

# The role of surface hydrology in planning salinity mitigation strategies

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**ABSTRACT:** Understanding of runoff and salt mobilisation processes at the sub-catchment scale remain generalised or vague in environments similar to the Eastern MDB. Given the requirement for the community to meet stream water quality targets, an improved understanding of processes is needed. This study attempts to address this requirement by examining salt and water mobilisation processes in a semi-arid 7.4 km<sup>2</sup> catchment in the Eastern MDB.

Analysis of hydrometric and geo-chemical data indicate that a large proportion of the stream salt load and all of the runoff >200 µS/cm is produced via a small saline scald. End Member Mixing Analysis (EMMA) using geo-chemical tracers indicates that most runoff produced from the scald is "new" water with groundwater and water from the near surface zone making up roughly equal proportions of the remaining runoff. However, because of the extreme salinity of the near surface zone, it is responsible for nearly the entire salt load mobilised from the scalded area. This study highlights the importance of the near surface zone within saline scalds as source of salt to the river system, and may mean that management of these areas will have significant impacts on stream salinity.

Land use change on the non-saline parts of the catchment intended to reduce deep drainage could not be recommended because of possible detrimental effects on stream water quality in the short and medium term. If similar processes are apparent in other catchments of the area, best management practices for stream salinity may need to be reformulated.

## INTRODUCTION

The eastern Murray Darling Basin (MDB) has been identified as a large contributor of salt to MDB river systems (Jolly et al., 2001), yet little is

known regarding the processes of runoff generation and salt mobilisation in this area.

A lack of data at appropriate scales has meant a reliance on simulation at broad scales (eg, (Albert et al., 2004; Herron et al., 2003). These

approaches do not examine within catchment processes, or rely on highly parameterised, distributed models (Beverly et al., 2005). Models with the exception of the most simple will suffer from problems associated with parameter uncertainty (Beven, 1989; Beven, 1993).

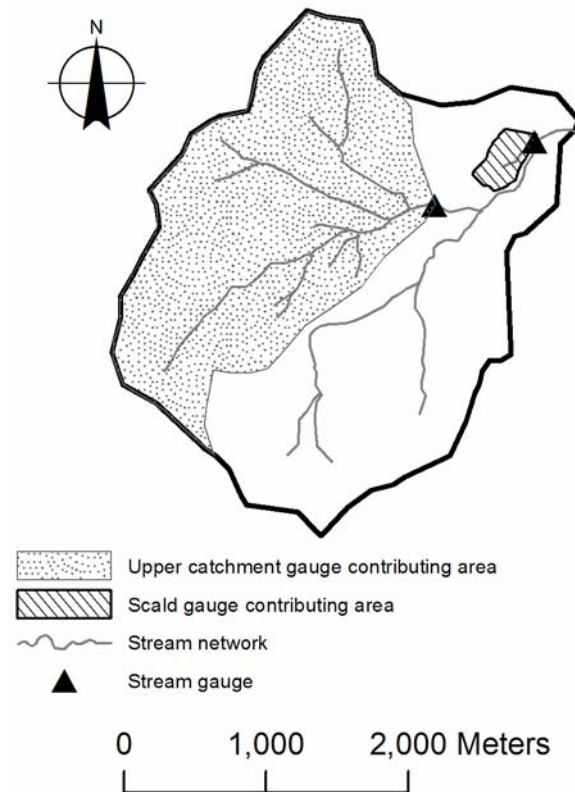
Using any approach, the need for more experimental data on runoff generation and salt mobilisation at a range of scales is apparent. This is especially true considering that “best management practice” to meet downstream salinity targets in the MDB is already being implemented.

This study aims to improve knowledge of the important runoff and solute transport processes occurring at the sub-catchment scale, utilising hydrometric and geochemical methods in a semi-arid headwater catchment in the eastern MDB. Hydro-chemical data is used to quantify the contribution of salt to runoff from identified geographic zones within the catchment

## METHODS

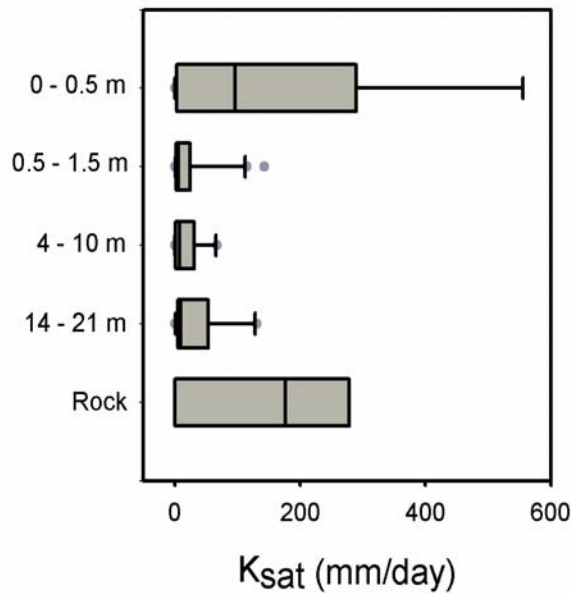
### Site characteristics

Brays Flat Creek Catchment (BFCC) is a headwater catchment in the northern portion of the Mandagery Creek catchment (33°04'S, 148°36'E), which is located in the north-east of the Lachlan River catchment (Figure 1). It is 7.4km<sup>2</sup> in area and land use is predominately agricultural. Steeper rockier parts of the catchment retain the original native vegetation, consisting mainly of *Callitris sp.* and *Eucalyptus sp.* The remainder of the catchment is utilised for agriculture, and consists of winter crops grown in rotation with annual and perennial pastures. The catchment features a small (~10 ha) saline scald near the catchment outlet (figure 2). This coincides with the area where the permanent ground water surface is closest to the ground surface (~1.2m). From this point onward “groundwater” refers to the permanently saturated zone and does not include seasonally or event saturated zones. The creek draining BFCC is ephemeral and usually ceases to flow within 4 days of a runoff event.



**Figure 1 Brays Flat Creek Catchment showing gauged areas and stream network**

The most common soil type in the BFCC catchment is Yellow Sodosol (Isbell, 2002), and occupies most of the arable area in all but the northern and eastern portions of the catchment. Subsoils are highly dispersive using the Emerson dispersion test (Loveday and Pyle, 1973). A horizon depth for Yellow Sodosols ranges from 20 – 60 cm. A “perched” water table can be observed in this horizon during wetter periods. Lithosolic, Clastic Rudosols and exposed bedrock dominate the ridge and hill tops in the southern and western fringes of the catchment. Litic Rudosols and Salic Hydrosols (Isbell, 2002) are associated with flow lines in the lower part of the catchment. A feature of the BFCC soils and regolith is the very low saturated hydraulic conductivity ( $K_{sat}$ ) (Figure 2).



**Figure 2 Hydraulic conductivity of soil and regolith at BFCC. Boxes show 25<sup>th</sup>, median and 75<sup>th</sup> percentile data**

### Stream gauging

Stream flow and salinity were measured at two points in the catchment to determine water and salt mobilisation processes in two distinct geomorphic zones. One gauge was located in the upper catchment zone, where groundwater is > 14 m below surface level; the second being the scalded area where groundwater was within 1.2 m of the soil surface year round (Figure 1). The upper catchment gauge consists of a 120° v-notch weir fitted with a pressure and Electrical Conductivity (EC) sensor, recording at a 15 minute frequency. Contributing area to the v-notch weir is 3.7 km<sup>2</sup>. The scald gauge consisted of a 0.45m H-flume installed in a small eroded gully that drained the scalded area. It was fitted with a pressure/EC sensor at a recording frequency of 15 min. Additionally, an auto-sampler was installed at the scald gauge to take water samples for later analysis of geochemical constituents.

### End-member mixing analysis (EMMA)

Runoff from the scalded area, along with groundwater and water from the near surface zone (0.05-0.4m below the soil surface) were collected, filtered and acid preserved prior to geochemical analysis.

An EMMA model was developed for the scald area using procedures outlined in the studies by Christopherson and Hooper (1992), Burns et al. (2001) and Hooper (2003). The EMMA model is

used to predict stream flow based on a mixture of identified end-members of importance in runoff generation and salt mobilisation. The steps are as follows;

1. all samples are analysed for the concentrations of chloride, sulphate, sodium, potassium, mono-silicic acid and alkalinity;
2. solute data is standardised into a correlation matrix;
3. Principle Components Analysis (PCA) is performed on the correlation matrix and the number of significant principle components selected according to the procedure of Hooper (2003);
4. end-member solute concentrations are standardised and projected into the mixing space defined by the stream water samples PCA analysis;
5. any stream water data points lying outside the mixing space defined by the end-members is reprojected orthogonally back to the mixing space;
6. for each stream water sample proportions contributed by each end-member are calculated;
7. end-member proportions are multiplied by concurrent stream flow data to allow the stream hydrograph to be separated into its end-member components.

## RESULTS

Rainfall for the measurement period (1/6/2005 - 28/9/2005) was 280 mm. This followed a relatively dry autumn and summer where no runoff was recorded at either gauge site

### Catchment runoff and salinity

Runoff recorded at the upper catchment gauge was much higher than the scald gauge as would be expected given relative contributing areas. However on an areal basis, runoff from the scalded area was higher than the upper catchment area (Table 1)

**Table 1 Runoff and salt export measured at scald gauge and upper catchment gauge**

	Upper catchment gauge	Scald gauge
Total runoff (m <sup>3</sup> )	15720	3460
Total runoff (mm)	4.2	34.6
Salt export (t)	0.7	4.8
Area weighted salt export (t/km <sup>2</sup> )	0.2	48
Flow weighted average EC (µS/cm)	71	2314

EC of runoff from the upper catchment area was very low and exceeded 100 µS/cm only 2% of the time (n = 540). Conversely, median runoff from the scalded area was 8829 µS/cm and was less than 2000 µS/cm at only 2% of observations. (n = 5811). Given this salt export from the scald is much higher than that of the upper catchment area (Table 1)

### Scald hydrochemistry and EMMA model

Three runoff events were sampled and analysed for geochemical constituents from the scald area. The first event sampled was the first runoff event for the year (29 June - 2 July) and had a total rainfall of 33mm. The two subsequent events (7 – 10 July and 12 – 15 July) were smaller with rainfall totals of 19 and 13 mm respectively. The concentration of runoff constituents used for EMMA are summarised in table 2.

**Table 2 Scald runoff solute concentration data**

	Units	Mean	Std. Deviation
Electrical conductivity	µS/cm	3717	1975
Chloride	mg/L	1056	638
Sulphate	mg/L	135	81
Alkalinity	mg/L CaCO <sub>3</sub>	77	34
Sodium	mg/L	467	260
Potassium	mg/L	6.7	1.2
Molybdate	mg/L	14.0	3.7
reactive silica			

The PCA used in the EMMA process included the solutes in table 2 with the exception of electrical conductivity. The first 2 principle components of the scald runoff explained 93% of the variation in runoff chemistry, therefore all water chemistry data including groundwater and near surface water was projected into the space defined by the first 2 principle components.

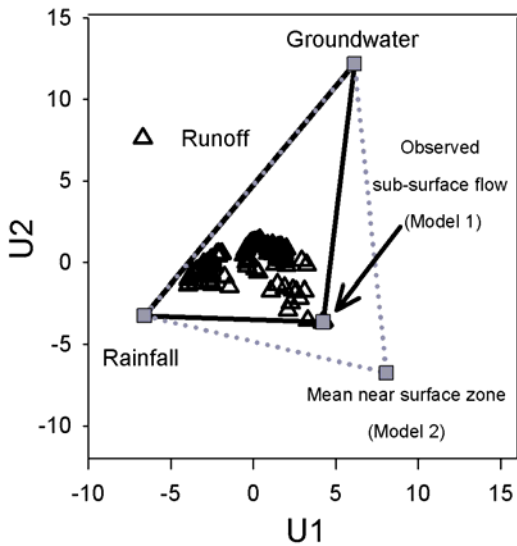
Three end-members were selected that encompassed stream chemistry variability and

were physically possible. Rainfall was selected as one end-member. This was assumed to have zero concentration of all solutes. Groundwater is within 1.2m of the surface year round at the scald, so groundwater was selected as an end-member. Water from the near surface zone is also likely to contribute to stream flow and was selected as the remaining end-member. This zone is seasonally saturated, ie dries out over summer and becomes saturated in winter. The chemistry of the groundwater was very different from that of the near surface zone allowing the influence of each to be identified in stream runoff. The near surface zone (0.05 – 0.4m below surface) had high spatial variation in terms of chemistry, prompting the use of two models to assess how this may affect model results. Two approaches are used here.

EMMA model 1 uses a stream flow observation (deemed to be sub-surface flow). Sub-surface flow was observed on 4 July when all overland flow had ceased. A small amount (~5 L/minute) was still moving through the flume just prior to the cessation of flow. It has been argued that stream flow observations provide a more integrated measure of end-member concentration than point measurements (Kendall et al., 1995; Neal et al., 1997; Soulsby et al., 2003; Wade et al., 1999).

The mean concentration of all samples taken in the near surface zone (excluding those showing groundwater influence) was used to define the mixing space for EMMA model 2. The mixing space for the two EMMA models is shown in figure 3.

End-member contribution to stream runoff was calculated using Model 1 and Model 2 for three consecutive runoff events. Runoff (L/s) at each sampling instant was multiplied by calculated end-member proportion to enable the hydrograph to be separated into end-member components. Chloride export was calculated by multiplying flow weighted end-member contribution to runoff by end-member chloride concentration. These data are summarised in table 3. The most striking result from the hydrograph separation is the high “new water” or rainfall component of flow, while the near surface zone contributes almost all of the chloride to the stream.



**Figure 3 Scald runoff and end-member projections into *U* space defined by runoff chemistry.**

The sequence of end-member influence throughout the three runoff events is plotted in figure 4. All three events show a similar temporal pattern of influence, beginning at the near surface zone, moving towards the rainfall end member at peak flow, then showing some groundwater influence during recession and finally returning to the near surface end-member near the cessation of flow.

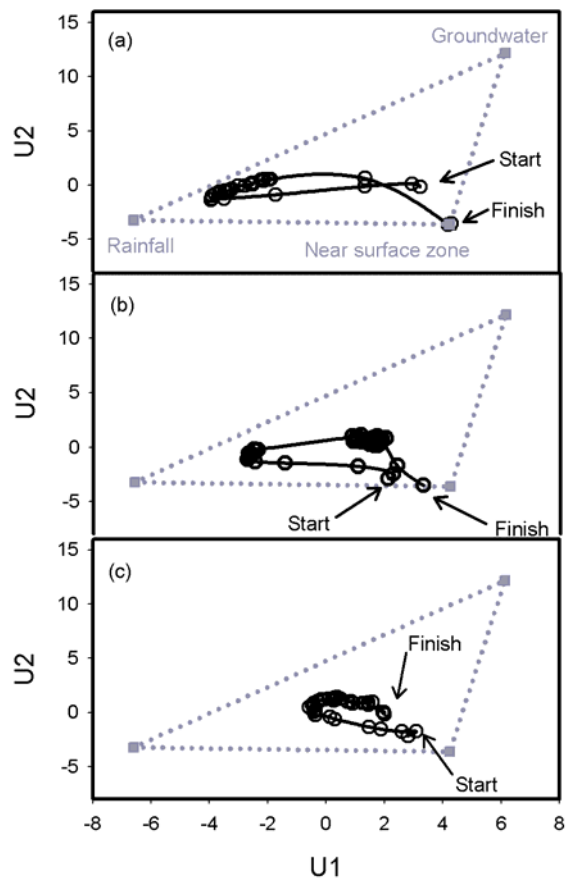
**DISCUSSION**

This study illustrates the potential of a combined hydrometric/tracer approach to understanding sub-catchment processes. One of the key reasons for this is that tracer measurements are valid on scales similar to the processes being observed. Similar approaches may have value in other studies.

This study demonstrates that large spatial differences can occur at the sub-catchment scale in terms of runoff generation and salt mobilisation. Runoff from the scald begins well before that of the upper catchment area and on an areal basis produces a greater depth of runoff (table 1). This illustrates the effect of higher antecedent water content which is in turn influenced by the proximity of the groundwater surface. This effect is similar to the usually large contribution of riparian zones to stream runoff in humid climates (Burns et al., 2001; McGlynn and McDonnell, 2003). Conversely, in the upper

catchment area there is no groundwater influence on runoff.

Solute concentration of runoff from the upper catchment area is very low reflecting the low solute concentration in the perched aquifer that forms in that area. In contrast, the EC of the near surface zone water from the scald is up to 28000  $\mu\text{S}/\text{cm}$ , reflecting evaporative



**Figure 4 Event loops for (a) 30 June – 4 July event, (b) 9 – 12 July event, (c) 13 - 14 July events. Plots show EMMA model 1 end-members.**

concentration of groundwater (3000 – 6000  $\mu\text{S}/\text{cm}$ ) over summer. Figures quoted in table 1 for the scald are based upon an area of 10ha, however field observations and data from the SGSL experiment on the scald (Crosbie et al., 2006) indicate that most runoff from the site is produced from an area of around 3 ha. Additionally, EMMA results indicate that the near surface zone is responsible for mobilising nearly all chloride (proxy for salt) from the site (table 3). Considering both these points, a very small volume of soil acts as a staging point for salt that is mobilised to the stream. Such a “bottle neck” to solute mobilisation may provide

opportunities for efficient salinity remediation/intervention.

**A conceptual model of salt mobilisation**

The data presented here shows clearly that the scald is the “staging point” for almost all salt that enters the stream at BFCC. However, to make any recommendations about how land management may influence stream salinity, knowledge of how scald is connected hydrologically with the rest of the catchment is required.

**Table 3 End-member contribution to scald runoff and chloride export using EMMA model 1 and 2**

	Model 1			Model 2		
	Rain	Near Surface	Groundwater	Rain	Near Surface	Groundwater
<b>30 June – 4 July (33 mm)</b>						
Proportion of total runoff	0.71	0.13	0.16	0.74	0.08	0.18
Proportion at peak runoff	0.74	0.13	0.13	0.77	0.08	0.15
Chloride export (kg)	0	179	54	0	191	59
Proportion of total chloride export	0	0.77	0.23	0	0.76	0.24
<b>9 – 12 July (19 mm)</b>						
Proportion of total runoff	0.55	0.26	0.19	0.62	0.17	0.21
Proportion at peak runoff	0.55	0.33	0.12	0.63	0.21	0.16
Chloride export (kg)	0	247	42	0	263	49
Proportion of total chloride export	0	0.86	0.14	0	0.84	0.16
<b>13 – 14 July (13 mm)</b>						
Proportion of total runoff	0.40	0.37	0.23	0.49	0.23	0.28
Proportion at peak runoff	0.41	0.40	0.19	0.51	0.25	0.24
Chloride export (kg)	0	190	29	0	202	34
Proportion of total chloride export	0	0.87	0.13	0	0.86	0.14

Hydrological connection in this context refers to both the time lag and the magnitude to which a change in one area causes a response in another area. Specifically, the connection between the upper catchment area and the scalded area at BFCC would be via groundwater. Since hydraulic conductivity through the regolith is so low at BFCC (figure 2), and recharge estimated from chloride profiles is very low (Crosbie, 2006), then the scalded area is very insensitive to changes in the upper catchment area. In fact the main recharge zone for this catchment is unknown and may be outside the watershed boundary (Mitchell et al., 2006). Given this, the scald area is effectively de-coupled from at least a large proportion of the catchment, in all but geological time scales.

**Implications for land management**

Reducing salt loads and salinity are management targets for governments and community groups within the MDB. To reduce stream salinity at BFCC land use should be directed at maintaining runoff from the upper catchment area, since this has been shown to be of high quality (table 1). Land use to reduce groundwater recharge is often promoted as a salinity management tool, but in this instance could not be recommended for the upper catchment area because such management may reduce runoff (Bosch and Hewlett, 1982).

The scald area presents an opportunity to reduce stream salinity and salt load in an efficient manner due to the small area that it

occupies, and the high salinity of source water.

The best form of management for the scald given the previously stated goals remains un-investigated to a large degree, but plant based, or engineering approaches may be employed.

If the disproportionate effects of the scald observed at BFCC are similar in other areas, then an opportunity exists to reduce stream salt loads efficiently. The contribution of salt from scalds at larger scale requires further investigation.

**CONCLUSIONS**

Results show that the bulk of catchment solute export occurs via a small saline scald (< 2% of catchment area) where solutes are concentrated in the near surface zone (0-0.4m). EMMA modelling shows that “event” water (direct from

rain) dominates the stream hydrograph from the scalded area. Non-scalded areas of the catchment are likely to provide the bulk of catchment runoff, although the scalded area is a higher contributor on an areal basis. Runoff from the non-scalded area is about two orders of magnitude lower in salinity than the scalded area.

The scalded zone in this study can be managed separately from the upper catchment area since they are effectively de-coupled except over long time scales.

An understanding of processes occurring within the catchment at the landform element scale has shown to be instructive here as in other studies (Summerell, 2005) and could add to or modify catchment modelling approaches for better predictions.

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