates results from CFC 11 and CFC 12 data. NA – no result returned from CFC-12 data.

Yelpawaralinna Dune (BH30)	1976 -1982
Floodplain (BH32)	1975 - NA

3.3 Infiltration potential

The reason for recharge to groundwater identified over the study period being restricted to near channel locations, despite floodplain inundation, was investigated by examining surficial soil characteristics to establish infiltration potential. Drilling activities confirmed that apart from the Yelpawaralina Dune location (BH30), the wider floodplain is characterised by a thin veneer of clay. This capping is underlain by fine-grained sands and silts with occasional clay lenses. Although preferential flow pathways (macropores) were identified at most floodplain locations, the high proportion of fines (35-50% fines, Table 3) could result in seal development once the crack capacity is exceeded [Singer and Shainberg 2004]. Only at the inner Yelpawaralinna location (BH30) are homogeneous sands likely to facilitate vertical recharge.

Table 3: Result of surfical sediment analysis. – indicates not analysed, % fines refers to clay + silt fraction.

Surficial sediment type		**% fines**
BH15	sandy clay	50%
BH14/ BH28	clay capping, silty sand	35%
BH32	Cracking clays	-
BH31	Sand with clay nodules	-
BH30	Silty sand	-

4. DISCUSSION

The piezometric, chemical and isotopic data presented indicates that event recharge magnitude and mechanisms are dependent on flood magnitude. Change in groundwater head and chemistry consistent with recharge, follow a single large event, however the effects are not prolonged and conditions soon return to base conditions. Small sub-bankfull flows effect near-stream floodplain groundwater levels, however, no coincident changes in groundwater salinity were identified. CFC dating and analysis of water chemistry data study suggest that any significant floodplain recharge following inundation occurs only after large or successive events. This raises the following questions: firstly, why is there a response of groundwater levels to surface water events but no recharge response in the chemical data and secondly, what is the main source of groundwater in the floodplain environment?

In answer to the first part, the response of groundwater levels without a corresponding response from the chemistry could be that the amount of recharge from any of the monitored events is too small in comparison to the groundwater store to make a significant change in groundwater composition. Density differences between recharge water (fresh floodwater) and groundwater (where saline) could explain the absence of mixing between recharge and groundwater. Recharging water would form a fresh lens in the bank stores and when gaining stream conditions return, this unmixed water forms return flow. The similarity in composition of the observed bank seepage to floodwater supports this mechanism. As to the source of groundwater in the absence of regular flood recharge, isotopic data suggest an isotopically depleted source, such as heavy rainfall or an isotopically depleted flood, dominates. Although the CFC result implies that sustained recharge to local groundwater occurs after successive large flood events, it could be that the reported CFC age is an average of all recent recharge weighted to the 1974 event due to the magnitude and longer period of inundation of this event.

5. CONCLUSIONS

Following flow events in an intermittent river, spatial differences and temporal trends in major ion and isotope chemistry in local groundwater, in addition to piezometric head data have allowed better understanding of the complexities of the system than any set of techniques in isolation. The study, which encompassed variable sized events, shows that recharge by surface water following flow events is dependent on flood magnitude. Following a single large event that inundated the floodplain, falling groundwater levels imply a groundwater response; however confirmation of recharge, indicated by changes in groundwater chemistry was restricted to near bank locations and ultimately the effects of event recharge are not sustained. Prolonged effects of localised recharge over the study period are only apparent in locations of sandy, homogenous sediments. Clay rich sediments across the floodplain surface likely inhibit vertical recharge but it is likely that bank recharge is an important mechanism. CFC dating and isotopic data give some indication that sustained recharge to the floodplain groundwater system occurs during successive flood events or wet years.

6. ACKNOWLEDGEMENTS

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