HYDROGEOCHEMISTRY OF HODGSON CREEK CATCHMENT, QUEENSLAND MURRAY-DARLING BASIN

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ABSTRACT
The majority of rivers in the Murray Darling Basin (MDB) export more salt than they receive via rainfall or inflow. This is generally ascribed to the change in water balance following clearing and agricultural development. The transfer of salts is generally treated as a hydrological problem, with electrical conductivity (EC) assumed to represent salt load. We use the Hodgson Creek, a 3rd order catchment in the Queensland MDB, to evaluate the efficacy of this assumption and make comment on the simplified notion of EC as a proxy for salinity in surface and groundwaters.

Hodgson Creek exports 9000t/a, or 16t/km^2/a; comparable to some of the higher exporting catchments of the southern MDB. Unlike most rivers in the southern MDB, EC in Hodgson Creek groundwaters is dominated by non-chloride salts (mostly sodium bicarbonate). Magnesium is also high, from weathering of the regional basalts. Salt export is dominated by infrequent, large flood events of low salinity, raising the issue of the significance of salt load when describing salinity impacts and end of valley targets.

The hydrogeology of the area can be represented as three groundwater flow systems. Flat-lying, Jurassic coal measures and sandstones are overlain by layered Tertiary basalts, with unconsolidated alluvium filling valley floors.

Of more than 1400 bores sunk in the area, only 21 are used for routine monitoring. About 500 have geochemical data and 200 are pumped for irrigation. We use chemistry and isotopes to help define the groundwater flow systems and the groundwater attributes required for modelling groundwater and salt movement through this catchment using reactive transport modelling.

We compare groundwater chemistry with stream base-flow and examine the significance of this for salinity studies and end-of-valley salinity determinations. We quantify the groundwater component and use equilibrium mass balance reactions to estimate the evolution of waters through the regolith.

INTRODUCTION

Whilst netting about 40% of Australia's farm-gate income, the Murray-Darling Basin (MDB) remains under threat from the effects of dryland salinity, particularly in the south, with about 25% of Victoria's agricultural land in the MDB, and 10% in New South Wales, under direct threat. In Queensland, less than 5% of agricultural land in the Queensland MDB (QMDB) is directly affected; consequently research into the causes and mitigation of dryland salinity has largely focussed on southern catchments. There is also a common misconception that there were little, or no, salinity issues north of the state border prior to this century (NLWRA, 2001; Cullen, 2006).

The different climatic regime for the north of the MDB has also been cited as a reason for subdued salinisation north of Armidale (QDNR, 1997). Thus, while the south of the basin receives dominant rainfall in winter months, when evapotranspiration is low and recharge potential is high; the north of the basin receives the bulk of its precipitation in high intensity events during the summer, when ET is high. This results in increased runoff and reduced potential recharge for the QMDB.

A consequence of this regime is that water–tables in the south of the basin have responded rapidly to land-use changes, and now contribute significantly to surface flow in many catchments (gaining streams) whilst many northern rivers remain disconnected from underlying deeper watertables and hence are losing streams. This is reflected in the salt output:input ratios (O/I) determined for rivers across the basin (Jolly *et al.* 2001). Annual input from cyclic salts in rainfall can be compared to annual export via stream flow, measured at gauging stations throughout the basin; high O/I reflects systems where there is a salt imbalance, generally as a result of human intervention through clearing and/or irrigation activities, and input from shallow groundwaters. A

large number of catchments higher in the landscape in Queensland are also gaining streams and commonly also export more salt than they receive via rainfall. Hodgson Creek is one of these, exporting 4 times as much salt each year than it receives.

Hodgson Creek catchment

Hodgson Creek exports nearly 9,000 tonnes of salt a year (16 tonnes/ha/a) from a catchment of 566 km^2 (Silburn *et al.* 2006). It has been chosen as a useful case-study catchment as it has a long and well-documented history of settlement and development; it has good stream flow data from a number of gauging stations (including electrical conductivity (EC) and some chemical data); there are sporadic outbreaks of salinity in the catchment; it represents a major landscape type for the Condamine catchment, a major tributary of the Darling; a large proportion of the landscape is given to cropping (51%) and cleared pasture (27%) and it is close to a regional office of the Queensland Department of Natural Resources and Water (QDNRW) at (Toowoomba!

The catchment can be sub-divided into 3 main geological units (Willey 1992). The majority of the catchment is underlain by Main Range Volcanics: Tertiary olivine basalts with inter-bedded sediments. The Jurassic age Walloon Coal Measures underlie the basalts and outcrop over about 100 km^2 in the SW of the catchment. They contain medium- to fine-grained sandstones, shales, coal and mudstones. Quaternary alluvium occurs in the valley floors and at the Condamine confluence.

Stream discharge data

Stream flow, salinity and water chemistry were measured from 1987 on-wards at Balgownie, near the confluence with the Condamine River (McNeil and Silburn 2005). Hourly auto-sensor readings of electrical conductivity (EC) are available since 1993; major ion chemistry was measured for all 180 events between 2002 and 2004, plus an additional 40 measurements collected between 1987 and 2002 (Figure 1). Two distinct populations can be discerned: samples dominated by groundwater input (EC ~1500-1800 $\mu S/cm^2$) and those dominated by overland flow (EC <1000 $\mu S/cm^2$). Pure base flow only occurs at very low discharge (<0.01 m^3s^{-1}), but considerable information on the groundwater component can be gleaned if we can discern the relative proportions of groundwater and surface flow for higher discharge events.

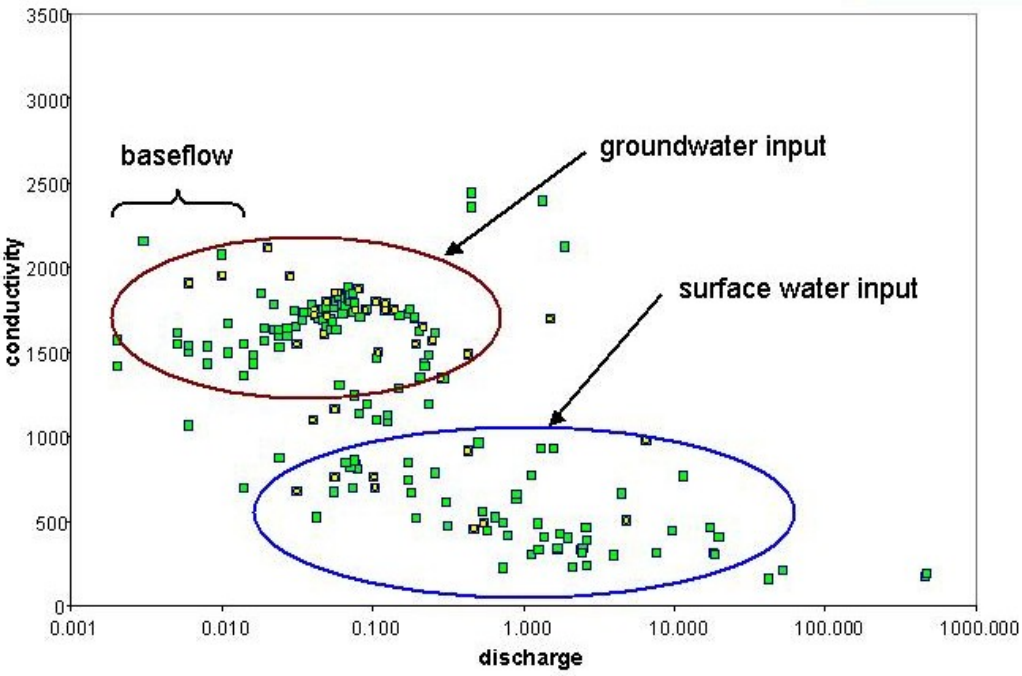

Figure 1. Discharge ($m^3.s^{-1}$) : conductivity relationship for the Hodgson Creek. Note the distinction between groundwater (baseflow) and surface water components, and baseflow defined by discharge.

Measured EC correlates well with total dissolved ions (TDI)(McNeil and Silburn 2005), so we estimate total salt load being discharged and note that 2 surface-water events exported 25% of the total salt load for a period of 18 months, in only 1% of the time. The average stream salinity was thus only 300 $\mu S/cm^2$; hence stream salinity is generally not an issue, except during the large flushing events that remove salts

concentrated in the near-surface following prolonged evaporative concentration. Using programs such as 2Csalt (Littleboy *et al.* 2005), there has been some success in modelling this discharge (Stenson *et al.* 2005).

HYDROGEOCHEMISTRY

General remarks

Of more than 1500 bores in the catchment, 478 have been sampled for major and minor element chemistry, some more than once, giving 688 analyses. Only 29 bores, however, have any time series water level data (Silburn *et al.* 2006). Sampling has been discontinuous since 1975, and most bores are completed in the basalts or shallow alluvium. Commonly, bores have been screened across multiple aquifers, making inter-aquifer distinction difficult. The bulk of the waters are of Mg-Na-HCO_3-Cl type, reflecting the influence of the basalt host-rocks. Curiously, the most Na-Cl-rich waters are found in the upper slopes of the catchment, while bicarbonate waters dominate lower slopes, in contrast to that seen in catchments in the south of the MDB (e.g. Cartwright *et al.* 2004).

Methodology

To help understand and quantify the input of surface and groundwaters to stream flow, we sampled 15 bores from Umbiram Creek, a tributary to Hodgson Creek, for chemistry, stable and radiogenic isotopes and CFCs. We also sampled the creek at a local gauging station site. Comparison of the chemical data with the complete Hodgson Creek dataset revealed that this represents a sub-set of Hodgson Creek waters. In general, the waters are bicarbonate-rich, with salinities varying from 300 to 1300 mg/L TDI.

Stable isotope data indicate that the groundwaters were recharged predominantly from slightly evaporated rainwater. The creek sample also plots on the same trend, so we cannot tell whether this represents groundwater discharge, or evaporated surface flow.

QUANTIFYING SURFACE-GROUNDWATER INPUTS TO STREAM DISCHARGE

The Umbiram groundwater samples allow us to examine a single flow path from the catchment boundary to the catchment outlet (Figure 2). Watertable height decreases from 517 m to 426 m AHD over a distance of about 25 km, giving a hydraulic gradient of 0.003. Additional bores feed this path from the east and west of the creek. Water level data from bores along the catchment divide suggest additional flow may cross beneath the topographic catchment divide. The salinity of the groundwaters increases down-gradient, increasing confidence in the continuity of the flow path (Figure 2).

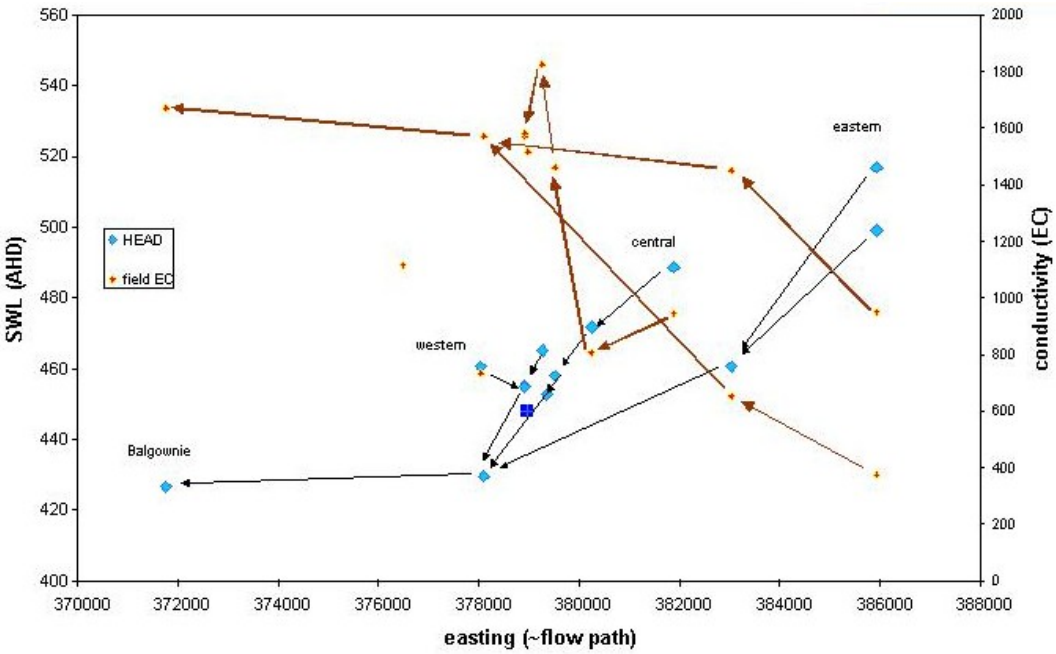

Figure 2. Watertable heads and conductivity along flow paths from the catchment divide to the catchment mouth, along Umbiram Creek.

Radiocarbon : bicarbonate mass balance

Radiocarbon determinations were corrected using the procedure for an open (CO_2) system (Fontes and Garnier 1979). Stable carbon isotope ratios ($\delta^{13}C$) show little variation (~ -11‰$_{PDB}$) across the area, suggesting

a similar process affects all samples, thus corrections may change absolute, but not relative, values. Corrections indicate that most samples are too young for an age determination (<100 years), but variability in the ^{14}C activity allows us to use ^{14}C as a tracer of groundwater movement. A single sample from a deep homestead bore does give a low ^{14}C concentration and may represent the mean age (~20,000ka) of deeper regional groundwaters in the coal measures beneath the basalts. Other isotopes (δD, $\delta^{18}O$, $\delta^{13}C$, ^{222}Rn) from this sample were also different to the other waters.

Radiocarbon concentration may be used with bicarbonate concentrations to estimate the proportions of mixing between different end-members. Whilst absolute end-members are difficult to establish, we may use samples along the flow path to estimate the contribution of different reaches to the final discharge site at the catchment mouth. Specifically, the bore located at the catchment mouth exhibits a mixture of carbon from 2 distinct sources (Figure 3), one corresponding to bores located along the river; the other from bores located away from the river, up the valley slopes.

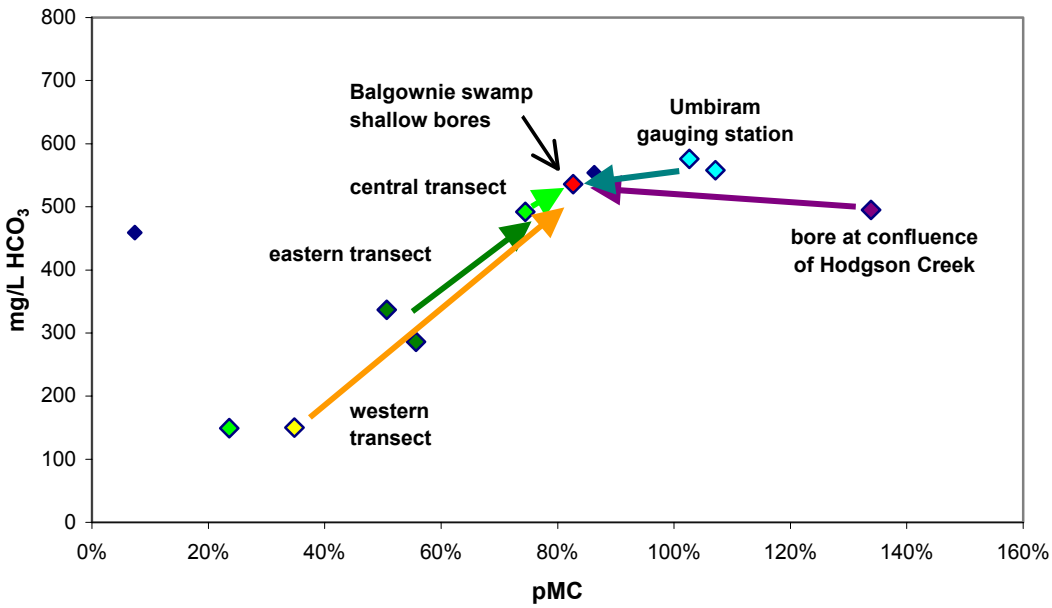

Figure 3. Radiocarbon (pMC) variability within the Umbiram flow-line. Note that high values (modern signature) are from bores located on the creek alluvial terrace. These bores also contained measurable concentrations of CFCs, indicating a component of the waters less than 50 years old. Plotting against bicarbonate concentration shows that the groundwaters at te discharge of the catchment are composites of waters from shallow recharge (high ^{14}C) and deeper groundwaters (low ^{14}C). Relative contributions can be calculated (Table 1).

Calculations for the relative ^{14}C and bicarbonate contributions from different water sources to the waters discharging from the catchment are given in Table 1. Three deep (within the basalt aquifer) flow paths are examined under 2 scenarios: 1) assuming surface water input from creek waters at the location of the Umbiram gauge, and 2) assuming input 5 km downstream at the confluence with the main Hodgson Creek channel. Values observed in bores in alluvium are taken as proxy for surface water recharge. For an Umbiram source, we calculate 66% mass input from groundwater originating from the catchment divide and 34% from surface water infiltration. If all groundwater was derived from the eastern hills, then 35% can be accounted for from groundwater; if from the west, then 29%. Alternatively, if substantial surface water input occurs further downstream, with substantial input from Hodgson Creek waters, we find groundwater plays an greater role (by 10%) at the catchment mouth. In other words, either more groundwater contributes from beneath Hodgson Creek, or the groundwaters beneath Hodgson Creek have a much lower ^{14}C signature than those of Umbiram. Future sampling will aim to resolve this. This information is then be used to partition groundwater and surface waters between different 'buckets' in salinity models such as 2CSalt (Silburn & Owens, 2005; Stenson, et al., 2006).

Table 1. Relative contributions of surface water to groundwaters at the exit of Hodgson Creek, assuming different end members for surface water input.

Groundwater input flow-line	Surface water input from Umbiram gauging station	Surface water input at RN42231597 (at confluence of Hodgson Creek)
Central	34%	26%
Eastern	64%	55%
Western	72%	64%

CONCLUSIONS

Hodgson Creek, in the QMDB, appears to export as much salt as similar-sized catchments in the southern MDB. Investigation of the flow and salinity relationships of discharge events, however, reveals that export is dominated by a few large volume events that flush the shallow system, while average flows carry relatively low amounts of salt, and this salt is bicarbonate-dominated and hence of minimal salinity threat.

Two main contributors distinguish stream discharge: a higher salinity (up to 1500 EC) groundwater component and a fresher (<1000 EC) overland flow component. Without EC data, it is not possible to distinguish these two components from discharge data.

Ground and surface waters are bicarbonate-rich, although the chloride: bicarbonate ratio increases slightly as total dissolved salts increases. This can be compared to a similar trend seen in an analysis of over 30,000 surface waters across Queensland (McNeil and Cox 2000).

Sporadic and non-sequential measurement of water levels across the catchment is further complicated by pumping for irrigation, and reduces confidence in establishing flow-nets for the catchment. A transect of bores within the Umbiram Creek sub-catchment were sampled to give a coherent set of data for chemistry and isotope measurements. This created a picture of groundwater movement and surface-groundwater interaction and we calculate the contribution of each component to the discharge waters of the catchment through simple carbon mass balance. Thus, we use radiocarbon and bicarbonate concentrations to estimate the relative amounts of shallow and deep groundwaters that pass through a bore at the mouth of the catchment. We find that the groundwater contribution varies along the flow-lines, but we can see the contribution from groundwater associated with the main arm of Hodgson Creek.

We may now use chemical data to estimate water-rock interaction and surface-groundwater interaction in the unsaturated zone. In addition, calculation of groundwater input to the surface discharge needs to be completed.

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