Key sites for hydrology salinity and model validation: A local Groundwater Flow Systems perspective

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ABSTRACT

Five sub catchments in NSW have been studied to determine the water balance size and direction of ground and surface water and salt flow. Conceptual models were developed for all sites. Four had widely varying groundwater systems while one appeared to conform to the predicted groundwater flow systems. Four of the sites appeared to be in local ground water systems that is to say there was local recharge and local discharge, while one appeared to be in an intermediate or regional groundwater system.

INTRODUCTION

Improved understanding of the hydrological response due to changes in land management is critical to the development of clear and consistent advice on land use change for both land holders and natural resource managers. In particular how catchments respond to landuse change will affect the extent of dryland salinity, the catchment water yield and water quality. However in NSW there is little long term hydrological data that has been collected at relevant scales (point scale through to farm/sub catchment scale) that allow this to occur.

The change in landuse in many parts of the Murray Darling Basin over the past two centuries has greatly affected the magnitude of components of the salt and water balance, in particular, deep drainage and transpiration (NLWRA, 2001). Increased groundwater recharge has caused salinity problems in many areas of Australia and around the world (Salama et al. 1999). Salinity has already transformed large tracts of previously productive land into bare scalds and waterlogged areas and it threatens much more land (NLWRA, 2001). Salinity also affects downstream water users as the salt is discharged from the land into the rivers.

In the landscape water and salt moves from rainfall to streamflow and from a spatial scale sense moves from a point scale to a catchment scale. These nested spatial scale changes results in multiple pathways and storages for both water and salt throughout the landscape.

To conceptualise these pathways and storages the Australian groundwater flow systems framework as part of the National Catchment Classification system was developed (Coram 1998). In essence the this study classifies the catchment via characteristics that can be used to determine the flow systems *viz*, local, intermediate or regional. The characteristics used to determine the groundwater flow systems are topography, geology and structural features such as hydraulic conductivity or geological restrictions.

The National Action Plan for Salinity and Water Quality Program funded project Key Sites for Hydrology, Salinity and Model Validation established, in NSW, eight sites that are and have been maintained over a number of years to measure and monitor the pathways and storages of salt and water. The sites are all located in the tablelands and slopes of NSW and cover a range of typical landscapes and farming systems. The sites are all sub catchments and range between 120 ha to 3000 ha. At all sites data from various agricultural and non-agricultural land uses are being monitored and analysed to relate point water balances to catchment water balance, measure salt movement through landscapes to streams, determine the effects of land use on plant water use, and measure landscape and catchment response to tree planting. Additionally the data is also being collated to assist with validation of landscape modelling.

At all the sites a physical conceptual model was developed to assist with the understanding of the hydrology of the sites and to identify components of the water balance. To develop the physical conceptual model all available data was assembled including digital elevation models, regional geology maps, borehole logs and electromagnetic induction (EM31) surveys. The most appropriate groundwater flow model from the National Classification of Catchment report (Coram 1998) was selected. The conceptual models were developed by using identified catchment characteristics the appropriate groundwater flow system. For brevity five sites are presented in this paper.

BOOROWA

The Boorowa site is a small first order catchment of 129 ha, 8 km north of Boorowa. The site has a main streamline running from the northeast to northwest with a saline scald at the bottom of the catchment (Fig.1). This property has been used as a demonstration for ‘best bet’ salinity mitigation strategies. Geology of the catchment is classified as Silurian period Douro Volcanics. Across the Boorowa River catchment this sub-group will consist of dacite, andesite, coarse and fine crystal tuff, tuffaceous sandstone, shale and limestone (Brunker and Offenberg 1968).

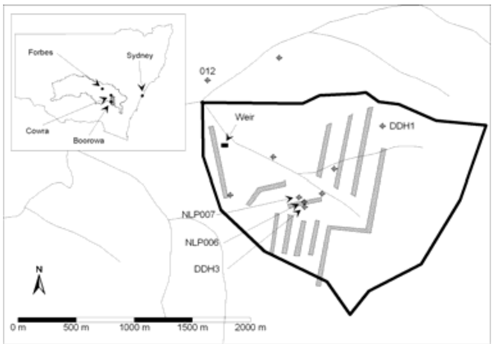

Figure 1. Boorowa Site showing location of the weir, piezometers and treelots (hatched areas). Inset shows location of Boorowa R. catchment (shaded) in the Lachlan R. catchment within NSW.

The site has been mapped as a being in an intermediate or local flow system in Palaeozoic rocks or Mesozoic intrusives (Coram et al. 2000). Soils across the site are predominately Red Kandosols, located on crests and slopes. Smaller areas of Salic Hydrosols occur in open depressions and lower slopes towards the outlet of the catchment (Crosbie et al. in press).

Conceptual model

The conceptual model developed for the Boorowa site was determined by long term (13 years) watertable time series and a DEM of the soil surface. A number of studies have used this site since its inception in 1991, however very little interpretation of the data had taken place. The details of the water balance and a full site description can be found in Crosbie et al. (in press).

Figure 2 Groundwater heights Boorowa

In 1993 the watertable elevation data showed the groundwater followed the surface topography (Fig 2). It was postulated that the saline scald at the bottom of the catchment was a result of the fractured rock aquifer being close (about 4 m) from the soil surface. This combined with a high hydraulic gradient forced water to discharge through the soil surface causing waterlogging and eventually via evaporative concentration a saline scald. This conceptual model fits well with the *Local model (iii) - Discharge from weathered fractured rock aquifers at break of slope* (Coram et al. 2000). With the implementation of a landuse change to perennial pastures in 1999 (Crosbie et al. 2006) the groundwater responded by gradually decreasing over the subsequent six years. This response is consistent with the developed conceptual model.

GUMBLE

Gumble is a first order catchment approximately 740 ha in size located 20 km west of Manildra (Fig. 3) upper parts of the catchment form the boundary between the Lachlan and Macquarie catchments. It has a main stream line running from the south west to the north east. It forms the upper reaches of Bray's Flat Creek and has a significant saline scald in the lower part of the catchment (Fig 4). The geology consists of two broad units; a Quaternary alluvium classification (Qa) that spatially correlates with the alluvial plain, and of Devonian age volcanics, the Dulladerry volcanics (Molong 1:100 000 sheet, Geological survey of NSW). The groundwater flow systems are mapped as an intermediate or local flow system in Palaeozoic rocks or Mesozoic intrusives

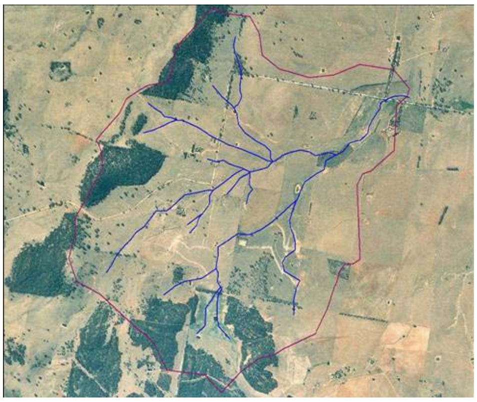

Figure 3 Aerial photo of the Gumble site showing flowlines and catchment boundary

Conceptual model

The topography and the pattern of expression of salinity at the Gumble site suggested that the *Local model (iii) - Discharge from weathered fractured rock aquifers at break of slope* would be an appropriate model (Coram et al. 2000).

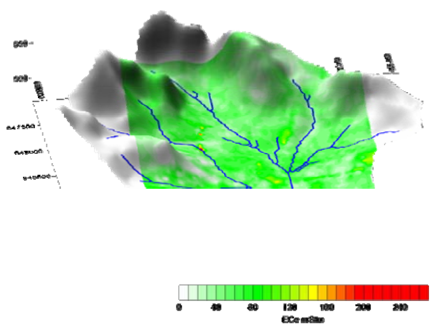

Figure 4 EM 31 Survey draped over DEM of Gumble site

The surface catchment appeared to a bowl shaped with stream lines converging at the catchment outlet which also coincided with a saline scald (Figs. 3-5). This pattern suggested that the surface water direction was analogous to the groundwater.

Redeveloped conceptual model

However in 2004 a number of piezometers were installed at the site to determine the shape and the direction of the predicted groundwater flow. The observed groundwater elevations showed that the groundwater flows outwards radially from a groundwater mound located near the northern boundary of the catchment (Fig. 6).

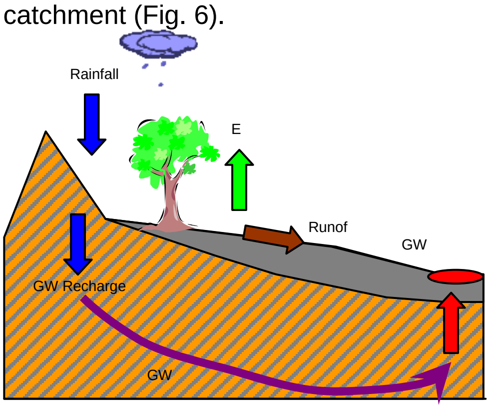

Figure 5 Initial conceptual model for the Gumble site

This was not consistent with the groundwater flow systems adopted for this site (Fig 5). The conceptual model was redeveloped to reflect the observed groundwater patterns and local geology using the drill logs generated in the piezometer installation (Fig. 7).

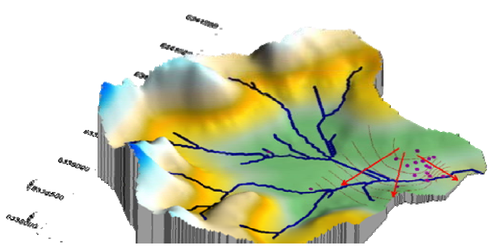

Figure 6 Groundwater contours for the Gumble site

The redeveloped groundwater model shows the groundwater mound that underlies the scald is a result of occluded drainage due to a granite intrusion below the scald (Fig. 7). The groundwater contours suggest that the groundwater may originate outside the surface catchment boundary and may indicate that the flow system is in fact an intermediate or regional groundwater flow system; unfortunately current project resources are unable to undertake further drilling to determine the nature of the flow system.

Soil profiles from the scald show a buried soil profile which suggests recent colluvium has been deposited on to the scald. Crosbie et al. (in press) describes the methodology that has been used to determine the groundwater patterns which include 1-D numerical modelling and analyses of the chloride profiles across the site.

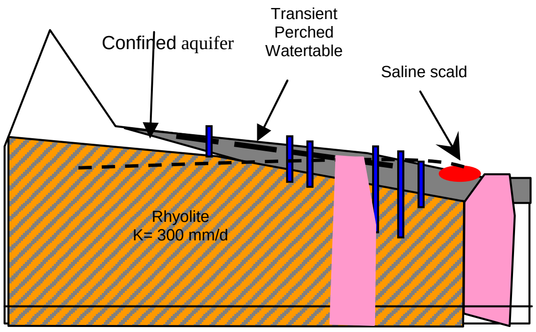

Figure 7 Redeveloped conceptual model for the Gumble site

Crosbie et al. (in press) describes the groundwater flow as a confined aquifer that originally discharged into an incised creek, however in the mid 20th century excessive erosion allowed the channel to fill and subsequently impeded this drainage. The excess water now expresses itself as a saline scald (Fig. 8). Crosbie et al. (in press) suggest that there are no studies in a local groundwater system that have shown that clearing of native vegetation for agriculture and the associated change in recharge is not responsible for the development of a saline scald.

LIVINGSTONE CREEK

The Livingstone Creek catchment is a first order catchment located 25 km south of Wagga Wagga in the Kyeamba Creek catchment. The Livingstone Creek forms the major streamline in the catchment running from south to north (Fig. 8). The catchment is dominated by Ordovician meta-sediments geology inter-bedded with a complex of siltstone, shale, phyllite, minor schist and quartzite with minor intrusions of granite (Summerall 2004). The site does not have structurally complex geology with few lineaments in the sub catchment (Summerall 2004). The catchment has large areas of both hilly landform and flat in filled valleys (Summerall 2004).

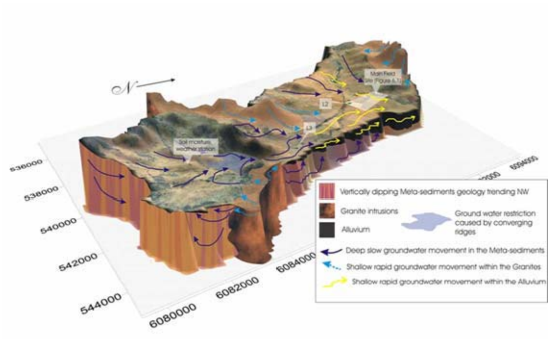

Figure 8 Physical conceptual model of the Livingstone Creek site (after Sumerall 2004)

Winter dominated rainfall occurs of approximately 700-750 mm per year. Land clearing has occurred across 95% of the catchment for uses including mixed farming of sheep, cattle and cereal crops (Summerall 2004). The groundwater flow systems are mapped as an intermediate or local flow system in Palaeozoic rocks or Mesozoic intrusives Coram *et al.* (2000). There is no localised expression of salinity but the Livingstone Creek catchment was identified as a major source of salt for the Kyeamba Valley. A rapid stream analysis was undertaken which determined that both event flow and base flow was saline.

Conceptual model

A physical conceptual model was developed in a prior study (Summerall 2004). The model was developed using a number of techniques including rapid stream analysis, detailed soil moisture and groundwater monitoring, EM 31 survey and ground and surface water chemical analysis. The model suggests groundwater processes occurring, groundwater from the meta sediment headwaters are transporting salt and water down the catchment and into the alluvial plains and the recharge from the alluvial plains are flushing this salt into the drainage line (Summerall in press). This mechanism also allows for the recharge from the alluvial plains to act as dilution flow for the saline base flow coming from the meta sediments underlying the upper catchment. Changing to perennial farming systems on the alluvial plains may result in little deep drainage on this landscape which in turn may allow saline encroachment. To control salinity in this landscape recharge control for the upper catchment is recommended (Summerall in press). This type of conceptual model is not well described by Coram et al. (2000).

BALDRY

The site is a 260 ha sub-catchment in the Little River. An eroded ephemeral creek drains northwards into the Little River (Fig 9). Since clearing in the 1930's the site has been alternately cropped and grazed for periods of three to four years. A large salt scald developed on the lower slopes and salt has been expressing all along the eroded creek line. The site has appreciable topography with a relief of approximately 50m. The site slopes in a northerly direction and is drained by a northward running ephemeral creek that runs into the Little River (Ackworth 2005). The geology of the site consists of fine grained Devonian age granites and granodiorites.

Figure 9 Aerial photo and DEM drape of the Baldry site

These out crop in several parts of the catchment and are not limited to the hill tops. The granites appear to be well fractured and deeply weathered in parts (Ackworth 2005). The groundwater flow systems are mapped as an intermediate or local flow system in Palaeozoic rocks or Mesozoic intrusives Coram et al. (2000).

Conceptual model

A physical conceptual model was developed for the Baldry site based on hill slope hydrology, which suggests that the highest salinity occurs at the bottom of the slope and lowest salinity occurs at the top of the slope. However an investigation by Acworth (2005) revealed that the highest groundwater salinities occurred at the top of the hill and the lowest groundwater salinity occurred around the bottom of the hill close to the saline scalds Acworth (2005). This investigation which also included resistivity measurements and groundwater chemistry speciation detected several intruded bodies which it was hypothesised had impeded or dammed the upslope groundwater and did not allow the water to travel down the slope Acworth (2005). The groundwater chemistry speciation and the analysis of the bore hydrographs suggested that the hillslope overlies a different aquifer than the aquifer feeding the saline scald. The scald was a result of evaporative concentration rather than saline groundwater. This would account for the lower salinity (Acworth 2005).

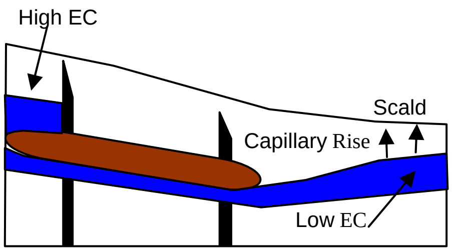

Figure 10 Baldry conceptual model

These observations led to a redevelopment of the conceptual model in which show the damming effect of the intruded geology and the hypothesised groundwater flow directions.

DURI

The Duri site is located 20km south-west of Tamworth, NSW. The site is approximately 620 ha and it encompasses a first order ephemeral stream, Timbumburi Creek that flows into the Peel River close to Tamworth. Timbumburi Creek flows through the middle of the sub-catchment, in a south-north direction. The site sits over the Tangaratta formation, which consists of Carboniferous mudstone and feldspathic arenite (Tamworth 1:250 000 Sheet). A fault divides the north east corner and a syncline runs in a north north-western direction through the middle of the site (Tamworth 1:250 000 Sheet). The groundwater flow systems are mapped as an intermediate or local flow system in Palaeozoic rocks or Mesozoic intrusives Coram et al. (2000). There is no expression of salinity in the catchment however there is localised waterlogging at the break of slope and stream.

These catchment characteristics were used to develop a simple conceptual model, similar to *Local model (iv) - Discharge from colluvial-alluvial slopes.* It was assumed that the geological features had no effect on the hydrology of the site.

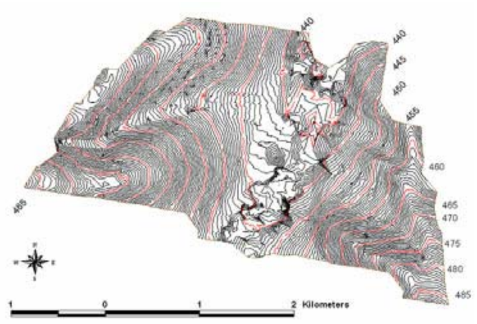

Figure 11 Digital Elevation Model (DEM) of the Duri Site

Conceptual model

In 2003 several groundwater observation bores were installed to monitor the groundwater. Additionally an EM31 survey was conducted with an RTK GPS to produce a DEM of the site. The groundwater data revealed that the groundwater elevations were the highest the further away from the stream, however there appeared to be a mound of groundwater originating from the stream line.

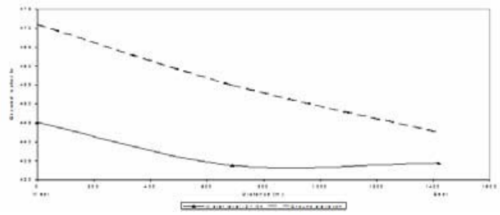

Figure 12 Groundwater height Duri (dotted line shows soil surface, filled line is groundwater surface)

This groundwater mound was also fresher than the groundwater at the mid slope (500 m from the origin in Fig. 12). The EM 31 survey (not shown) shows a small area of high ECa, above 220 mS/m, in the middle of the site near the main stream line which correlates with the observed localised waterlogging.

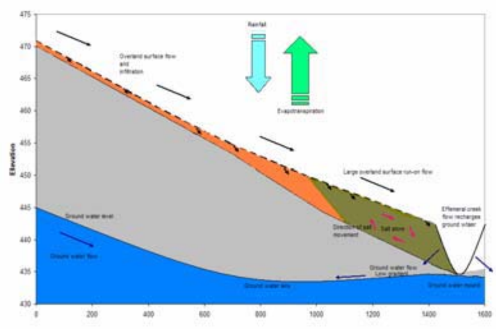

Figure 13 Conceptual model Duri

The measured groundwater data suggests that the Timbumburi Creek is an influent (losing) streamline, and provides net recharge to the local groundwater system. Along parts of the streamline outside and downstream of the study area there are semi permanent waterholes which may be the discharge point for the local groundwater system (Fig. 13). This conceptual model also suggests that the Duri site may be a gaining salt from up stream and storing it in the landscape. The implications of this finding are currently the focus of continued investigations.

DISCUSION

Five subcatchments have been and continue to be studied in detail to develop an understanding of the hydrological processes operating within those sites. Initially when the sites where selected published data including geology, soils, and topography were analysed in conjunction with the National Classification of Catchments framework (Coram 1998) to develop a physical conceptual model of the site. This model would be used to strategically target further investigations as well as to assist with the conceptual understanding of how the catchments hydrological processes occur.

The National Classification of Catchments framework (Coram 1998) did not accurately describe the conceptual physical model of four of the five sites presented above. The one site, Boorowa was accurately portrayed by Coram (1998). This site appears to be "text book" catchment in which the groundwater responds in a predictable manner, possibly due to the fact that both the surface and the groundwater catchments coincide. At this site the regolith and underlying geology appear to be relatively simple with no geological intrusions and a reasonably permeable fractured rock aquifer. The system appears to conform with a local groundwater flow system model. At this site there was a change in landuse in 1999 to perennial pastures, the effect of this landuse change on the hydrological response agrees with the developed conceptual model.

Three of the remaining four sites, Gumble, Duri, and Baldry have quite complex geology with intruded structures such as dykes and folded sediments that appear to control or affect the groundwater flow in some manner. The Duri and the Baldry site appear to be local groundwater flow systems in as much as there is local recharge and discharge. The hydrology at the Baldry site appears to be dominated by intruded geology. Dykes appear to be damming up groundwater towards the top of the slope. At this site there appears to be at least two aquifers of different salinity operating at this site.

The measured groundwater data at the Duri site suggests that the Timbumburi Creek is an influent stream that may contribute to salt stores in the landscape. The geology of the site includes mapped fault and folded sediments which may be preferential pathways of groundwater movement. The concept of an influent stream is not a well recognised catchment characteristic and will play an important role in the development of understanding of the hydrology for this site and possibly other sites in this area of NSW.

Of all the site it appears that the Gumble site contains the most complex regolith and geology. This has a major influence on the movement of salt and water in this catchment. The current developed conceptual model attempts to integrate our current understanding of the processes but may be revised as additional measurements and analysis are undertaken.

The Livingstone Creek site while not having complex geology appears to have complex salt delivery mechanisms. The conceptual model presented above shows that the upper catchment meta-sediments deliver salt to the alluvial plains and these plains are maintained fresh by recharge from annual cropping. To control the saline base flow from the upper catchments landuse that minimises recharge is required.

The process described in this paper of developing conceptual models process is entirely consistent with the National Catchment Classification system which recognised that the study may produce 'defensible hydrogeological models' these may be 'rendered inaccurate by the presence of an unknown dyke or bedrock high' (Coram 1998, p. 9). It is pertinent here to issue a note of caution about the use of the National Catchment Classification system to develop local conceptual models for investment and or landuse decisions. If the five sites described here were the target of public investment to remediate the expression of dryland salinity the use of "off the shelf" conceptual models would have been widely variable in terms of salinity control. In the Boorowa case the best bet landuse change has brought about salinity control, however if the same treatment was applied at the Gumble site there would be no change to the expression of salinity, and if the alluvial plains at Livingstone Creek were targeted for increased perenniality may result in decreased dilution flows and increase of expression of dryland salinity.

CONCLUSION

The developed conceptual models presented in this paper should be regarded as the best understanding of the hydrological processes of these five sites at the time of publication. It is envisioned that like all simplified models that they cannot fully capture all the processes in action. Additionally as new information comes to hand such as new investigations or measurements of the processes our understanding will change and the conceptual models will require updating to reflect our better understanding of the processes.

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REFERENCE LIST

Ackworth RI 2005 Hydrogeological Study of the Baldry Site Water Research Laboratory Research Report UNSW Sydney

Brunker, R. L., and A. C. Offenberg. 1968. Goulbourn Geological Map. *in*. Geological Survey of New South Wales.

Coram J 1998 national Classification of Catchments for Land and River Salinity: A catalogue of groundwater systems responsible for dryland salinity in Australia. Publication No.98/78 Rural Industries Research and Development Corporation Canberra

Coram, J.E., Dyson, P.R., Houlder, P.A. and Evans, W.R. 2000 Australian groundwater flow systems contributing to dryland salinity, Bureau of Rural Sciences project, undertaken for NLWRA Dryland Salinity Theme, Canberra.

Crosbie R, Hughes J, Friend J, Baldwin B, (In Press) Monitoring the Hydrological Impact of Land Use Change in a Small Agricultural Catchment Affected by Dryland Salinity in Central NSW, Australia *Agricultural Water Management*

Crosbie R, Hughes J, (in press), Challenging the Paradigm: An example of anthropogenic modification to groundwater discharge causing a saline scald rather than increasing groundwater. 10th Murray-Darling Basin Groundwater Workshop.

Molong 1:100 000 sheet, Geological survey of NSW Map no 8631 NSW Department of Mines

NLWRA. 2001. Australian Dryland Salinity Assessment 2000. Extent, impacts, processes, monitoring and management options. National Land and Water Resources Audit, Canberra.

Salama, R. B., C. J. Otto, and R. W. Fitzpatrick. 1999. Contributions of groundwater conditions to soil and water salinization. *Hydrogeology Journal* **7**:46-64**.**

Summerall 2004 Understanding the processes of salt movement from the landscape to the stream in dryland catchments PhD Thesis University of Melbourne

Summerell GK Shoemark V Bernardi T Littleboy M (in press) Management of a representative flat alluvial landscape generating stream salt loads in the upland Murray Darling Basin. 10th Murray-Darling Basin Groundwater Workshop.

Tamworth Sheet 1:250 000 Geological Survey of NSW 1971, Tamworth Sheet SH 56-13 NSW Department of Mines