A case study of integrated hydrology research in the Murrumbidgee Catchment: Livingstone Creek Catchment Key Site

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The research that forms the basis of this report has been conducted with the assistance of farmers of the Livingstone Creek area and their patience, cooperation and information is gratefully acknowledged.

Recommendations

It is recommended that

- Monitoring of the environmental variables continue through a La Nina phase to validate our understanding of the catchment processes during a wetter climate phase.
- All salinity modelling tools should include a conceptualisation which allows for the processes of alluvial landform salt and water movement to the stream, as identified by this project.
- Continue to use Livingstone Creek as point of focus for ongoing international national and regional collaboration, including NRM training and capacity building.

Executive Summary

The Livingstone Creek site provides unique resources that represent the major landforms in the mid MDB. As such it has been integral to the hydrology, salinity and natural resource management training in southern NSW.

The intensive baseline collected on the site enables Livingstone Creek to be part of a suite of long term land and resource condition monitoring sites. The individual research projects have added significant information to the public domain, but the defendable conclusions and recommendations are only possible because of the collective understanding at large and small scales within the catchment.

Many of the conclusions and recommendations about and for Livingstone Creek Site are only possible because of the range of information collected over a range of temporal and spatial scales. Such intense information collection will be possible in only a minor number of catchments and a process must be found to generalise from such work to assist the management of the vast number of catchments for which no detailed information will ever be collected.

Collaborations and activities

Livingstone Creek has provided a point of focus for ongoing international national and regional collaboration, including NRM training and capacity building. This has manifested in up to 10 separate research activities being undertaken on Livingstone Creek since 2002. This has included directly two universities (University of Melbourne, University of NSW, five CRC's (Catchment Hydrology, eWater, Salinity, Future Farm Industries, Spatial Systems) 3 state government agencies, (DECC, DWE, DPI) two CMA's (Murray, Murrumbidgee), CSIRO, and a range of international organisations including NASA and United States Geological Survey as part of Livingstone Creeks input into the Murrumbidgee Monitoring Network (MMN) which in turn is part of the OZNET project.

Physical processes

Usually, leakage across all parts of the landscape is controlled by changes in landuse and management. In cropping areas, a reduction in cropping and the introduction of high water use perennial pastures is usually recommended. However, in the Livingstone Creek catchment saline groundwater water moves down the valley through the meta-sediments geology. Salts are leached into and from the clays in the

alluvial landform, which during wet catchment conditions are flushed out into O'Brien's Creek through soil water and localised groundwater movement.

Even though the flat alluvial landscape is contributing major salt loads to the stream, the landform is however, the conduit for the catchment to flush salts. By maintaining the leakiness of the alluvial landform, salts are able to be flushed out of the productive alluvial landscape, and are not concentrated. The solution proposed is strategic recharge control in the head waters of the meta-sediment geology to reduce the pressure head of the underlying meta-sedimentary groundwater system to prevent the salts from becoming mobilised, and to leave the flat alluvial landform "leaky". This may result in this area of the catchment become fresher as the pressure responses from the meta-sediments groundwater systems are reduced, thereby reducing the salt mobilisation process of placing salts near the land and stream surface. These results are applicable to large portions of the upland Murray Darling Basin where large extents of salt affected flatter alluvial landforms dominate.

Meanwhile the granites landform provides fresh surface and ground water to the catchment. It is recommended that it continue as broadly a cropped landscape and be recognised as a fresh water generating landscape. It should be noted that the soils in this landscape vary greatly and as such need to be managed more specifically. Further research is needed to fully understand the processes occurring on these landscapes.

Resource condition

The major change in resource condition that occurred at the Livingstone Creek site has been the dramatic decrease in rainfall over the six years of monitoring. At the same time while this has affected the land management decisions landholders have made there has not been a great if any change to the landuse within Livingstone Creek. Therefore it is argued that any changes to resource condition must be from changes to climate and in particular rainfall.

This decrease rainfall led to a decline in the groundwater elevation between 1-3 m while it can bee seen that the amount of salt and water draining from the catchment is highly dependent on rainfall, with higher salt and water exports occurring in the wetter years as opposed to low salt and water exports in the drier years.

1. Livingstone Creek

Land salinisation and increasing stream salinity are major environmental issues confronting Australia. A high priority has been given to on ground actions focussed on minimising down stream impacts on river water quality for domestic and farming use and targets to improve river ecosystem health. Understanding the dominant salt transport processes within a landscape and how these are related to landforms will lead to better model development, salt load estimates and management decisions.

Livingstone Creek Catchment is a representative dryland catchment of the mid Murrumbidgee. It is one of eight high priority dryland salinity sites currently being studied by NSW DPI.

The site was initially instrumented in 2000 by the Department of Land and Water Conservation with the aim of providing information which would assist in developing a better understanding of the processes of salt movement from the landscape, to the stream, in a dryland catchment. In 2005 it was incorporated into NSW DPI's Key Sites project and receives support from the National Action Plan for Salinity and Water Quality.

1.1 Site description

Livingstone Creek catchment (~43km²) is located within the Murrumbidgee region of inland southern New South Wales. The geology of the Livingstone Creek catchment includes Ordovician meta-sediments interbedded with a complex of siltstone, shale, phyllite, minor schist and quartzite with minor intrusions of granite. The landscape of this catchment varies from steep and gently undulating hillslopes to large areas of alluvial flats. Average annual rainfall is 650-750 mm per year and predominately occurs during winter (June – August).

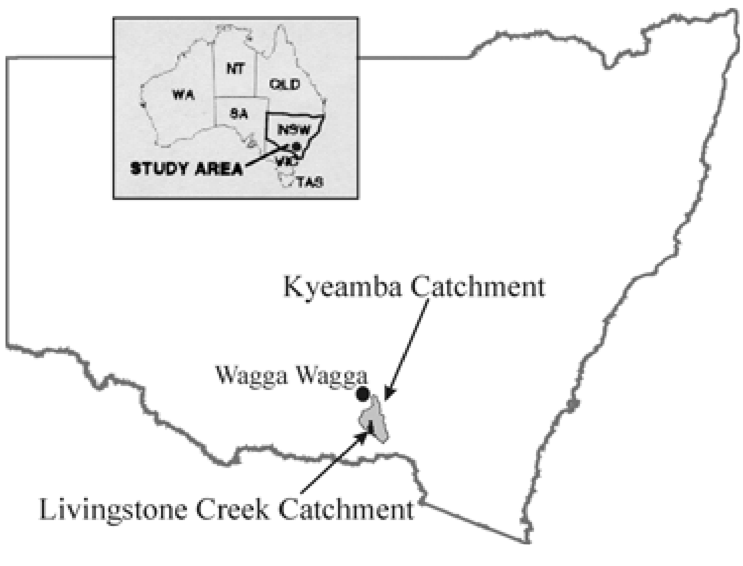


Figure 1 Location of Livingstone Creek Key Site

Clearing of native vegetation has occurred across 95% of the catchment for agricultural uses, including mixed farming of sheep, cattle and cereal crops. The Livingstone Creek research project is designed to investigate in the field, the processes of salt movement from the landscape to the stream, in catchments with larger upland alluvial areas. This is one of the very few experimental studies in

Australia that focuses on discharge dynamics with a view to create a better understanding of salt delivery mechanisms from landscape to the stream.

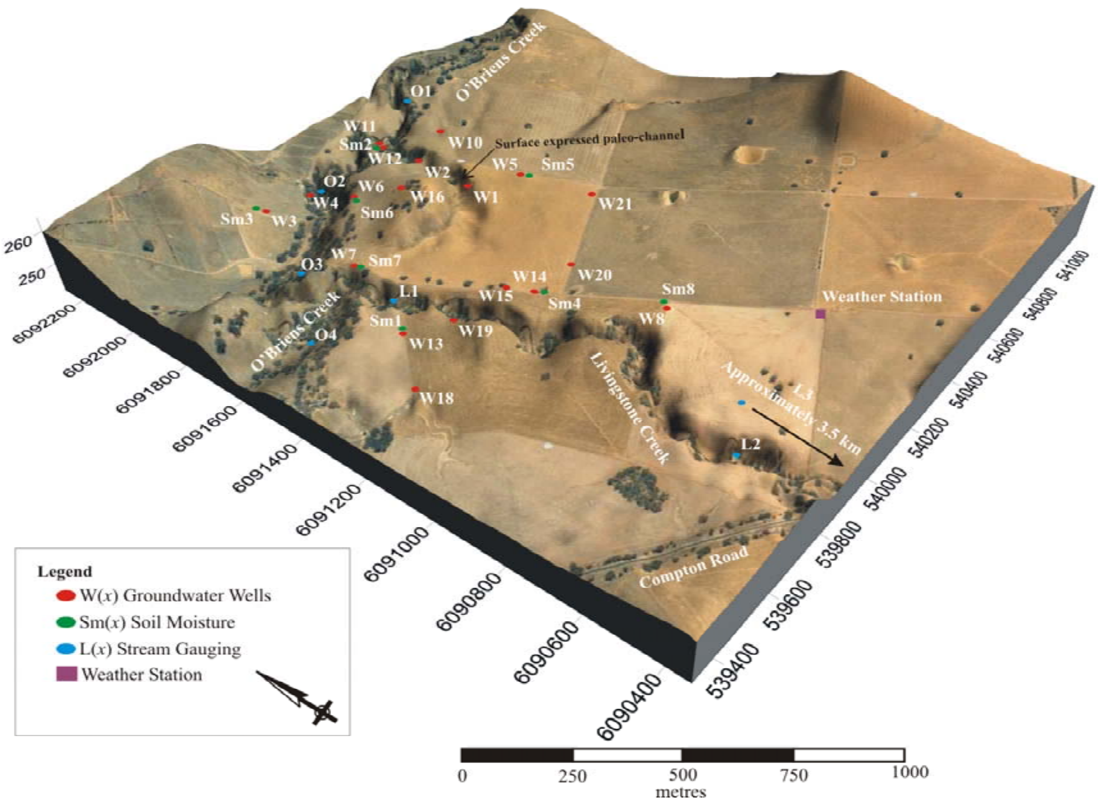


Figure 2 Livingstone Creek instrumenation

1.2 History of the hydrological imbalance after clearing in the fractured rock meta-sedimentary groundwater system

When interviewing Alan Cox (the current owner of the property "Livingstone Gully"), whose family settled the headwaters of the Livingstone Creek, Alan was able to recall the rising groundwater after clearing took place.

Alan's grandfather was a squatter and settled in the headwaters of the Livingstone Creek. He chose this location because Mitchell Tomas Livingstone, an explorer inscribed on a tree what he believed to be a permanent water source running in a small creek. Previous squatters had looked at the headwaters of the Livingstone Creek but the water was saline. These squatters tried digging a well to find fresher water but after reaching about 8 metres the well began filling with water which settled about 4m below the surface. The quality of this water was said to be brackish just like the creek so they moved on. Alan's grandfather decided he would settle this area and after building a log cabin to live in he started work on building a dam as the Livingstone Creek only ran seasonally with the wetter weather. After two years of settlement and completion of the dam, the government approached Alan's grandfather and asked him to clear the land as government policy required certain amounts of clearing to be undertaken for each year of settlement. Alan's grandfather commenced on a major tree "ring barking" exercise (to kill the trees) across the headwaters of the creek. The following year the creeks began to run throughout the year and rarely have they stopped even till today. Alan was also able to recall that the soils in the headwaters of the Livingstone Creek remained quite fertile and productive for about

30 years after the clearing, however productivity and soil health declined rapidly after this. Alan's grandfather ended up naming his property "The Folly", because after putting in a huge effort to building the dam he ended up not needing it as the creeks changed from ephemeral to perennial.

Historically it appears that this catchment has always been saline. The salinity problem was exacerbated by rising groundwater due to increased recharge. This inturn increased discharge out of the catchment through the creeks that are now constantly exporting salt.

1.3 Wagga Wagga Resource Centre (DECC Site)

Additional to the Livingstone Creek site is a smaller research site located on the NSW DECC Resource Centre. The site is a focus of agro forestry research specifically target at understanding the effect of tree plantings on saline scalds. The site was initiated in the late 1990's when a saline scald in the front cropping paddock at DECC Research Centre developed. To ameliorate the scald trees planted, 14 hectares of Eucalypts, for Farm Forestry to demonstrate the value of plantations to lower the watertable on a 'discharge' site.
Detailed monitoring carried out since planting in 2002 has shown a progressive decline in water table depth. This decline is much greater than would be expected due to the drier prevailing weather. Tree planting as a means to manage dryland salinity is usually targeted within 'recharge' areas of a catchment. However, more recent evidence suggests that it is important to intercept more saline (surface and groundwater) water before it flows to streams. Trees planted in saline discharge zones may perform poorly if unsuitable species and management are used. Appropriate species based on growth and water use, silvicultural strategies and area needed for planting are constrained by current lack of information. There is opportunity now to assess the productivity and water use of these eucalypts in order to confirm broad predictions of differential water use between species.

2. Research Activities.

Numerous research activities have taken place on the Livingstone Creek site, this section provides an overview of the research activity outlining the aims and objectives of the activity and identifying the major research personal associated with the activity.

2.1 Understanding the processes of salt movement from the landscape to the stream in dryland catchments (Greg Summerell PhD)

Aims

Determine an appropriate scale that represents landscape processes that induce different processes of salt movement from the landscape to the stream.

To demonstrate through a field based study at the selected scale, the processes of salt movement from the landscape to the stream.

Objectives

Using and further developing terrain analysis techniques to represent major landforms of a catchment.

Investigate historical salinity data within large catchments (600-2000km2) to compare stream salinity patterns against the dominance of different landforms within these catchments.

Select an area for detailed field site studies where complex stream salinity patterns occur in the identified critical landforms.

A multi-disciplinary field investigation to analyses water and salt movement is groundwater, streams and soils, incorporating continuous monitoring and discrete sampling plus chemical and isotopic methods.

Research Questions

Do different landforms within a catchment influence pathways of salt movement to the streams?

Can the complexities of water and salt movement be described within these landforms including features such as paleo-channels?

Can we quantify the impact on salt loads and concentrations in streams from these different landforms?

2.2 Recharge Validation Project

Aims

Mid 2002 the site was instrumented for the Recharge Validation Project funded by the NSW Salinity Strategy. This project aimed to determine the pathways of salt and water in the landscape, and to gather data of sufficient high quality to validate current modelling frameworks including 2CSalt the model used tin the 2006 salinity audit.

Objectives

Obtain data at relevant temporal and spatial scales to validate current modelling frameworks at key upland dryland catchments in NSW

2.3 Key Sites

In June 2005 the Recharge Validation Project became part of the Key Sites project funded by the National Action Plan for Salinity and Water Quality. This renewed funding has enabled the Livingstone Creek site to continue data collection and analysis.

Aims

The research program aims are to continue monitoring the major environmental fluxes present at eight key in upland dryland catchments in NSW, including Livingstone Creek. These environmental fluxes include evapotranspiration via solid state Bowen Ratio stations, groundwater elevation, stream flow, Stream EC, soil moisture, rainfall, and standard climate parameters.

Objectives

To identify economically feasible and appropriate land use options that will mitigate the process and expression of dryland salinity in the landscape. This will include a multitude of outcomes from decreased salt loads in streams to reducing the areas affected by rising watertables.

2.4 Rapid stream survey

In 2000 the rapid stream survey methodology was developed and deployed to test whether this technique could identify landscapes that delivered salts to streams.

2.5 NAFE

The National Airborne Field Experiment (NAFE) was completed at LC in October November 2006. NAFE was run over LC and Coleambally IA. The aim was to measure soil moisture and vegetation parameters from airborne and satellite platforms and to compare to ground measured sites of which LC was one. The overall outcome of the experiment was to measure components of the catchment water balance.

2.6 OZNET

The LC site is part of the OZNET program and is providing soil moisture data to the database. The national (OZNET) data monitoring program which aims at evaluating the land surface component of the Australian Bureau of Meteorology's operational weather forecasting model. Much of these data will soon be incorporated into the World Climate Research Programme's Coordinated Enhanced Observing Period (CEOP) database (www.ceop.net) marking a substantial new contribution from the Australian continent.

2.7 HYDROGRACE

The HYDROGRACE project aims to provide the first in-situ based validation of terrestrial water storage observations from the GRACE (Gravity Recovery and Climate Experiment) mission launched by NASA. HYDROGRACE is using the OZNET data as part of its validation exercise.

2.8 UNSW Water Resources Laboratory resistivity survey

Understand or validate the conceptual understanding of the connection of the paleo-channel in the alluvial landform to the stream undertaken by Prof Ian Acworth.

2.9 SaltCHECK - Community Stream Sampling project (Murray CMA)

Saltcheck is a stream sampling project which works closely with the community to monitor the condition of inland waterways. Information gathered will be aid in decisions regarding land management options.

LC site was used to demonstrate and validate methodology currently in use, including the rising stream sampler that is now used as the basis of this project.

2.10 Tree Plantations To Manage Saline Groundwater in Low – Moderate Rainfall Regions

The aim of this activity was:

To determine the effect of planting trees on recharge and discharge site. In particular study measured tree survival and growth rates and the groundwater response to this activity at the discharge site.

To identify tree species that can manage the rise of saline water tables in the discharge areas of a low-medium rainfall catchment.

To determine the contribution of groundwater to tree growth, carbon sequestration and water use of three species; *E. occidentalis, E. cladocalyx, E. camaldulensis*

To determine what impacts trees are making on fluctuations of the water table.

To evaluate the potential of growing trees as a means of managing locally high watertables in the region.

To demonstrate and quantify the effect of thinning on growth, water use and groundwater use.

To develop general guidelines for effective thinning strategies to allow tree plantings to adequately manage watertables whilst providing biodiversity benefits.

To apply the information generated to calibrating and testing landscape models for salinity management.

3. Collaborators and Partners

Livingstone Creek has provided a point of focus for ongoing international national and regional scientific and technical collaboration, including NRM training and capacity building. This has manifested in up to 10 separate research activities being undertaken on Livingstone Creek since 2002. Since its inception the Livingstone Creek site has enabled a wide range of institutions agencies and individuals to collaborate to understand the how water and salt move ion the landscape. This section outlines briefly the organisation and the type of collaboration that occurred.

3.1 DECC/DNR/DIPNR/DSNR/DLWC

The Livingstone Creek site was instigated through DLWC activities and officers of this department and subsequent iterations including Greg Summerall Tony Bernardi Vic Shoemark Mark Littleboy. All of these officers participated and contributed to the research program and activities at this site

3.2 CSIRO Forestry and Forest Products

Measure the amount of water use on a tree plot over a shallow groundwater system at NSW DECC Wagga Research Centre

3.3 Wagga Wagga City Council

WWCC was trained in salinity management at the tree discharge site. Additionally the WWCC recognise the value the discharge site plays in salinity abatement on the western outskirts of the city.

3.4 The CRC Salinity Program 3 (woodys)

This program was measuring tree water use on the discharge site and have developed an annual water balance for three species at the site.

3.5 CRC Future Farm Industries

This CRC is scoping out the Livingstone Creek Site as part of the extension to the CATPlus project which is a large catchment scale modelling project.

3.6 Charles Sturt University – Wagga Wagga

Farm Forestry student field visits to the tree plantation study site at DECC.
http://www.crcsalinity.com.au/online_subjects/csu/agroforestry/

3.7 The University of Melbourne

University of Melbourne coordinate the NAFE research program and Greg Summerell graduated with a PhD from the university in 2005. As part of the NAFE project there are a number of international collaborators including NASA

3.8 CRC eWater/CH

Greg Summerell obtained a PhD scholarship through the eWater CRC to explore the mechanisms of salt delivery in upland catchments.

3.9 University of NSW Water Research Laboratory

conducted resistivity experiments on the alluvial landform to determine the paleochannel connection between this landform and the stream

3.10 CMC/CMB/CMA/Kyeamba Landcare

These bodies have been connected to this site in one form or another over the last ten to fifteen years. This includes developing the Kyeamba Valley Land and Water Management plan (LWMP).

4. Results

At the Livingstone Creek Site there are three broad landforms; alluvial, granite, and meta sediments. Specifically the geology of the Livingstone Creek catchment includes Ordovician meta-sediments interbedded with a complex of siltstone, shale, phyllite, minor schist and quartzite with minor intrusions of granite. The landscape of this catchment varies from gently undulating to steep hillslopes to large areas of alluvial flats. Clearing of native vegetation has occurred across 95% of the catchment for uses including mixed farming of sheep, cattle and cereal crops.

4.1 Landforms

4.1.1 Low Lying Meta-sedimentary landform

The A-horizon on the hillslopes is generally a clay loam derived from weathered bedrock and organic material. The B-horizon consists mostly of colluvial washed fragments of meta-sediments. This horizon has a sandy clay texture and appears to provide a good conduit for rapid water movement laterally from the hill-slopes. Below the B-horizon are more clay soil layers until bedrock is reached. Soils on the lower slopes of the low lying meta-sedimentary hills are derived from colluvial wash processes. Clay products (due to increased weathering) dominate these profiles. At a very shallow depth of around 15cm, a light medium clay B-horizon is typical. This clay layer is very impervious and during wet conditions surface water logging occurs across this landform. When digging the soil profiles at these locations, the soil within and below this light medium clay layer was very dry even though the surface soil was wet (boggy). The texture of other layers below the B-horizon have less clay and sand starts to occur at depths of around 5 to 6m. These layers may be associated with a past alluvial/colluvial deposition.

Below the sand layers a light sandy medium clay layer occurs which sits on top of the bedrock. Once this layer is penetrated by digging a hole, groundwater from the fractured rock aquifer in the meta-sediments geology rapidly rises to settle around 4-5m below the surface, indicating a degree of confining layer.

4.1.2 Alluvial landform

The alluvial landform consists of soils that are well drained. The soils are stratified and quite heterogeneous although at different locations common layers are identifiable between sites. These layers represent different deposition periods and were identified not only by soil textures, colour and layering but sometimes by the presence of charcoal traces. The alluvial soil tends to have light clay B-horizon grading into light medium clay. Below these layers are mixes of clays, sands and gravels and these layers vary in thickness depending on proximity to palaeochannels. Groundwater occurs at 4-5m and unconfined and not restricted by any of the depositional layers within the profile.

4.1.3 Recently deposited alluvial benches landform

The recently deposited alluvial benches landform consists of alluvium that is deposited by existing creeks. Due to the younger age of these deposits, very little clay formation has occurred and the soil profiles are dominated by sandy textures. These deposits are connecting landform between the streams and the two landforms discussed above. Groundwater levels in these landforms closely reflect creek water levels.

4.2 Groundwater

4.2.1 Alluvial

In the alluvial area the groundwater system is within 4-5m of the surface and occurs to the full depth of the alluvium (~ 7m), contacting with a semi-confining clay layer that overlies the meta-sediments groundwater system. Salinity in the alluvium ranges from 400 – 2500 μS/cm. The alluvial groundwater system is unconfined.

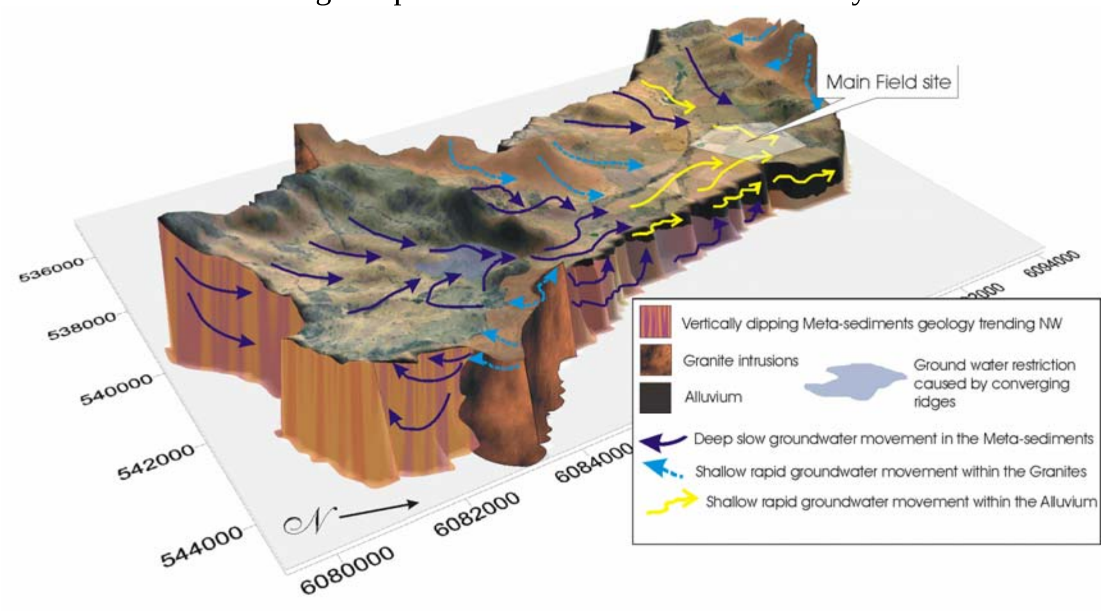
4.2.2 Granites

In the areas of granite geology the groundwater flow system is very shallow (~0.5-3m), moving quickly through the coarse textured soil on top of the bedrock. More sustained groundwater flow (longer duration) in the granite are associated with springs that are also shallow and most likely connected to deeper fractures in the massive structures of the granite. Groundwater salinities in these locations are generally <500 μS/cm (Summerell, 2004)

4.2.3 Meta sediments

In the meta-sediments, groundwater is usually semi-confined in valley floors and the water table is within 1-8m of the surface. Salinity in the meta-sediments ranges from 2000 – 15000 μS/cm.

A schematic representation of the groundwater flow model from Summerell (2004) is shown in Figure 3 and descriptions of the groundwater characteristics are given below. The groundwater flow arrows on the figure depict the common groundwater flow directions and were developed from field monitoring of water table levels obtained from monitoring and production bores located in the study area.



4.3 Resource condition

This section reports on the changes and trends of the measured hydrological processes over the current observation period 2002 to 2008. These processes include climate groundwater surface water and soil moisture.

4.3.1 Climate

During the period of monitoring at the Livingstone Key Site (2002-2008) the rainfall has been well below the long term median average (Table 1). To determine how far below the long term median long term rainfall records from the nearest SILO site were analysed and the annual and seasonal residual mass rainfall curves were calculated. To describe the seasonal pattern of the rainfall the data was split into autumn (March to May), winter (June to August), spring September to November, and summer December to February.

Residual mass is calculated by subtracting the long term average from the annual rainfall and summing the residual over the period of the average. Periods of below average rainfall show declining trends while periods of average rainfall show flat trends and periods of above average show increasing trends.

Using the 120 years of rainfall record from Pulletop (SILO station no 74195) reveals that the current period of monitoring coincides with the longest and largest period of rainfall deficit at the site since record commenced in 1889 (Fig. 3 represented by downward trend in the RMR graph).

Overall the residual mass rainfall curve shows that from about 1950 to 2000 rainfall while it was variable was on average reasonably reliable. However a number of patterns emerge since 1889 there has been four significant protracted (greater than 5 years) drying phases 1895 to 1914, 1921 to 1929, 1936 to 1946, and 2000 to present date. The wetting and drying patterns are quite distinctive with long periods of below average rainfall punctuated by usually 1-2 years of higher rainfall, eg 1916 annual rainfall was 1058 mm, 1931 1040mm, 1950 908 mm and 1952 922mm.

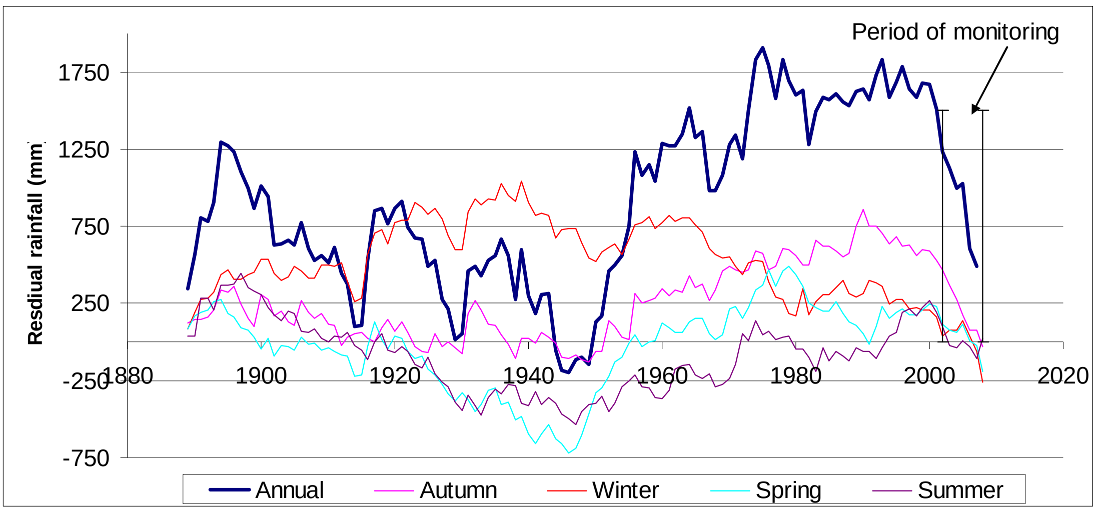


Figure 3 Residual mass rainfall from Pulletop SILO station no 74195 (1889-2008)

As discussed above there have been periods of longer below average rainfall none of these periods have had as a big rainfall deficit than the current period. Over this period which commenced in 2000 there is accumulated deficit of over 1200 mm (48 inches) of rainfall over this period or on average about 150 mm per year.

Significantly it can be seen that this period of below average rainfall is part of a longer pattern that started with below average rainfall autumn and winter rainfall in 1990. This below average rainfall was partially offset during the 1990's by above rainfall in summer and spring. However from 2000 onwards there has been below average rainfall for all four seasons (Fig 3) which has resulted in drier conditions prevailing throughout the monitoring period.

Climate 2002 onwards

Annual rainfall at the site over the last six years has been in general below the long term median rainfall (Fig. 4). Out of the 72 months that monitoring has been in place rainfall has been at or below the monthly median for 49 of those months. Overall long term median average rainfall was received in 2005, with al other years being well below average; the other five years were below the 25th percentile of rainfall received with 2006 being the lowest measured rainfall since records began in 1889 (Table 1).

Table 1 Annual and seasonal rainfall Livingstone Creek (woolshed) 2002 -2008

	Total	Autumn	Winter	Spring	Summer
Median	**637**	**134**	**204**	**160**	**125**
25 centile	**519**	**87**	**151**	**108**	**80**
2002	354	87	86	47	42
2003	520	48	240	124	94
2004	502	51	203	147	133
2005	680	35	270	270	120
2006	218	44	84	66	45
2007	534	168	132	101	239
2008		27			
Average 02-07	**468**	**65**	**169**	**126**	**112**

This analysis shows that since 2002 only the 2007 autumn was there been median or above rainfall, and the rest have been at or well below the long term 25th centile (Table 1). The average rainfall deficit for autumn was 62 mm and a similar pattern exists for winter and spring with an average rainfall deficit for both those two seasons of 34 mm. The summer of 2007-08 was one of the wettest on record with 239 mm falling this was well above the long term median of 125 mm for this period and was the seventh wettest summer on record and the wettest since 1984 (285 mm).

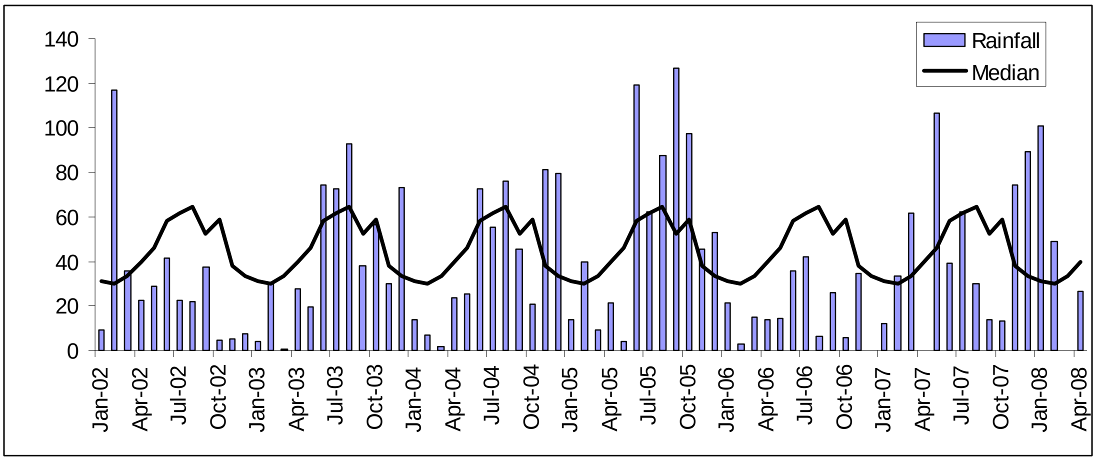


Figure 4 Monthly and long term median rainfall for Livingstone Creek

4.3.2 Groundwater

Observations since 2002

The depth and pressure of groundwater in the 15 observation wells at the site has declined since monitoring commenced in the beginning of 2002. Some of the observation wells show "spiking" indicating recharge after significant rainfall events and this pattern reflects a better connection between surface recharge and groundwater than other groundwater flow systems eg w14 as compared to w 11 (Fig 5).

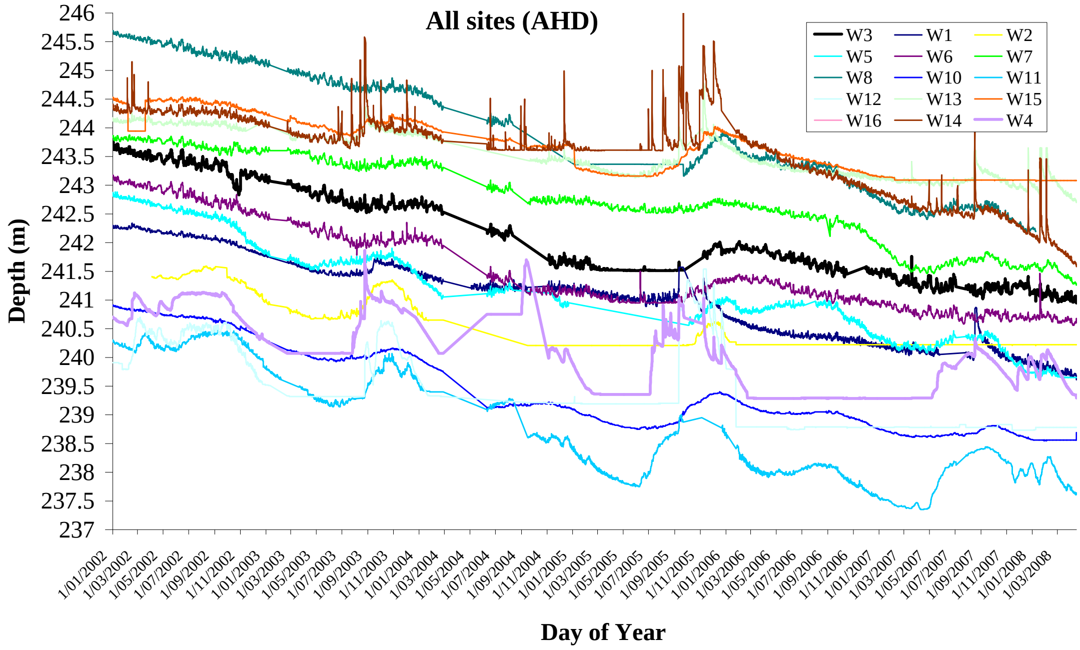


Figure 5 Livingstone Creek groundwater hydrographs 2002-2008

Four representative observation bores were selected for further evaluation; the selection is based on earlier reporting (Summerell 2005). The bores selected represent the quick responding alluvial groundwater system W4, the slower responding meta sediment groundwater flow system, the very slow responding colluvium W3 and the hard rock bore W16. Two of these observation bores show a particular responsiveness to rainfall (W4, W14). These two wells were associated with a paleochannel that dissects the alluvial plain. The observation well W11 monitors the paleochannel as it exits the plain and drains to the creek; as such the hydrograph shows the groundwater flow system responding to rainfall. The pattern is consistent with the conceptual model presented by Summerell (2005) with the deep groundwater flow systems draining the meta sediments landform into the alluvial landform then this pulse of water dissipating through the paleochannel to the stream.

The W14 hydrograph shows that during the late winter spring there were rising water levels which then would have drained to the creek creating flow. This observation is consistent with the measured stream flow (discussed in next section) the stream appears to be have changed from a perennial/intermittent stream to an ephemeral stream.

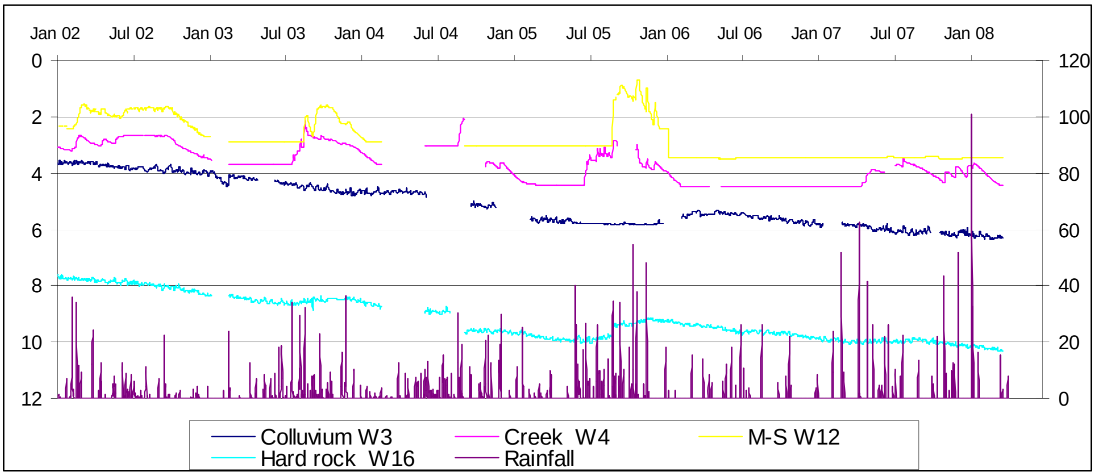


Figure 6 Representative Livingstone Creek groundwater hydrographs

A low pass filter was used to assess the trend in groundwater over the observation period. This method allows the diurnal or seasonal fluctuations to be removed and allows any persistent trends to be identified (fig. 7). The data was then normalised from the minimum depth to provide a representation of the change in watertable over the observation period.

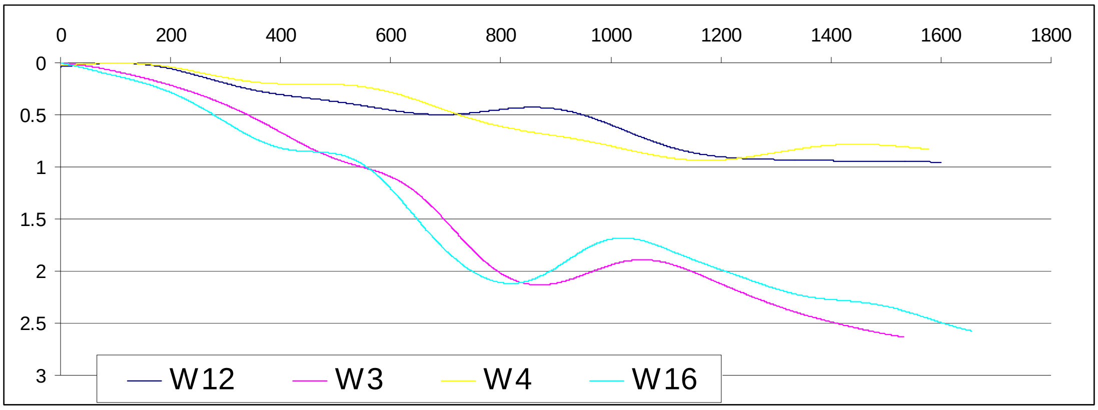


Figure 7 Low pass filtered Livingstone Creek groundwater hydrographs

It should be noted that the filtered data sets have unequal length due to the missing values of the individual data sets and as such the over all trend should be noted not the variation within the trends. This method allows estimation of the change in the depth or pressure of the watertable over the observation period.

The bores representing the meta sediments and colluvium show a decrease in height of 2.6 m over the observation period (Jan 2002 to Apr 2008), while the bores measuring the alluvial groundwater show a decrease of between 0.8 and 0.9 m over the same monitoring period.

4.3.3 Soil Moisture

Soil moisture was collected at three locations at Livingstone Creek representing the major landforms contributing to salinity expression in the creek (fig. 2). These sites were site 1 measuring the soil moisture in the paleochannel, site 3 measuring soil moisture in the low-lying meta sediments and site 5 measuring soil moisture in alluvial plains. Soil moisture was measured at 4 depths 0.6 m 1.6 m 3.0 m and 4.0m by Theta probes.

Soil moisture is reported as volumetric soil moisture (m^3/m^3) and will be discussed across the three landforms by depth.

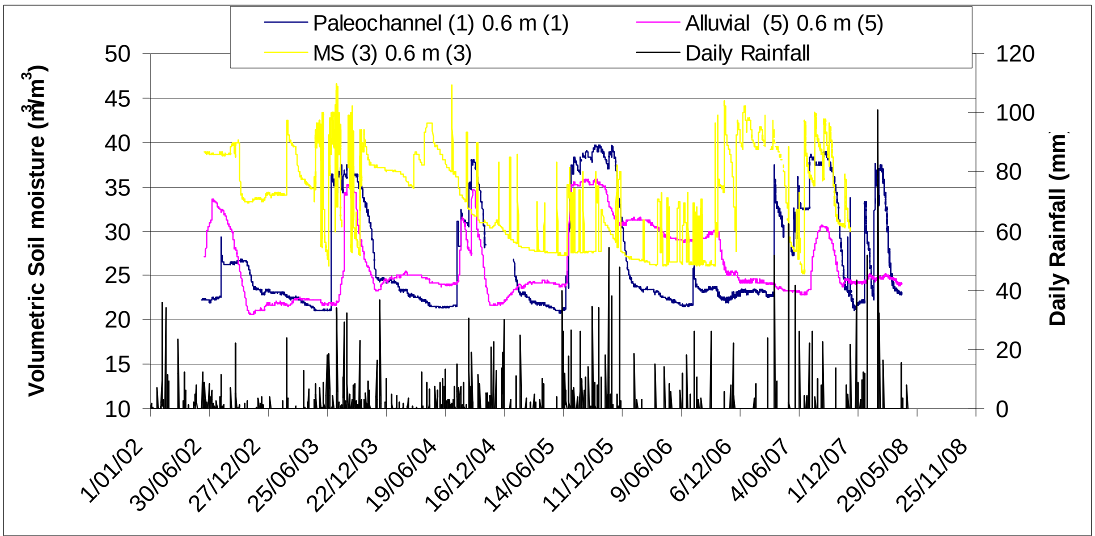


Figure 8 Soil moisture at 0.6 m measured by Theta Probes

The soil moisture within all three soils landforms responded quickly to rainfall by increasing in soil moisture (Fig 8). The wetter winters and springs can be clearly seen as soil moisture at 0.6 m rose and slowly dissipated through early to late summer (Fig 8). Only in late 2005 early 2006 did soil moisture persist for ant length of time. The spiking in the MS soil moisture appears to be a logger issue efforts to resolve this have been undertaken with limited success. The soil moisture within the MS was generally higher than the alluvial or paleochannel possibly due to the heavier texture of the soil in that landscape. This heavier texture would allow the soil to hold more water and this is reflected in the lower residual water content and the longer draw down time.

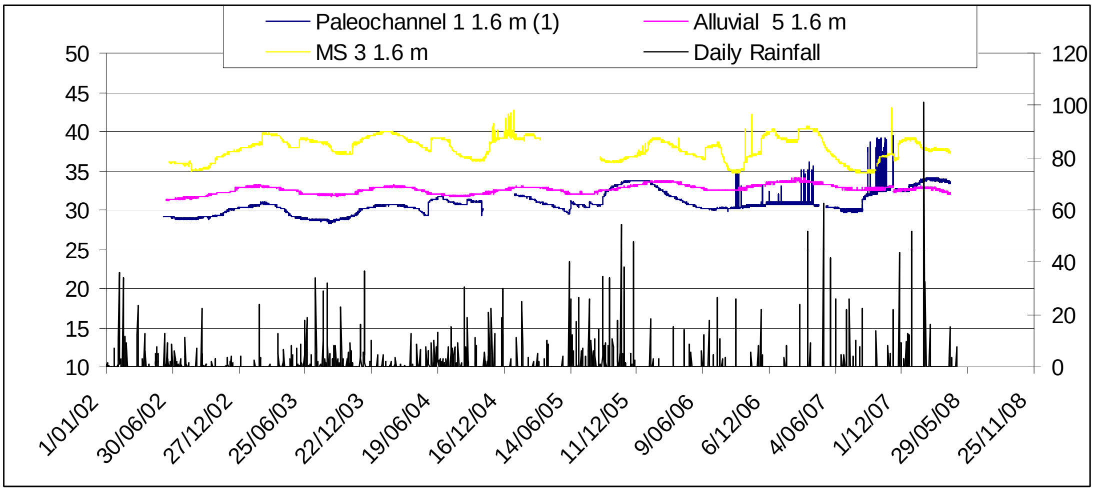


Figure 9 Soil moisture 1.6 m

The deeper soil moistures (1.6 m) as expected show less variation than the shallow soil at 0.6 m. There appears to be an increase in soil moisture during the late summer autumn months of the years and a subsequent drying in the following winter/spring. It is unsure if this is a true measure of the soil moisture or a temperature effect causing the sensor to measure higher soil moistures.

Disregarding this inter annual pattern there appears to be some increase in soil moisture at the end of the wet spring of 2005 and the wet summer of 07-08 in the meta sediment and the paleochannel sites while the alluvial soil appears to be not affected by any seasonal or higher rainfalls.

4.3.4 Stream flow

Stream flow was measured at three locations through the Livingstone Creek Key Site O1, L2 and L3.

Site O1 measures the stream flow on O'Brien's creek downstream of the junction of the surface expressed paleo-channel to capture potential paleo-channel discharges during rainfall events and as such is the end of catchment for stream flow and located on sand. Site L2 is located on the alluvium landform and on a stable streambed. Site L3 was chosen as a gauging station location as it was at the boundary where the landforms change from lower slopes derived from very hilly landscapes into an alluvial landform. The gauging site was stable with a small rounded rock streambed surface.

L3 Streamflow

Site L3 measured the stream flow and electrical conductivity at the bottom of the drained the meta sediment landform and recorded persistent stream flow for the first 3 years of measurement. Due to logger malfunction no data was recorded from mid 2004 to late 2005. The sensor was replaced in 2005 and subsequent rainfall allowed stream flow to be measured through 2005 through until Oct 2007 when the sensor malfunctioned again.

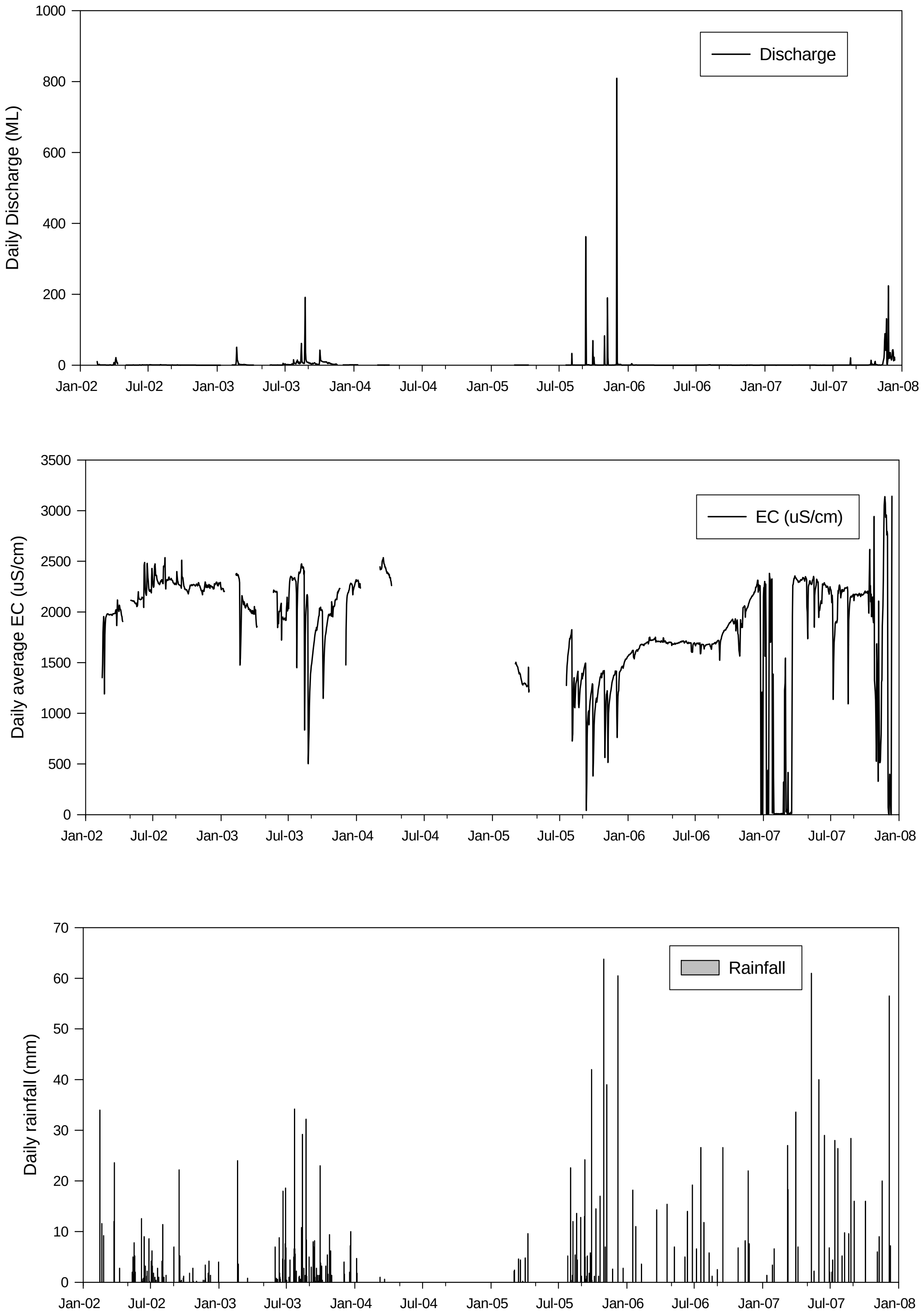


Figure 10 Daily discharge, EC and rainfall at L3 stage 2002 to 2008

Over the period of observation saline base flow dominated the record with persistent flows occurring throughout the period of measurement. These flows were also saline with the average EC over the period being 1796 υS/cm. The mean flow weighted EC for the period was 1413 υS/cm. Peak EC recorded was just over 3100 υS/cm in late 2007 however this reading is suspect as the sensor malfunctioned soon after.

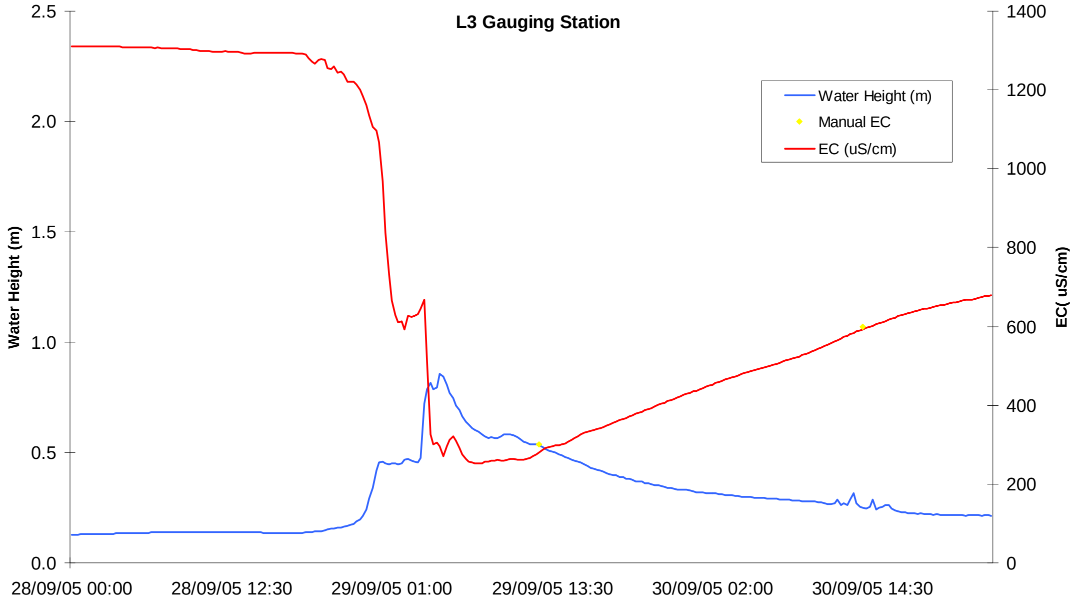


Figure 11 Typical steam flow event from meta sediments showing saline base flow then subsequent dilution the re-establishment of equilibrium

The patterns of salt transport follow that described by Summerell (2005), as saline baseflow then dilution by rainfall then re-establishing the EC back to the pre event equilibrium (Fig 11). The saline baseflow is sourced form the meta sediments and flows to the creek line, groundwater that does not drain to the creek line pressurises the meta sediment ground water system (w12) and transport salt to the alluvial landform.

L3 Salinity transport

Significant amounts of salt were mobilised and drained from the meta sediments over the observation period. Using the incomplete data set it can be estimated that just over 4500 tonnes of salt was drained over from this landscape over 7 years of observation. The severe drought in 2006 it was estimated that only 22 tonnes of salt was drained from the meta sediments it had a relatively high flow weighted mean EC, indeed it can be seen that in the two dry years 2002 and 2006 although the salt load was low the flow weighted mean EC was high as compared to the other years.

Table 2 Streamflow and salt load L3 gauging station

L3	Discharge ML	Salt t	Flow weighted EC υS/cm
2002	196	254	2026
2003	1448	1516	1633
2004*	16	25	2335
2005	1790	1070	933
2006	21	22	1643
2007	1351	1677	1937
Total	4821	4563	1435

*incomplete data

L2 stream flow

The stream flow recorded at L2 measures the water drained from the meta sediment head waters as well as some of the surface water that is drained from the alluvial landform. The main advantage of this gauging station is that it located on a stable cross section and low flows from this site can be accurately gauged.

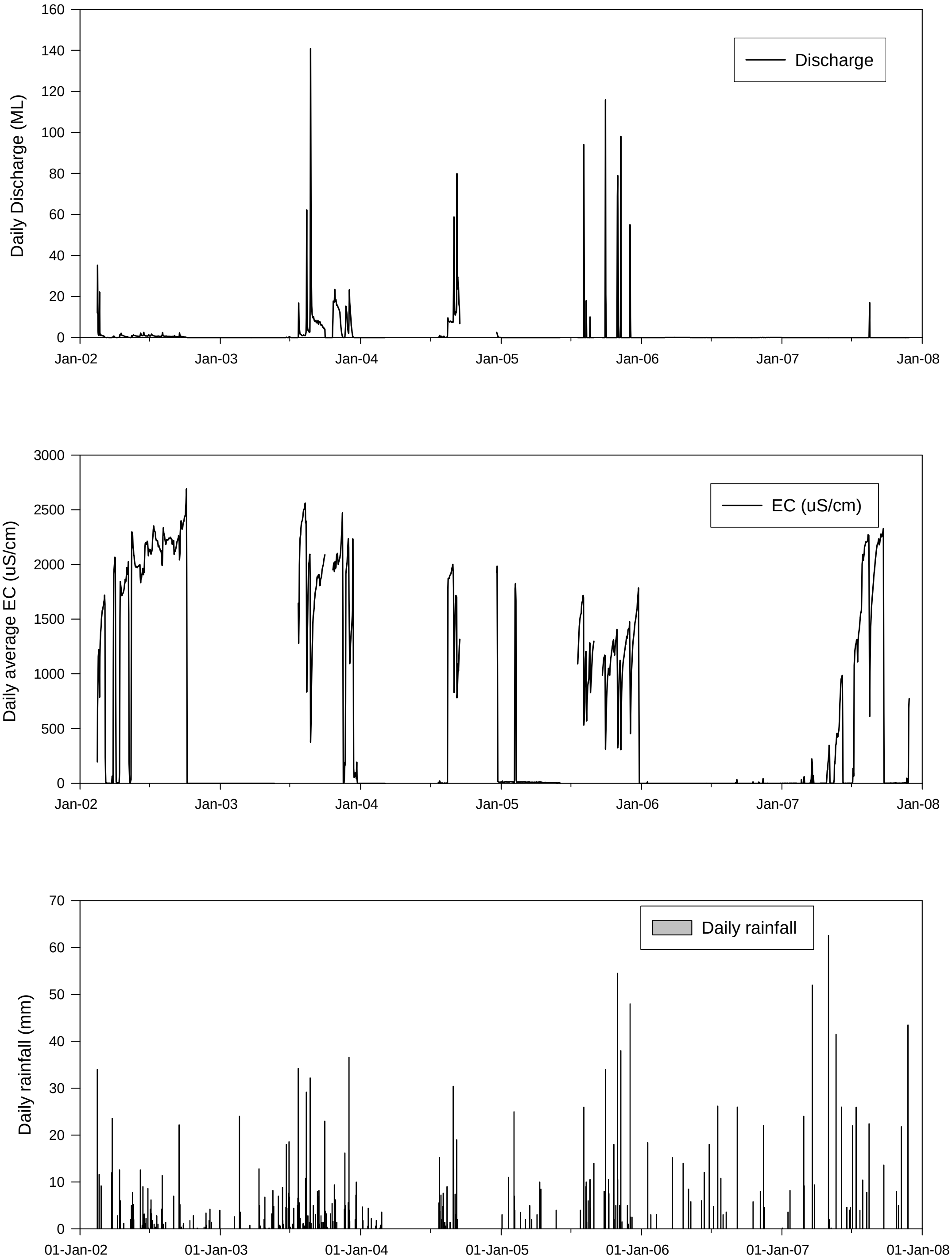


Figure 12 Daily discharge, EC and rainfall at L2 stage 2002 to 2008

The average EC of the stream flow from beginning of the observation period in February 2002 to October 2007 was 578 υs/cm. However significant spikes in EC were recorded in this observation period with the maximum recorded EC being 2688 υs/cm in October 2002. A significant stream flow event is recorded in the data between 18 Jan 2005 and 2 Feb 2005, however this appears to be a sensor error.

Using the rating curve developed by Summerell (2005) total salt load past L2 for the period was 1557 t, with the majority of the salt being exported during the wetter years 2003-05.

The patterns of salt movement are similar to L3 with saline base flow being present prior to a runoff event and with the onset of runoff and stream flow this additional water acts to dilute the base flow. However at this site there is an additional salt source evidenced by the rapid rise and fall of the stream EC trace during the rising limb of the hydrograph. This follows from Summerell (2005) which suggests a pulse of salt is generated and transported to the stream via the paleochannel in the alluvial landform. This flushing effect allows the salt to be transported from the alluvial landform to the stream and minimises the risk of land salinisation.

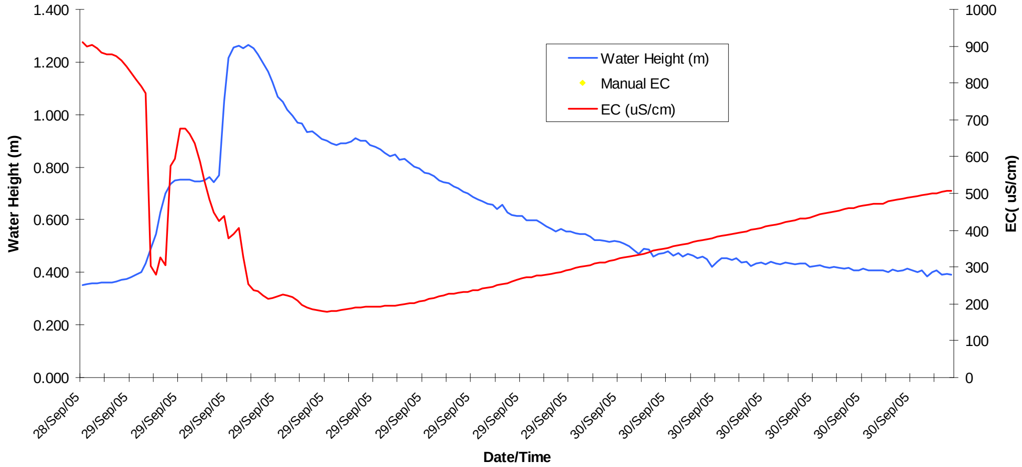


Figure 13 Stream flow event September 2005 L2

L2 Salinity transport

The patterns of salt mobilisation and transport observed at the L2 gauging station as compared to the L3 gauging station were initially broadly similar with high amounts of salts exported in 2003 and 2004. However there was a marked change in patterns of the flow weighted mean EC at L2 as compared to L3 with L2 having a declining trend in flow weighted mean EC from 2002 onwards suggesting that less salt per ML was being exported.

Table 3 L2 Streamflow quantity and quality

Year	Discharge (ML)	Salt load (t)	Flow weighted mean EC (υs/cm)
2002	221	218	1542
2003	1176	1122	1489
2004	533	437	1279
2005	604	206	531
2006	0	0	31
2007	17	7	610
Total	2551	1989	1217

This fits with the conceptualisation of the catchment and the observations of declining groundwater pressures in the alluvium. As the gradient of groundwater decreases then there is a decrease in the amount of salt that this transport and less salt is then leached from alluvium into the paleochannel and it to the stream.

O1 stream flow

The stream flow recorded at O1 measures the water drained from the site and represents the end of catchment for the Livingstone Creek site. The site was located on sand and a number of events in 2002-03 were used to develop a rating curve. It should be noted that due to resources this stage has not been re-rated since 2004.

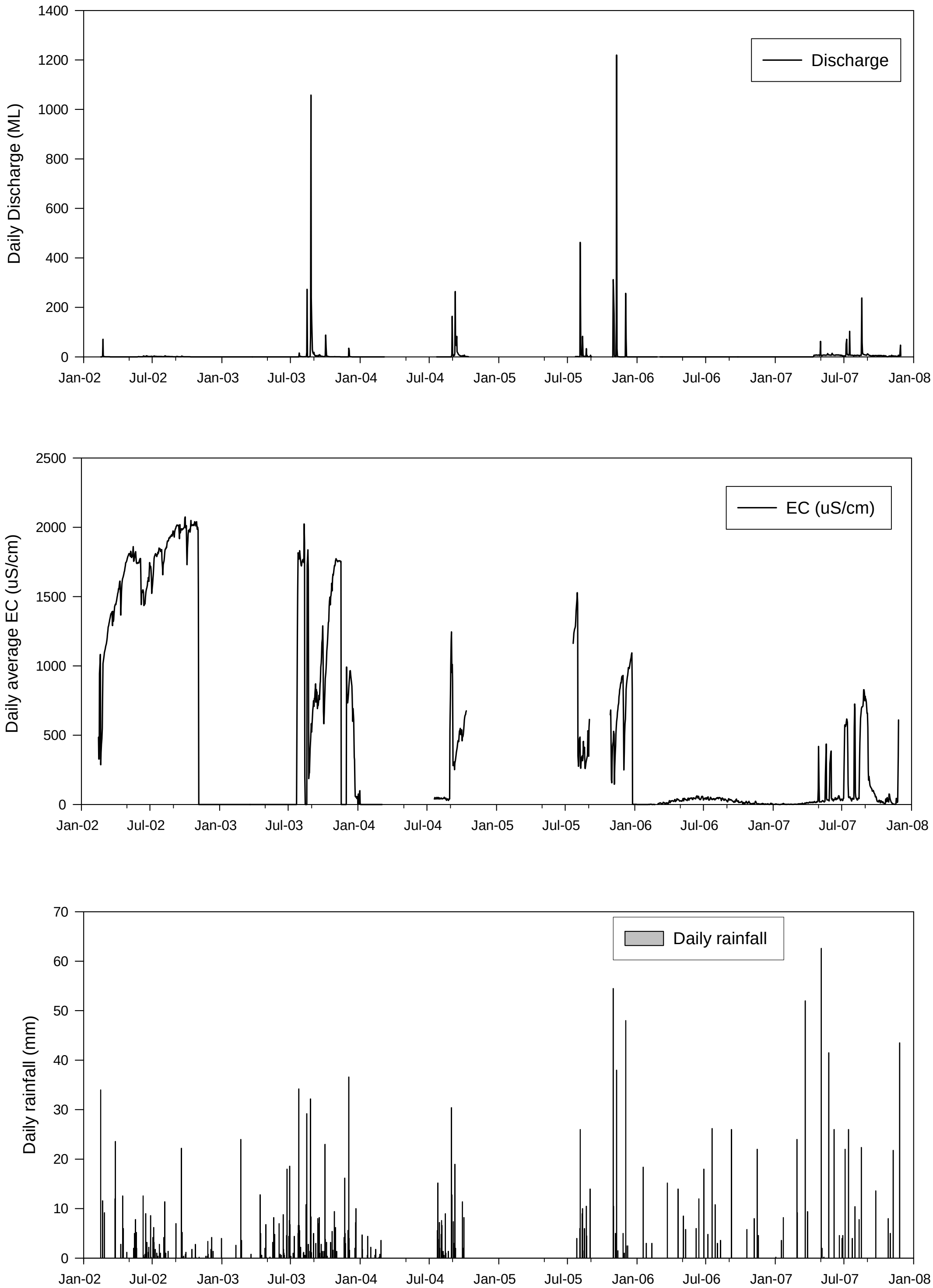


Figure 14 Daily discharge, EC and rainfall at O1 stage 2002 to 2008

The average EC for the O1 site from February 2002 to late 2007 was 500uS/cm with the maximum EC recorded was 2247 uS/cm in late 2002. There was a number of significant runoff events occurred during this time however it should be noted on 8 November 2005 when 38 mm fell causing a significant runoff event to occur. The pattern of salinity appears to be declining through the observation period with the higher EC's occurring in the earlier part of the observation and then declining as the observation periods progressed.

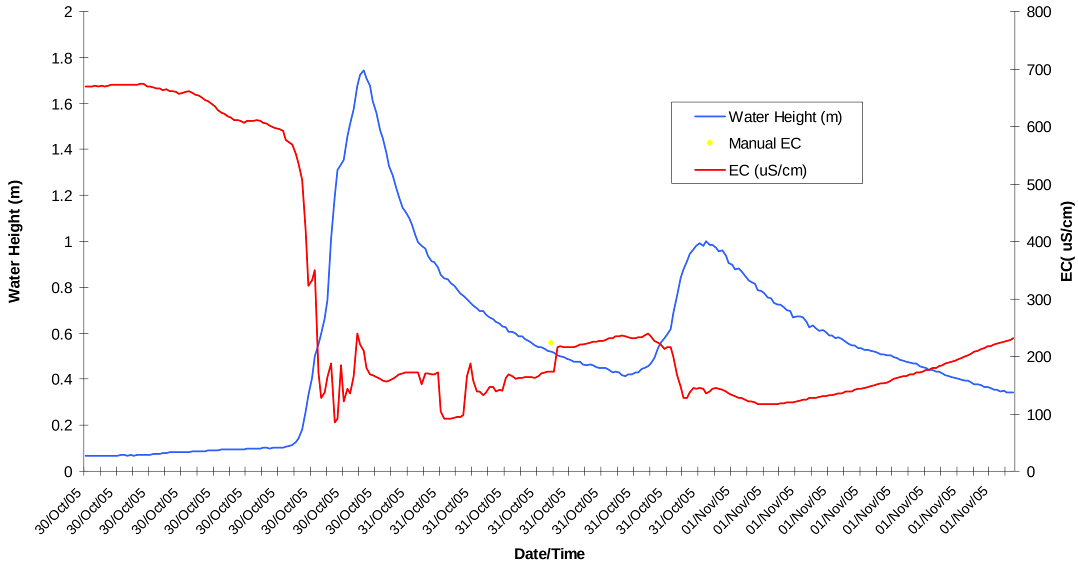


Figure 15 Streamflow event as measured at O1 30 Oct 2005

As O1 is the end of systems the stream flow and EC measurement is an integration of the range of catchment processes. This can been seen in a typical response to a rainfall event (fig. 15) where moderately saline base flow was flowing until the rainfall diluted the stream flow, there was small increases to the EC as the paleo channel contributed to the salt load, but as runoff event dissipated the EC began to return to pre-event conditions.

O1 Salinity transport

The patterns of salinity expression as measured at the O1 gauging station show a the total salt load depends on the rainfall, with the relatively wet years 2003 and 2005 exporting the most amount of salt while the drier years 2002 and 2006 exported the least. The missing data for most of 2004 is the reason for the low salt export for that year. The declining trend of annual flow weighted EC shows that since 2002 there have been less salt mobilised per ML of water drained from the Livingstone Creek catchment. This is similar to the L2 and L3 gauging station which also show declining trends in flow weighted EC.

O1	Discharge ML	Salt t	Flow weighted EC υS/cm
2002	290	245	1317
2003	2388	549	384
2004*	934	232	388
2005	3213	606	294
2006	0	0	
2007	1984	314	246
Total	8809	1984	351

*incomplete data

Stream flows, losses and water quality
Streamflow is measured at two stages longitudinally down the Livingstone Creek and further downstream of the confluence of Livingstone Creek and O'Brien's Creek. Initially when to gauging sites were developed it was thought that salt and water balances could be developed from the data derived from these sites. However due to a range of factors there appears to be significant in stream losses that mitigate the formation of salt and water balances from the Livingstone Creek site. Summerell (2005) measured large mass balance errors in salt load (up to 50%) for individual events as well as smaller mass balance errors for streamflow.

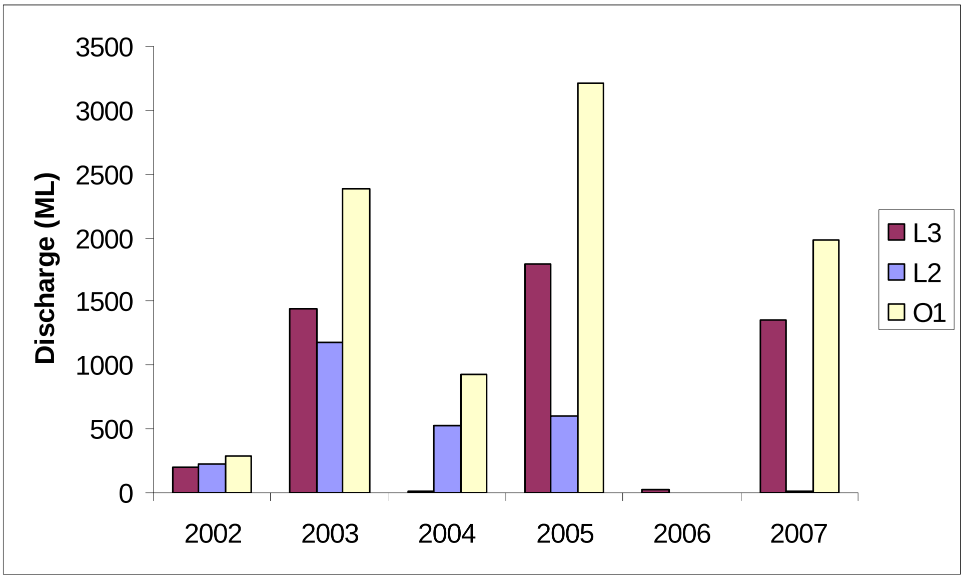


Figure 16 Annual Streamflow from L3 L2 and O1 gauge

Factors such as the sandy bottom of the creek and water infiltrating the dry creek beds were suggested as reasons for the mass balance error. Additionally there has not been a re-rating of any of the sites since 2004, and Summerell (2005) pointed out that as the sites L2 and O1 have a sandy bottom, significant errors can occur without independent measure of stream velocity and cross section.

It is difficult to attribute total stream and salt generation from the three broad landforms as measured at the O1 gauging station due to the additional losses and sinks in creek that are not accounted for and hence the mass balance cannot be completed.

However looking at the streamflow and salt load data from the three gauging stations it can been seen that most of the water appears to be generated in the headwaters (meta sediments, L3) but there are additional sources of water that contribute to flow (fig16).

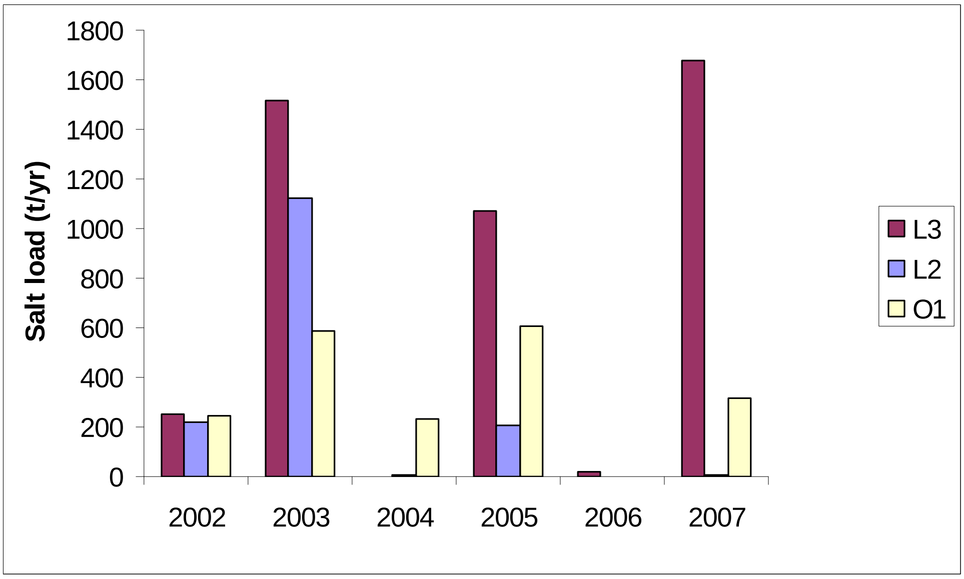


Figure 17 Annual salt loads from L3 L2 and O1 gauge

However in terms of salt generation it can be see that the headwaters (meta sediments, L3) mobilise and transport more salt than that is actually drained from the catchment (fig 17). This suggest that salt is being mobilised and transported from the meta-sediments and then being stored in the near alluvial or hyporheic zone further downstream from L3.

4.3.4 Implications of the resource monitoring

The desired outcome of the monitoring is to understand the effect and of both land use and climate on changes to the resource condition at Livingstone Creek over the monitoring period. The major change that occurred at the Livingstone Creek site has been the dramatic decrease in rainfall over the six years of monitoring. At the same time while this has affected the land management decisions landholders have made there has not been a great if any change to the landuse within Livingstone Creek. Therefore it is argued that any changes to resource condition must be from changes to climate and in particular rainfall.

To identify what the changes if any to overall salt mobilisation and transport both the annual total salt load (fig 18), and the annual flow weighted EC of the stream (fig 19) were plotted against annual rainfall.

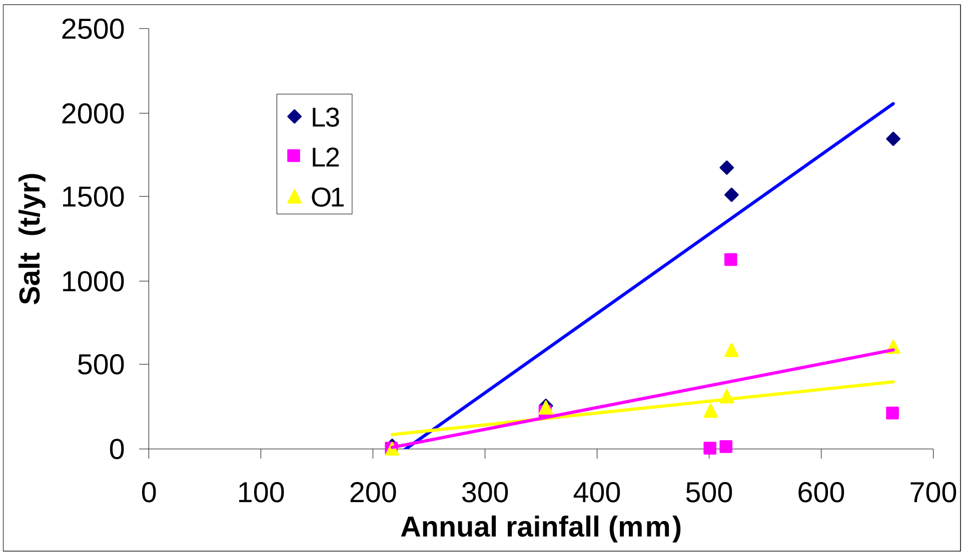


Figure 18 The effect of annual rainfall on salt load as measured at L3, L2 and O1 gauges

In general increasing rainfall increased the salt load in the Livingstone Creek and there appears to be an annual rainfall threshold which needs to be exceeded before significant salt is exported from the catchment. From the limited collected data this appears to be about 350 mm. It should be noted that this is based on seven years of measurement and there are many other factors to be considered including seasonality of rainfall and landuse. One of the factors is that this relationship assumes that the system is in equilibrium however as the last seven years has been well below average rainfall this assumption may not be valid.

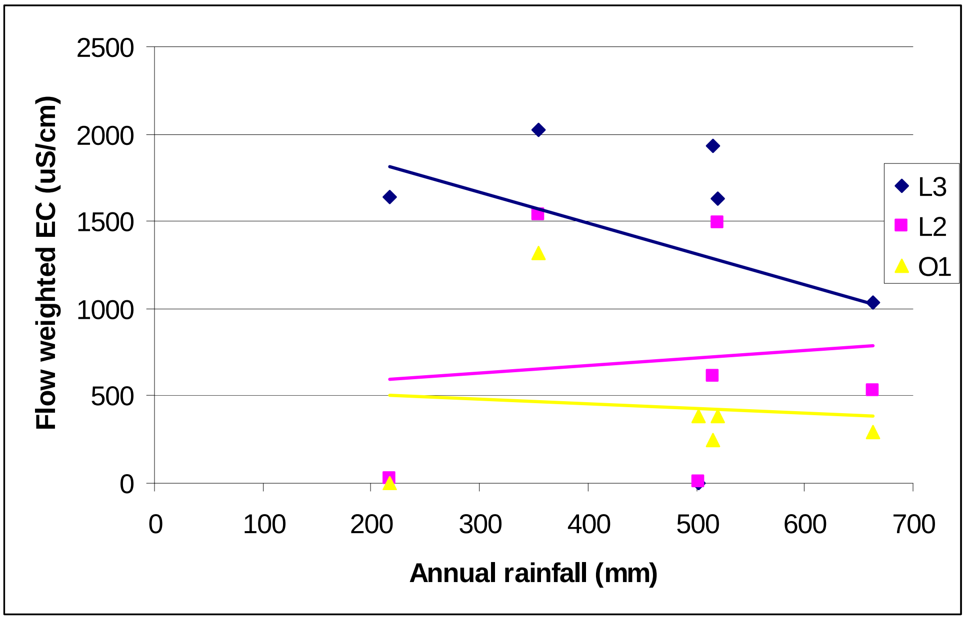


Figure 19 The effect of annual rainfall on flow weighted EC as measured at L3, L2 and O1 gauges

There appears to be less relationship between the flow weighted EC and annual rainfall than between salt load and annual rainfall. However the trend shows that in the dry years when there was between 200 and 400 mm of annual rainfall the flow weighted EC increased with increasing rainfall, however when average rainfall occurred it provided dilution flow and the flow weighted EC decreased with increasing rainfall.

Conclusions

This decrease rainfall led to a decline in the groundwater elevation between 1-3 m while it can bee seen that the amount of salt and water draining from the catchment is highly dependent on rainfall, with higher salt and water exports occurring in the wetter years as opposed to low salt and water exports in the drier years.

It is postulated that the below average rainfall over the study period has been a proxy for a perennialisation of the Livingstone Creek site, the drought has substantially reduced recharge into the meta sediments which in turn has reduced salt mobilisation and transport to the stream in the alluvial landform. The flow weighted EC for the meta-sediments remains about the same level at below annual rainfalls of up to 500 mm. However with increasing rainfall the additional water appears not to mobilise additional salt and dilution occurs.

This finding agrees with the conceptualisation of the catchment proposed in Summerell (2005). This also suggest that there may be a window of opportunity to establish perennial landuses within the meta sediments while this drought signal, (decrease in groundwater levels and streamflow) works it way through the groundwater flow systems within the Livingstone Creek site.

4.4 NAFE

From October 30th to November 20th 2006 the second NAFE field campaign was undertaken to field test a range of airborne sensors to detect near surface soil moisture (0-30 cm). The Livingstone creek was a major field site for groundtruthing of the sensors.

During the 3-week experiment, the Polarimetric L-band Multi-beam Radiometer (PLMR) and supporting instruments (thermal imager and NDVI scanner) were flown over two well-instrumented sites in the Murrumbidgee: the 3600 km2 Yanco area and the 600 km2 Kyeamba Creek catchment.

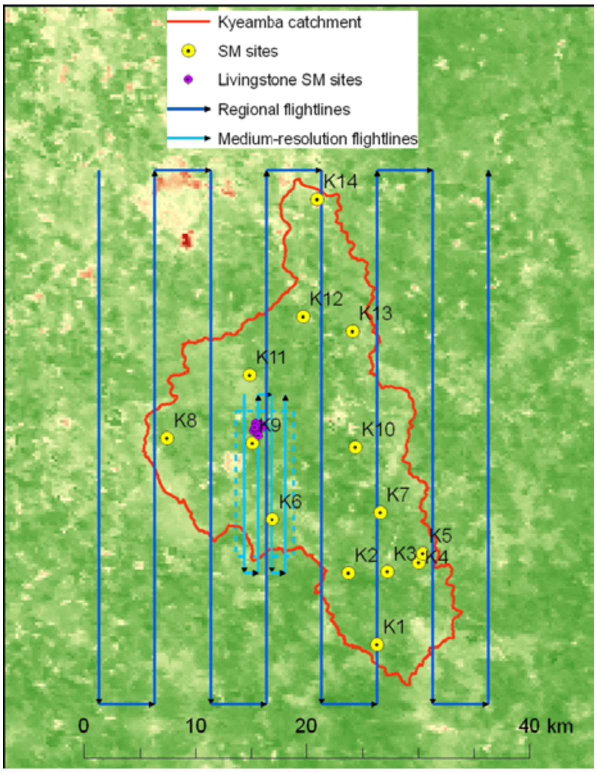


Figure 20 NAFE flight lines Purple point shows Livingstone Creek

To that end a monthly water balance was developed

Landform	Rain (mm)	ET (mm)	Deep Drainage (mm)	Runoff (mm)	Total
Meta-Sediments bottom of Catchment	218	265 (122)	0	0	265 (122%)
Alluvium	218	271 (124%)	0	0	271 (124%)
Upper-Catchment	224				

4.5 Tree water use

Summary of results (after 12 months)

- Growth and water use of the three species were similar.
- DBH and CWA for *E. occidentalis* are slightly greater than for *E. camaldelensis* and *E. cladocalyx*

- *E. occidentalis* uses a considerable amount (45%) of saline groundwater with *E. camaldelensis* also using a significant amount (25%)

Future
A thinning study will be carried out to determine growth and water use response and to quantify different, sources of water for their growth over another 12-month period.

- Continue monitoring the water balance components:
  - transpiration
  - evaporation
  - soil moisture, depletion
  - watertable fluctuation
- Continue monitoring tree growth and physiological components:
- Use 3-PG+ to prescribe optimal thinning strategy in order to maximise growth and water use of these species and test against measured growth and water use data.
- Evaluate options for applying 3-PG+-FLUSH to this mini-catchment

This work will broaden our understanding of how we can manage saline ground water tables in these environments and increase the availability of technical knowledge about species selection and management of discharge area tree plantings.

4.6 Model Validation

Data from the Livingstone Creek site was used to formulate and validate the three stores model (Dawes *et al.* 2004) and was used to reconceptualise 2C Salt (a salinity model accredited by the MDBC) and add an additional store of salt and water.

4.7 Capacity Building

The Livingstone Creek site has been used to demonstrate, explain the train CMA staff in the basics of salinity management and processes. It provides a microcosm of the typical landforms that is present in the mid Murrumbidgee and mid Murray catchments. Specifically there was training and demonstration of methods and equipment for stream sampling.

NSW DPI provides salinity training to a private and public natural resource and agricultural advisors. As such the Livingstone Creek site has provided a site to demonstrate and train these advisors. At the time of writing XX of advisors have been trained by DPI. Additional to the training that was performed at the Livingstone Creek site additional training was undertaken at the linked discharge site at the Wagga Resource Centre for Wagga City Council staff.
CSU agro forestry course

4.8 Data

As part of the research activities that have taken place at the Livingstone Creek site a high quality long term eco-hydrological data set has been created. This data set was started in mid 2001. This data set includes groundwater soil water stream flow and EC and climate data including ET as measured by a solid state BR unit.

Instrument	Environmental variable	Measuring frequency	Number
Piezometer	Groundwater depth	8 hourly	21
Theta probe	Soil moisture	8 hourly	8
Pressure/EC	Stream flow	hourly	3
Weather Station	Climate	hourly	1
BR unit	Evapotranspiration	hourly	1

5. Discussion

Significant salt loads are generated out of the alluvial landform in Livingstone Creek compared to other parts of the catchment where hillslope hydrology dominates. In managing salinity problems, salt loads calculations are often used to target areas for amelioration as large quantities of salt entering the streams are identified. Under this scenario the alluvial landform of Livingstone Creek would be treated by reducing recharge in the alluvial landform to stop the flushing of salts out of the landscape. This option would only exacerbate the problem. To treat the salinity problem we need to reduce the amount of salts being placed into the alluvial landscape store by reducing the pressure of the groundwater in the underlying semi-confined meta-sedimentary fractured rock groundwater system. Recharge in the alluvial groundwater system needs to be maintained as:

(a) The greater the head of water in the alluvial groundwater system, the more weight it applies to the underlying pressurised semi-confined meta-sedimentary fracture rock groundwater system. This will reduce the ability of the metasedimentary groundwater to mix into the alluvial landform.

(b) The rapid recharge that generates the subsurface lateral flow mechanisms in the alluvial landform allows for flushing of salts out of this landscape. If these salts are not flushed then salt concentration would occur and the development of soil salinity and sodicity problems. This scenario is happening in the low lying meta-sedimentary landform where flushing of salts does not occur. Within the Murray Darling Basin metasedimentary basement rock overlain by large expanses of alluvial landforms in upland areas is common. Therefore other stream and land salinisation areas caused by the processes described for Livingstone Creek may occur. Defining a simple way to define these areas will be the challenge.

Water movement through the landscapes of upland catchments is often conceptualized as being dominated by hillslope hydrology. This study follows on from a field study undertaken by Summerell *et al.* (2006) where they showed that the flat alluvial landforms within the catchment were delivering significant contribution of soil and groundwater mobilised through rapid recharge into the soil profile. This recharge initiated lateral flow process into the stream network during rainfall events. Within the Livingstone Creek catchment hillslope hydrology dominated in the sloping landscape whereas in the flat valleys water movement and infiltration occurs via the lateral flow processes just described. The stream salinity responses in the hillslope landscapes showed the classical salinity response to an event. This includes an initial spiking of salinity at the beginning of an event (due to first flush) which then trended to dilution of salinity as the event continued. In the flatter alluvial landforms, the response shows a quite different form where salinity continues to trend with event flows.

Groundwater salinities and hydrographs

Groundwater salinities varied throughout the field study site but generalisations could be made. Groundwater in the metasediments where of higher salinity than the alluvial which were higher again than the granites. The groundwater in the semi-confined meta-sedimentary fracture rock system is around 3000 μS/cm.

Rapid rises and falls in groundwater levels in the alluvial occur during rainfall events and can take up to 2 weeks to dissipate. This groundwater trend occurs throughout the alluvial landform although groundwater fluctuations are not as extreme (number height change). Summerell *et al* (2004) also indicated that these groundwater fluctuations are not the result of stream water feeding back into the alluvial landscape through paleochannels as water level gradients are towards the creek. These groundwater hydrograph trends also occurred when stream flows were not present.

Stream salinities trended with flows through the alluvial landform during events. This is the result of soil and groundwaters flushing salts out of the alluvial landform. During dry periods the salinity increases and salt speciation changes to reflect the sodium chloride groundwater within the meta-sedimentary groundwater systems, and or as a result of evapo-transpiration processes and reduced bio-activity and carbon dioxide escape of pore water from quickly recharge waters (Freeze and Cherry, 1979).

Resource condition

The value of long term (more than 5 years) and high spatial (within 1 km) and temporal (at least daily) resolution data set is shown by the results and knowledge generated. The data that has been acquired during the seven years at the Livingstone Creek reveals that climate has a major influence on both salt mobilisation and transport, a fact that until now has only been shown in one previous study in NSW (Crosbie *et al.* 2007) and recent modelling studies such as the 2006 NSW Salinity Audit (Littleboy *et al.* 2008). Ongoing datasets such as the one being developed for Livingstone Creek adds not only the regional understanding of eco-hydrological and biophysical processes but also to national and international studies that are being conducted to determine what is the effect of anthropogenic and natural activities on the environment. All of these studies are leading to greater understanding of the effect of these processes and more importantly these studies are looking at what are the possible management options that can be implemented to address changes to the natural resource base.

Collaboration

Livingstone Creek has provided a point of focus for ongoing international national and regional collaboration, including NRM training and capacity building. This has manifested in up to 10 separate research activities being undertaken on Li vingstone Creek since 2002. This has included directly two universities (University of Melbourne, University of NSW, five CRC's (Catchment Hydrology, eWater, Salinity, Future Farm Industries, Spatial Systems) 3 state government agencies, (DECC, DWE, DPI) two CMA's (Murray, Murrumbidgee), CSIRO, and a range of international organisations including NASA and United States Geological Survey as part of Livingstone Creeks input into the Murrumbidgee Monitoring Network (MMN) which in turn is part of the OZNET project.

6. Outcomes

1) Model development should be constructed around the distribution of landforms to best represent landscape to stream connectivity of water and salt movement. Many different landforms exist within a catchment. Therefore landform heterogeneity within a catchment must be accounted for.

2) Stream salinity responses can be conceptually linked to landforms

3) Understanding of initial catchment wetness conditions before an event will determine the magnitude of a stream salinity response between landforms and also provide indications of new and old water contributions from the landscape.

4) Antecedent catchment wetness conditions determine the types of salts available for transport during an event. Therefore the choice of salt load conversion factors for both rising and falling limbs of an event can be determined.

5) Catchments dominated by hill slope landscapes are better represented by current salinity modelling techniques that are based on hill slope hydrology. Catchments dominated by low relief / alluvial landscapes need further model development most likely at finer time steps, representing infiltration of water through preferential flow paths and potentially interaction with deeper groundwater systems.

6) It is critical to represent lateral flow processes in both hill slope and alluvial landforms as this is an important pathway for salt delivery mechanisms to the stream.

7) Response times of salt fluxes to the stream are closely associated to landform type, distance of recharge and discharge zones, conductivity and transmissivity. Model development needs to incorporate these landscape attributes.

8) Measuring and modelling these processes require generalisations to be made. An understanding of soil material properties and checks against stream water and salt contributions provide one way of determining the most likely locations in the landscape that these flows are generated from and an overall lateral flow contribution estimate.

9) Data set that helped conceptualise and validate 2C Salt specifically measured data from LC was used to add a third water/salt store to the model.

10) Data from the NAFE program confirmed that the ridge tops appear to be major source of recharge for the catchment.

11) Significant training site for natural resource advisors

12) Long term high quality eco hydrological data set of sufficient spatio-temporal resolution essential for calibration of climatic models

13) Maybe a window of opportunity to establish perennial landuses within the meta sediments while this drought signal, (decrease in groundwater levels and streamflow) works it way through the groundwater flow systems within the Livingstone Creek site.

7. Recommendations

1. The meta-sediment geology landscape needs to be targeted for perennial plantings that limit recharge.

Strategic recharge control in the headwaters of the catchment underlined by the meta-sediment geology landscape is needed to prevent the salts becoming mobilised and being transported into the alluvial landscape.

2. Maintain the leakiness of the alluvial landform. At present the landuse on this landscape is an annual cropping dominated farming systems and is highly productive and profitable and this activity should continue.

Salts are flushed out of the alluvial landscape and into the nearby waterways, as noted above in the Livingstone Creek catchment saline water moves down the valley through the meta-sediments geology. These salts leach into the alluvial landform, and during wet catchment conditions are flushed out through soil water movement. It is this process that drives the stream salinity response of salinity trending with flow.

3. The granites landform provides fresh surface and ground water to the catchment. It is recommended that it continue as broadly a cropped landscape and be recognised as a fresh water generating landscape. It should be noted that the soils in this landscape vary greatly and as such need to be managed more specifically. Further research is needed to fully understand the processes occurring on these landscapes.

4. Monitoring of the environmental variables continue through a La Nina phase to validate our understanding of the catchment processes during a wetter climate phase.

5. All salinity modelling tools should include a conceptualisation which allows for the processes of alluvial landform salt and water movement to the stream, as identified by this project.

6. Training and capacity building should continue on the Livingstone Creek Site.

The Livingstone Creek site has provides a unique resource that represent the major landforms in the mid MDB. As such it has been integral to the hydrology, salinity and natural resource management training in southern NSW.

7. Future funding arrangements should be pursued.

The intensive baseline collected on the site enables Livingstone Creek to be part of a suite of long term land and resource condition monitoring sites. The individual research projects have added significant information to the public domain, but the defendable conclusions and recommendations are only possible because of the collective understanding at large and small scales within the catchment.

Many of the conclusions and recommendations about and for Livingstone Creek Site are only possible because of the range of information collected over a range of temporal and spatial scales. Such intense information collection will be possible in only a minor number of catchments and a process must be found to generalise from such work to assist the management of the vast number of catchments for which no detailed information will ever be collected.

Livingstone Creek field site has attracted many other new research programs and organisations including; University of Melbourne, University of Adelaide, CSIRO Land and Water, CRC eWater and the former CRC for Catchment Hydrology, NASA, Department of Natural Resources

8. Future

A major research effort has been directed into the Livingstone Creek Site, with significant changes to the management recommendations for both public and private investment that may relate to salinity management. However, as always, significant gaps in knowledge remain. The most significant seem to be:

1 Continued monitoring will capture variations in current climate patterns and will indicate how this variation affects the transport of salt from the landscape to streams providing better information with regards to climate change

2 Quantifying the catchment outcomes (potential reductions in downstream salinity) from the range of interventions that are possible. The major intervention is to replant the metasediments landscapes to perennials to reduce recharge. The research suggests that catchment benefits will increase across a range of interventions, but this must be quantified in order to assess the likely return on (especially) any public investment made.

3 Management of granite and alluvial landscapes should be pursued as part of sustainable land management practices promoted by NSW DPI. These activities include establishment and management of perennial pastures and conservation cropping.

4 The series of studies presented in this report highlight the increased understanding that can arise when agencies take a long term integrated approach to natural resource management research. Agencies should not look solely at providing outcomes to the investor but using the investment to pursue long term integrated and strategic research goals.

Partners in this work may include CMA's NSW DWE, DECC, CRC's eWater and FFI, Universities, CSIRO and private individuals.

9. Publications and Further Reading

Understanding the Processes of salt movement from the landscape to the stream in dryland catchments. Summerell GK (2004) PhD Thesis, The University of Melbourne.

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