

*A case study of integrated hydrology
research in the Macquarie
Catchment:
Sloanes Creek Catchment Key Site*

Title: A case study of integrated hydrology research in the Macquarie Catchment: Sloanes Creek Catchment Key Site

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History

In August 2000, the NSW Salinity Strategy was released with a vision to have a State that has:

- Healthy ecosystems, where environmental values are maintained and, where possible, restored;
- Sustainable, productive land and water uses; and
- Secure, sustainable and prosperous communities.

The Salinity Strategy has eight key tools to achieve its outcomes and within these tools 52 actions, one being to undertake research to increase the knowledge of how to remediate salinity at a farm and paddock scale and identify productive solutions to combat salinity. Additionally there was a need to identify an appropriate range of land uses to mitigate salinity while maintaining fresh water flows. NSW Agriculture and then NSW DPI developed two research sites and six model farms to assist in identifying appropriate land use and farming systems one of the research sites was the Sloane's Creek Site.

The site was developed in spring 2002 and this was supported by the NSW Salinity Strategy. The instrumentation was installed to identify and measure the processes of that cause and contribute to salt and water movement within the landscape and also from the landscape to the stream in a typical upland dryland catchment. In July 2005 it became a part of NSW DPI Key Sites Project funded by the National Action Plan for Salinity and Water Quality.

Site Description

The Sloane's Creek catchment is located 33km North of Molong and 35 km South of Wellington on the Mitchell Highway and is part of the Bell River catchment (fig. 1). The Sloane's Creek catchment is approximately 700 ha and average annual rainfall is 600 mm.

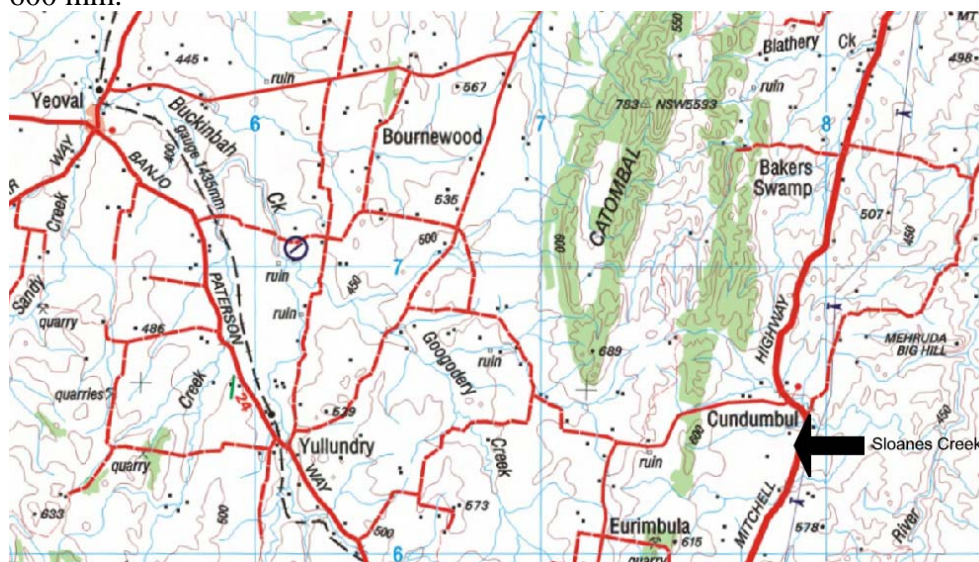


Figure 1 Location of the Sloane's Creek Key Site

The catchment is bounded on the west side by a high ridge of the Catombal Group, consisting of Devonian sandstone, conglomerate, and shale. The bulk of the catchment consists of Ordovician andesite, tuff, conglomerate, siltstone and

limestone. An intermittent stream rises on the western side of the catchment and drains on the eastern side and a large saline scald (approximately 10 ha) near a topographic constriction located on the eastern side upstream of the catchment outlet. The catchment has an easterly aspect, topographic relief of about 80 m and a slope between one and four percent. The majority of the catchment is arable but has some areas of remnant revegetation and there has been afforestation on the saline scald.

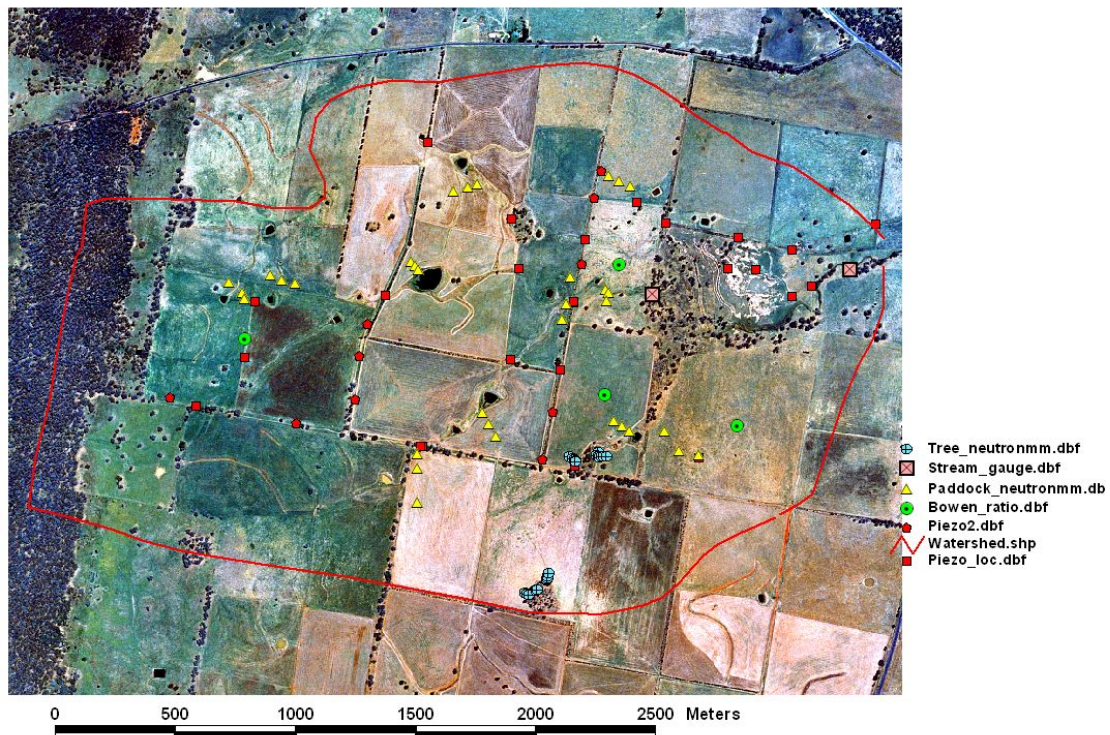


Figure 2 Aerial photo of Sloane's Creek research site and location of instrumentation

Geology

The Sloanes Ck catchment sits within the Lachlan Fold belt a large syncline within the larger subsided Tasman trough. Within the Lachlan Fold belt a number of geologies are present with the oldest from the Cambrian or early Ordovician, then continuing through to the Silurian, Devonian and Carboniferous. The last major geological event was the Tertiary volcanic intrusions 10-15 Ma.

The geology at the site is dominated by the Cabonne group (green shades in fig3) specifically the Oakdale group (unchecked green shade and the Fairbridge volcanics (labelled θcg). The scald is underlain by Ordovician aged geology specifically the Mitchell Formation while the upper end of the catchment is underlain by the Catombal group specifically the Macquarie Park Sandstone (brown checked shade) Kurool formation.

The Oakdale formation is primarily mafic volcanic sandstone with basalt, basaltic andesite, latite lavas and intrusions; volcanoclastic breccia and conglomerate, siltstone, shale, chert; minor allochthonous limestone and calcareous sediments. The Fairbridge volcanics are basaltic to andesitic and latitic volcanics, volcanoclastic sandstone, tuff, conglomerate, breccia, siltstone; minor limestone, partly

allochthonous. The Mitchell formation is formed from latitic conglomerate, sandstone, siltstone; minor latite



Figure 3 Sloanes Creek catchment (red line), and scald (grey lines) geology

Catombal formation is a massive to bedded, red to brown, purple and green quartz and lithic sandstone, siltstone, shale and conglomerate, the Macquarie Park Sandstone is massive to bedded, fine to medium-grained quartz sandstone and the Kurool formation fine-grained arenite and red mudstone.

Western (1995) observed outcropping of intermediate to mafic volcanic rocks identified as andesitic porphyry. In the main creek line large metamorphosed rocks can be seen within the solum suggesting large debris flows.

Soils

The catchment has a mix of soil types that reflect the geology and hydrology of the site. The major soils types are Yellow Dermosols with smaller areas of Red Ferrosols and Brown Chromosols. The yellow Dermosol lacks texture contrast but has a well structured B horizon; Ferrosols are formed on either basic or ultrabasic igneous rocks, and well structured and have high levels of free iron oxide are very similar to the great soil group Kraznosems; while Chromosols are texture contrast soils without acidic or sodic B horizons (Red Brown Earths).

The lack of alluvial layering in the soil and the reasonably well developed soils eg ferrosols and dermosol suggest that soil development is not recent and is consistent with soil development over the last 10-100k years.

Land Use

Land use is typical of the mixed farming enterprises of the Bell river catchment. This includes 3-6 years of annual winter cropping followed by a perennial pasture phase of similar length. The perennial pastures are predominantly lucerne based but some areas have been planted to phalaris and/or native grass pasture. Annual winter cropping is based around a rotation of canola and wheat. The approximate areas of the individual

enterprises in 2003 was 60% perennial pastures, 30% crops, 5% tree cover (“Landcare” plantings and remnant native vegetation) and 5% roads and building.

Climate

The long term average rainfall at Wellington (closest rainfall station) is 576 mm and long term annual median rainfall is 571 mm, with a long term monthly median of 39 mm. There is no seasonal pattern to the rainfall however March and April have the lowest monthly median of 35 and 33 mm respectively while the October and January have the highest monthly median rainfall of 46 mm. Data from Datadrill for the catchment suggest that long term annual median rainfall is 623 mm with a long term monthly median of 44 mm. This data set suggests that February to April has the lowest median monthly totals of 36, 38 and 39 mm respectively.

Wellington has an average annual maximum temperature of 24 °C and an annual minimum temperature of 10 °C. The area is characterised by hot summers and cold winters with daily maximum temperatures reaching into the low 40 °C, and with a highest maximum temperature of 45 °C in Jan 1932 and Jan 1939. The area receives frosts from late April through to early September with daily minimum temperatures of 3-7 °C, with the lowest recorded temperature of -7.4 °C in August 1974. Potential evaporation peaks at 269 mm in January and exceeds average rainfall in all months, giving the area a semi-arid climate.

Monitoring equipment

A range of biophysical and hydrological processes has been measured on the site by the following monitoring equipment; soil moisture was measured at 33 neutron moisture meter (NMM) sites in pasture/crop paddocks; groundwater was measured at 26 piezometers; evapotranspiration was measured at four paddocks by Bowen Ratio units; and two stream gauges were installed at the catchment outlet and just above the scald (Figure 2.).

Climate

Several weather stations were located at the site from September 2002, these include an automatic rain gauge near the scald, and three Bowen Ratio units that measured evapotranspiration (fig. 2).

Soil

Location of the soil moisture monitoring sites was determined using a combination of FLAG (Fuzzy Logic Analysis GIS) terrain modelling, soil type and watertable height. A FLAG lowness value was determined across the catchment and was used to identify suitable sites for soil moisture monitoring with a NMM. This allows a certain degree of extrapolation for soil moisture measurements and resulted in strategic positioning of instruments to better represent the hydrology of the catchment.

Four sets of neutron probes access tubes were drilled to 6m and arranged in transects radiating out from tree lots have been installed to allow tree/crop or tree/pasture competition effects to be ascertained (Figure 1.).

Stream

Rectangular notch weir was installed at the catchment outlet in September 2002. The weir was 50 mm high and the notch was 20 mm deep and wide. A Greenspan CTD pressure transducer measured the water depth and EC upstream of the weir. A series of ratings was carried out on the stream in 2002 using a Pygmy meter to measure the velocity profile.

Groundwater

Piezometers were installed at 26 locations determined by a combination of EM 31 and FLAG lowness values. A series of transects were established to measure the groundwater response at strategic locations throughout the catchment. The piezometers were installed using a rotary air drill to depths ranging from 4-20 m deep. The piezometers were cased in 70 mm pvc and slotted for 0.5 m.

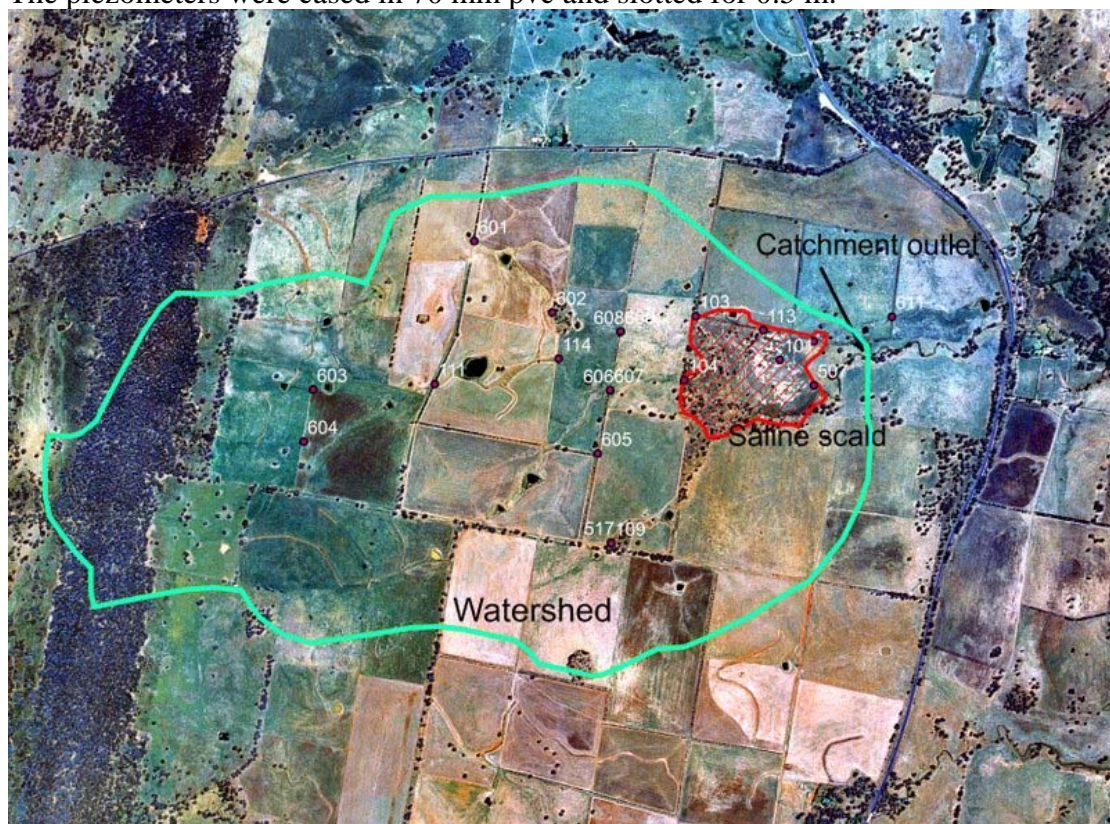


Figure 4 Piezometer location and names

Hydrograph Analysis: Rainfall and Time Trend (HARTT)

HARTT statistically separates the effect of atypical rainfall events from underlying time trends in groundwater movement. In the HARTT method rainfall is represented as an accumulation of deviations from average rainfall, and the lag between rainfall and the effect on groundwater is explicitly represented. To calculate the accumulation of deviation from average rainfall, residual rainfall is determined by:

$$AMRR = \sum_{i=1}^j (M_{ij} - \overline{M}_j)$$

where

AMRR is accumulative monthly residual rainfall

M_{ij} is rainfall in j month of year i

\overline{M}_j is mean monthly rainfall for month j
t is the month since the start of the data

A regression model (eqn 2) was fitted to the time series where;

$$\text{Depth}_t = k_0 + k_1 \times \text{AMRR}_{t-L} + k_2 \times t$$

Where

Depth is depth to groundwater (m)

k0 is approximately equal to the initial depth to groundwater (m),

k1 is the impact of above- or below-average rainfall on groundwater level (m),

k2 is the trend rate of groundwater rise or fall over time (m).

Evapotranspiration

Evapotranspiration consisting of transpiration of water from plants and evaporation from plant leaves, soil and free water surfaces was measured by solid state Bowen ratio units developed at NSW Agriculture. These units consist of:

2 Vaisala HMP45A humidity and temperature probes mounted in aspirated radiation shields

REBS Q*7.1 net radiometer

REBS HFT-3.1 ground heat flux plate

Pacific Data Systems PDS-WD/WS-10 wind speed and direction sensor

Hydrological Services TB3/0.2 tipping bucket raingauge

Datataker DT50 datalogger

CDMA modem

Solar panel, regulator and battery

The SSBR units measure the energy balance of the soil surface which in turn can be used to determine the Bowen Ratio which is the ratio between sensible heat and latent heat. This then can be used to measure evapotranspiration of plants. (needs more details).

Land use change

In January 2006 the main scald site was fenced and stock was excluded and salt tolerant grass and pasture species were sown. These species included Rhodes grass (*Chloris gayana*), *Puccinella*, tall wheat grass (*Thinopyrum ponticum*).

Investigations

Specific investigations were undertaken to identify the physio-chemical characteristics of the Sloane's Creek catchment. A survey was undertaken that coupled an EM31 with a RTK GPS in November 2003, this array allowed sensing of the apparent electrical conductivity (EC_a) of the soil and elevation (Table 1). The EC_a was measured to sub metre accuracy while the elevation was measured to within 2 cm accuracy.

Table 1 GPS, EM 31 and survey specifications

RTK GPS	Trimble 5700 RTK TSC1 logger (+/- 40mm vertical error)
Sampling interval	1 per second
EM	Geonics EM31 (vertical dipole)
Datum	WGS84,

EM31

Apparent electrical conductivity of the soil was measured with a Geonics EM 31 with the dipole in the vertical position. The survey was completed on a paddock by paddock basis with transect spacings of 25 m and aggregated to form a catchment survey. The data was imported into ARCGIS and a map produced using ordinary kriging with the default parameters.

Digital Elevation Model (DEM)

Elevation was measured using a Real Time Kinematic (RTK) GPS concurrently with the EM 31 survey. A digital elevation model was developed with ARCGIS using ordinary kriging with the default parameters.

Fuzzy Landscape Analysis Geographic information system (FLAG)

The elevation data collected in the survey was subjected to a Fuzzy Landscape Analysis Geographic information system (FLAG). FLAG is a process that identifies using elevation and position areas that may be subject to waterlogging or salinity, the technique is fully described in Roberts *et al.* (1998). In essence the catchment is divided into equal area usually 10 m by 10 m, these elements are then represent the surface of the catchment, The elements are then assigned a value based on their spatial relationship with all other cells, ie the highest cell may be given a value of 1 and the lowest cell a value of 0 and all other cells are ranked in order according to their elevation. A LOWNESS analysis assigns cells in a defined moving window (typically 13 x 13 pixels) and assigned a value according to the difference between the smoothed set and the unsmoothed set. Values that were low in the local (smoothed) landscape had high values, while cells that were equal or higher were assigned a zero value. An underlying assumption of the FLAG analysis is that the groundwater conforms to surface topography therefore cells that had high values would be areas where watertables would be expected to intersect the land surface and are susceptible to waterlogging or salinity.

Results and Discussion

Temperature

From 2002 to July 2007 average monthly maximum and minimum average temperatures were close to the long term average. Exceptions were summer 2003, 2004 and 2005 when higher average monthly minimum and maximum temperatures were recorded. The average monthly minimum in July 2002 of 0.7 °C was well below the long term average of 3 °C and temperatures in May and June 2006 of 1.7 and 0.8 °C were also much lower than the long term monthly average of 5 and 3 °C.

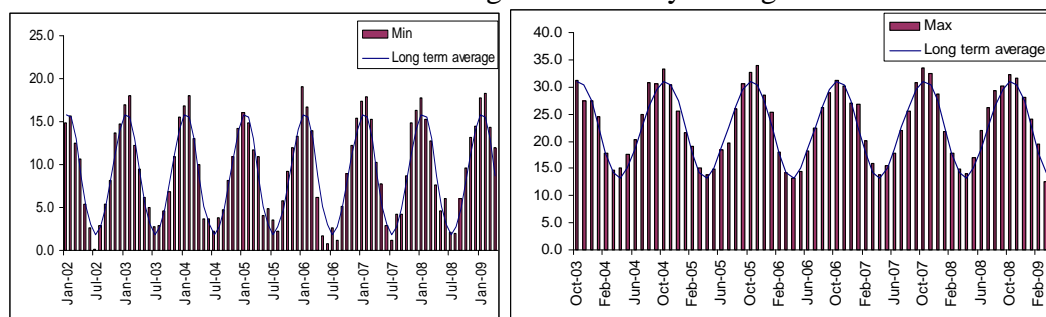


Figure 5 Maximum and minimum temperatures (solid bars) from Datadrill, long term mean blue line

Rainfall

Rainfall was collected at the site since September 2002 however due to equipment malfunction a complete time series is unavailable. A data was extracted from the Datadrill database and used as a surrogate. In the mean time the data will be retrospectively filled using the Data drill data.

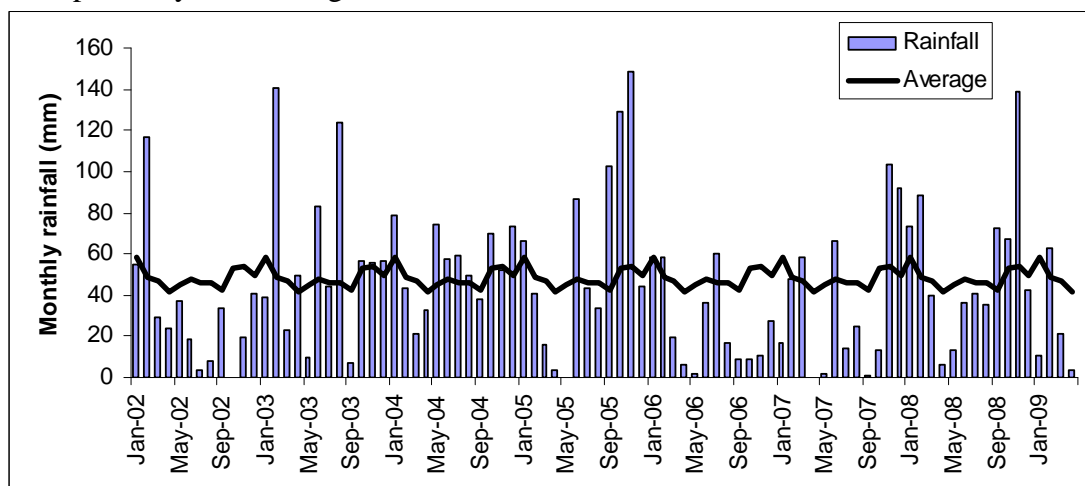


Figure 6 Monthly rainfall from Sloane's Creek Site (blue bars) and long term average monthly rainfall (black line)

Over the time period of 67 months, 24 months (36%) exceeded the long term median rainfall for that month by 10 mm; 25 (37%) months were below the long term median rainfall for that month by 10 mm and 18 (27%) were within 10 mm of the long term median monthly rainfall. The largest difference was in November 2005 where monthly rainfall 172 mm was recorded 127 mm higher than the long term average. This was the end three months of high rainfall that started in September 2005 with 98 mm and 134 mm in October 2005.

The lowest variation in rainfall from the long term monthly median was in October 2002 when no rain fell for the first time since records began in 1889. A factor to note is the measurement period was characterised by low variable autumn (March–May) rainfall with on average 70 mm falling in the autumn between 2002 and 2006 as compared to the long term average of 122 mm. The lowest autumn rain was in 2005 and 2006 of 31 mm. Two springs (Sep–Nov; 02 and 06) recorded 52 mm and 37 mm rainfall respectively as compared to the long term average of 131 mm. The highest daily rainfall total measured at the site was 84 mm 21/02/03

The rainfall record for Wellington NSW commences in 1889, and using the annual rainfall data the residual rainfall mass was calculated. This shows the periods of annual above average rainfall (rising trend), below average rainfall (falling trend) and as well as median rainfall (flat line) (fig. 4).

The annual residual mass rainfall shows that the first half of the rainfall record from 1889 to 1949 was a period of below average rainfall while from 1950 to 1973 was a period of above average rain. From about 1973 onwards until 2000 was a period of average rainfall. It can be seen that the observation period for Sloanes Creek has been undertaken in a period of declining average rainfall (fig 5).

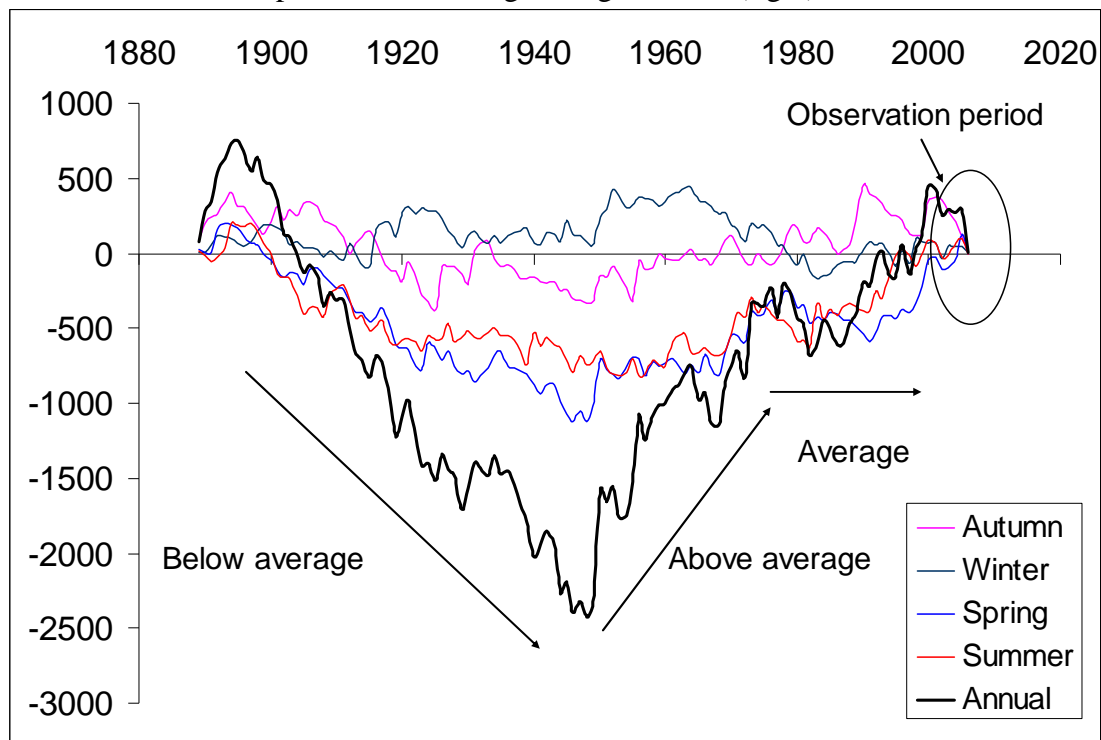


Figure 7 Residual mass rainfall Wellington NSW

Dividing the year into season, namely; autumn (March to May) winter (June to August), spring (September to November) and summer (December to February) and analysing the three monthly rainfall record to determine if there were any seasonal rainfall responses. Figure 5 graphically shows that since 1957 there has been an increase in summer rainfall as compared to the average for the period. There have been changes in the other season including a declining trend in autumn rainfall since 1990 except 2000 which was well above average. It appears that during the 1990's spring rainfall increased offsetting the declining autumn rain. However from 2001

onwards spring rainfall declined as well, and there has been little trend in the winter rainfall.

Soil moisture

Changes to soil moisture between the November 2002 and May 2003 showed no significant changes in subsurface soil moisture which indicates that the rain that fell during these months was either used quickly by plants, evaporated, or produced runoff and did not contribute to deep drainage.

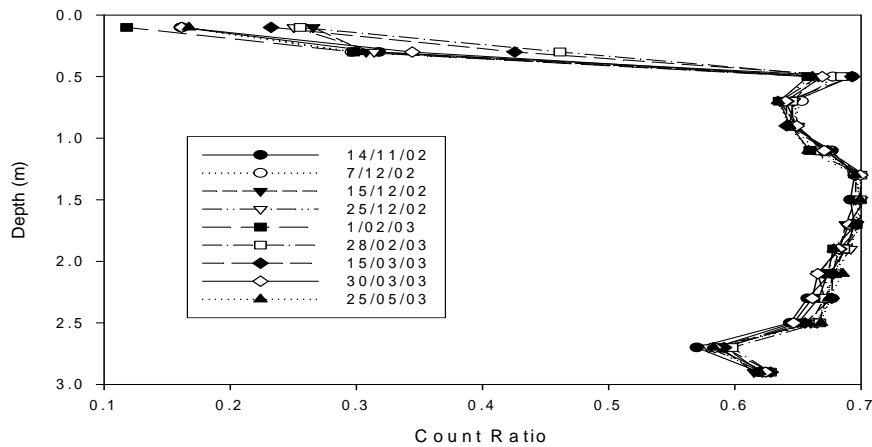


Figure Count ratio (NMM) – Phalaris

Groundwater

Examination of the piezometric heads in relation to their position in the catchment generally shows groundwater gradient to be in the same direction as surface water flows. The gradient is however quite steep from the northern side of the catchment indicating either large groundwater fluxes from the area and/or a restriction to groundwater movement along a north/south transect (Figure 7).

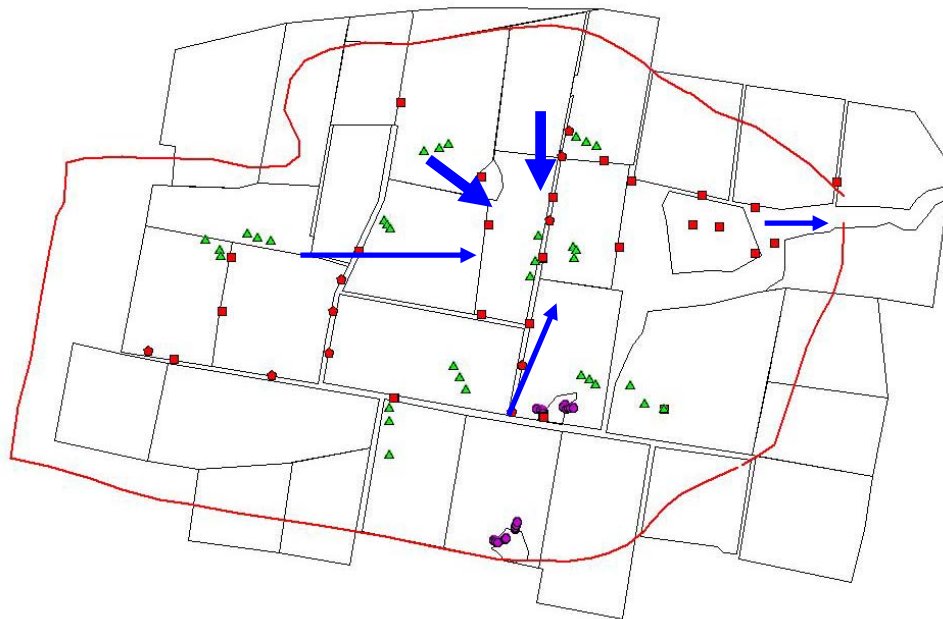


Figure 8 Groundwater flow direction at Sloane’s Creek research site (thickness of arrow indicates higher gradient)

The data from piezometers located on the scald shows in general that the groundwater has been declining since the commencement of monitoring in 2002. However, it is clear from the groundwater hydrographs that excluding well 101 the watertable responds rapidly to rainfall by rising and then a slow decline, and overall since the start of monitoring in September 2002 there has been a general drop in piezometric head.

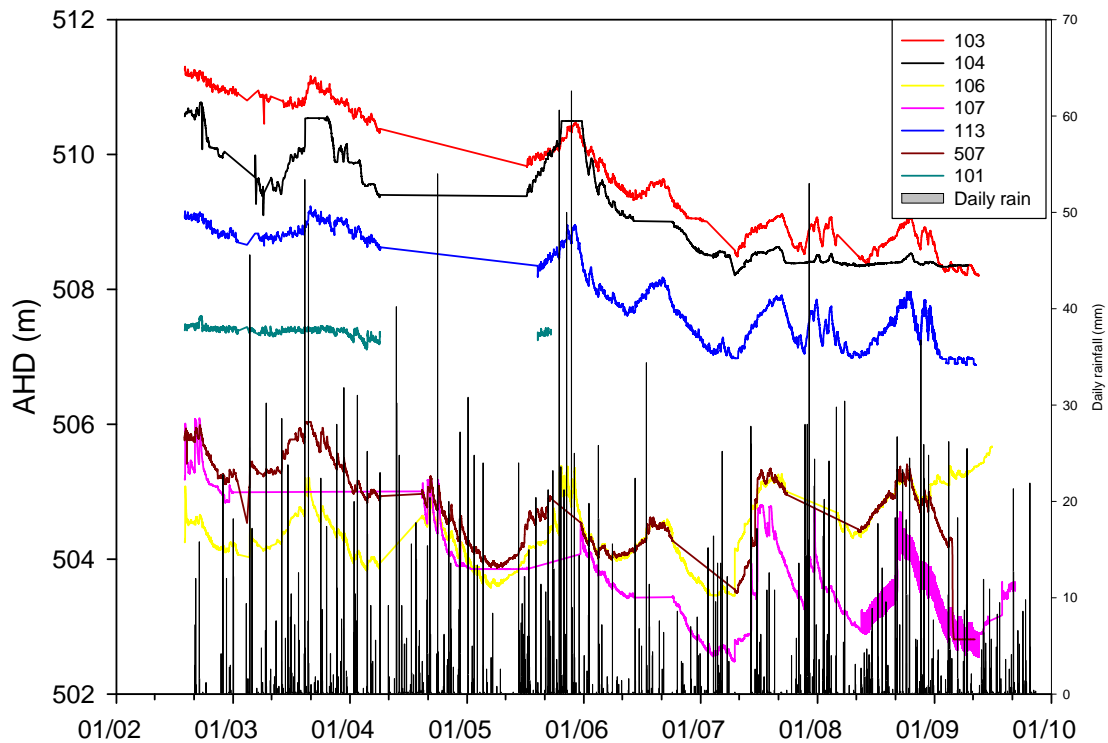


Figure 9 Watertable depths from groundwater wells located in the Sloanes Creek scald

However within the hydrograph appears to be a range of trends in the watertable data. In wells 104, 107, 113, and 507 there has been an overall drop in piezometric head of 2.0 m, while well 103 has dropped 2.5 m and, well 106 has risen just under 1.0 m. There was no change in well 101.



Figure 10 Watertable zones within the saline scald

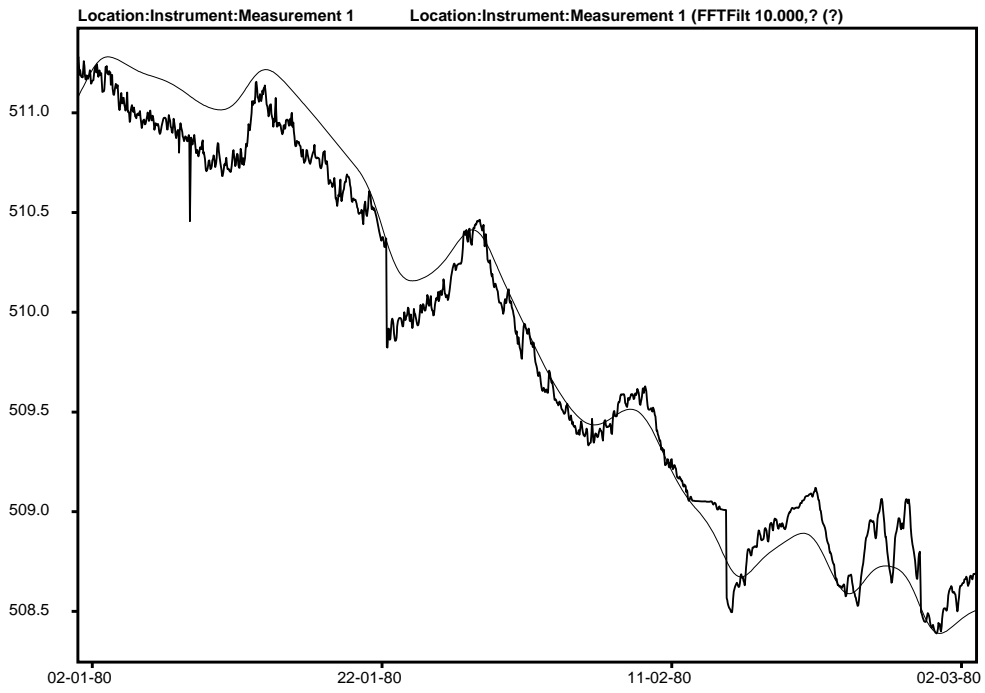
The watertable response in well 507 shows a dramatic draw down in Feb March 2009. This may be due to the reduced rainfall and the established pastures drawing on groundwater. If this possible land use effect is ignored then well 507 and well 106 follow a similar pattern. These wells are sited on the eastern side of the scald and also

appears to be unconfined responding rapidly to rainfall, however the difference being there has been no overall change to the depth of watertable during the monitoring period.

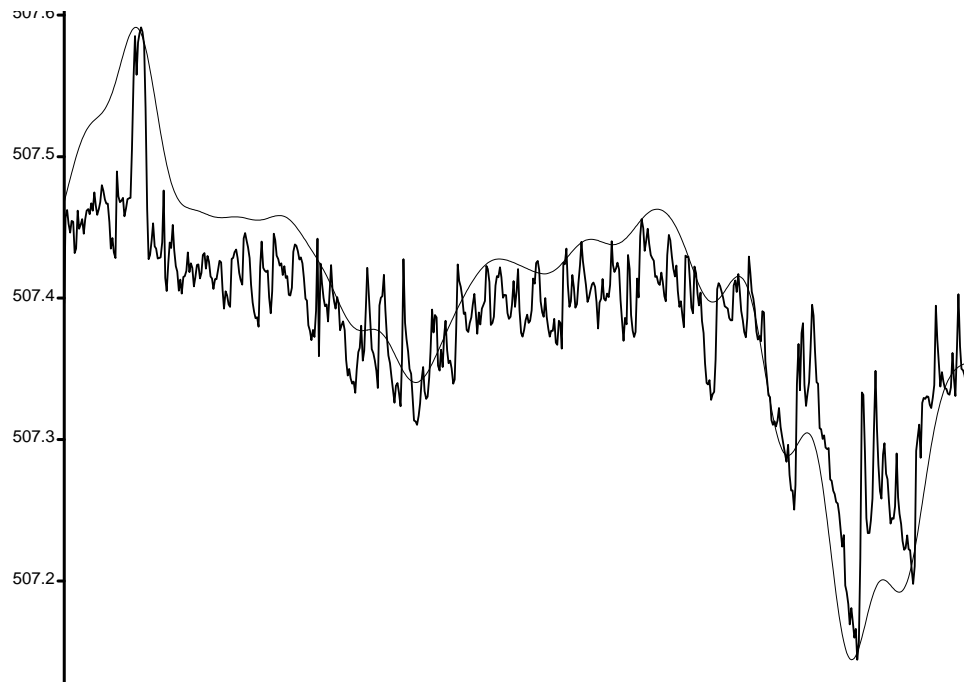
Well 101 is sited in the middle of the scald itself and the watertable appears to be confined with a persistent watertable regardless of the prevailing climate. It appears that this groundwater is constantly discharging from either near the soil surface at or at the soil surface hence causing the scald. It should be noted here that no deeper wells are present and there is no data to determine if the groundwater is confined or unconfined however this is an area of ongoing research

Long term trends in groundwater

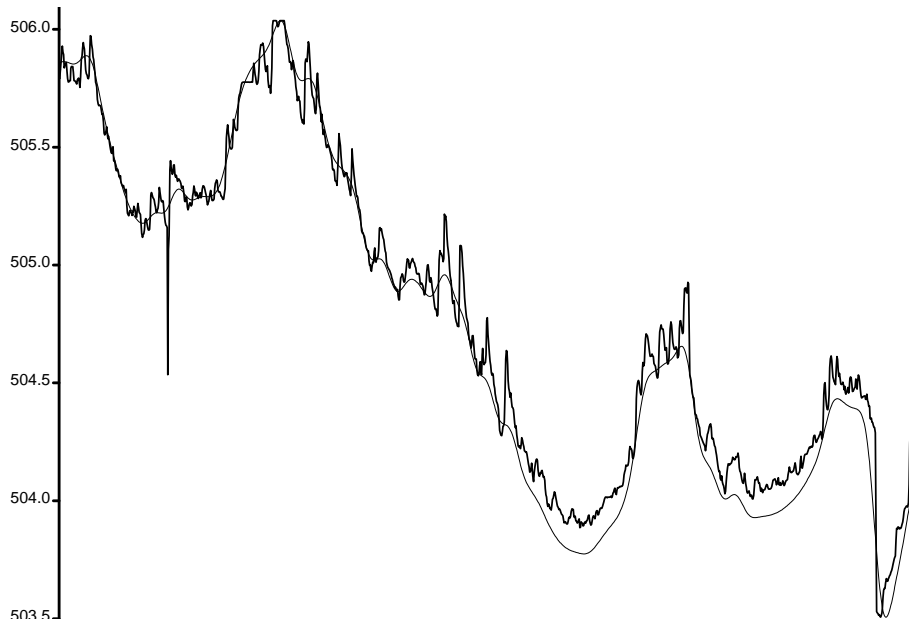
The groundwater data was smoothed using a low pass filter to eliminate short term fluctuations in the measured data. This also allows for a more unbiased assessment of over all changes to ground water elevation over the observation period. Analysis of four years of groundwater data 2002 to 2006 for Sloane's Creek show that in general the ground water has dropped between 0.5 to 3.0 m over the observation period.



a



b



c

Figure 11 Measured and smoothed watertable data a) 103 b) 101 c)507

To determine if the trends in groundwater fluctuations were influenced by rainfall the data was analysed using the HARTT technique (Fedowosian et al 2002). This technique separates the effect of atypical rainfall events from the underlying time trend and the lag between rainfall and its effect on groundwater is explicitly represented.

Bore	Best Fit Delay	R ²	Acc. Residual Rainfall (mm)	Time (month)	p
	AMRR months		p	value	
106	5	0.38	0.0005%	-0.01	0.003804
107	5	0.67	0.0123%	-0.06	4.45E-09
507	3	0.37	0.0001%	-0.04	8.87E-08
101	0	0.42	9.0792%	-0.01	0.564891
103	0	0.95	0.0137%	-0.03	1.76E-17
113	0	0.85	1.4113%	-0.02	1.53E-07

The analysis shows that there the groundwater is responding differently depending on the location of the monitoring well. The wells towards the north and western side of the scald (wells 103 113) appear to be responding to the declining trends in rainfall. While the wells on the eastern and southern side (507, 106) show no significant effect of rainfall over the observation period. The groundwater in the middle of the scald (101) shows no effect of either time or rainfall.

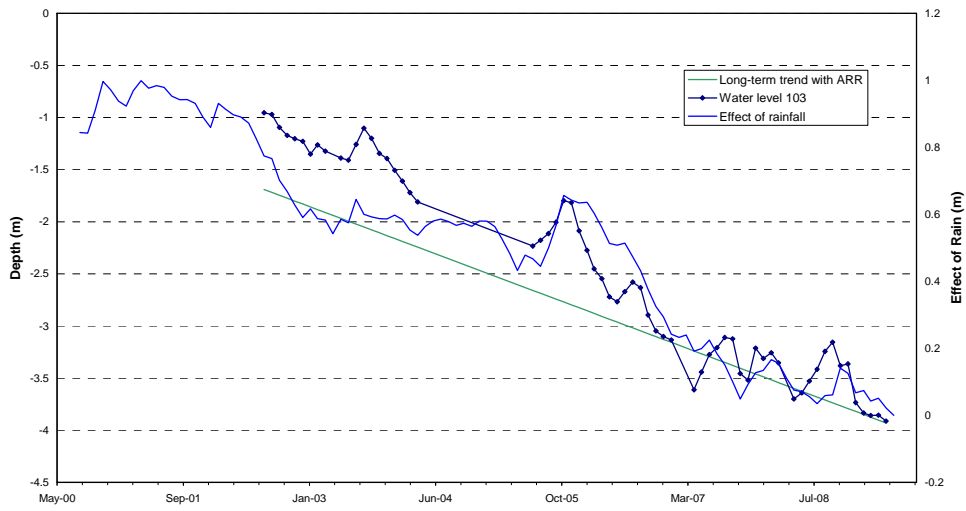


Figure 12 HARTT analysis for Well 103

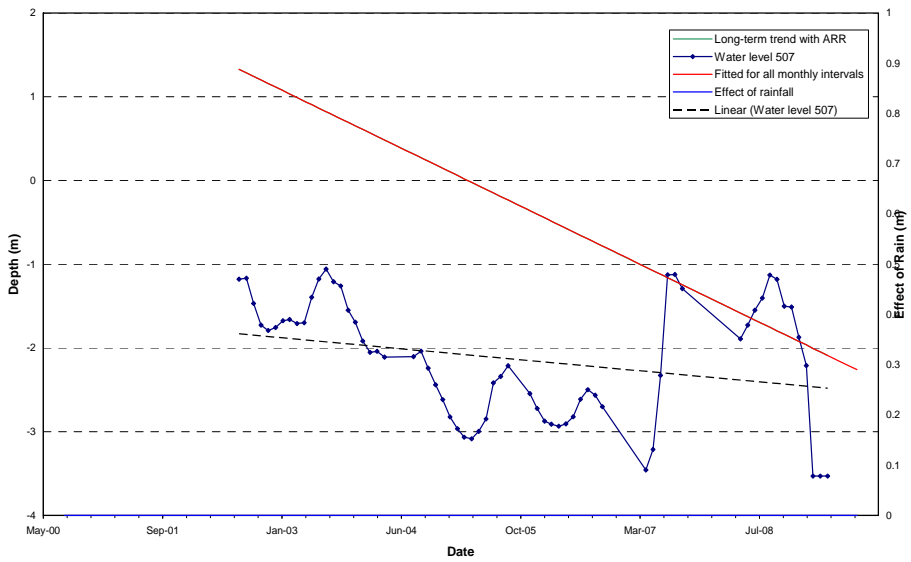


Figure 13 HARTT analysis for Well 507

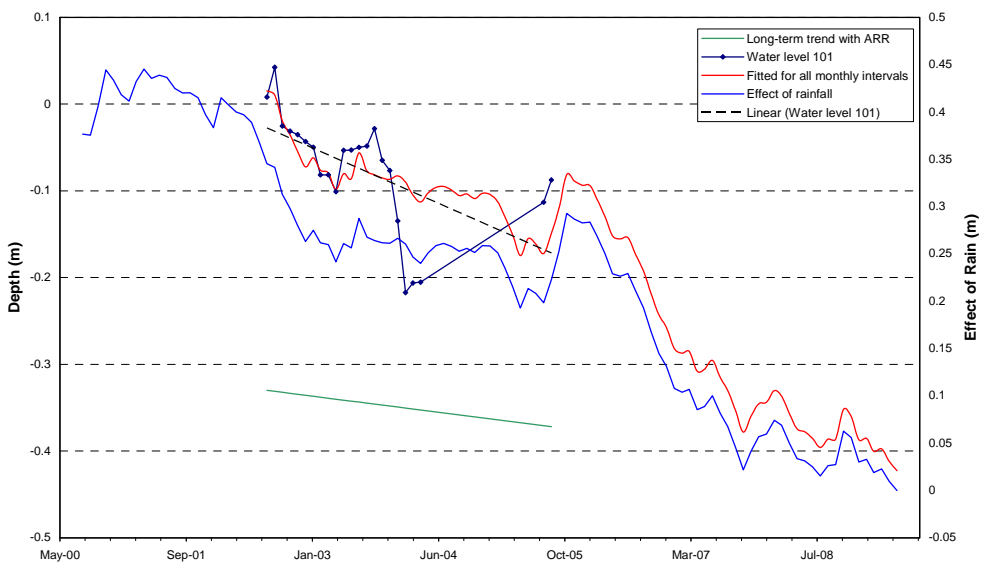


Figure 14 HARTT analysis for Well 101

Based on this analysis there appears to be three separate groundwater systems interacting on the Sloanes Creek scald. A unconfined groundwater system that is responding to and is affected by rainfall in the short and long term (wells 104103 113). This groundwater system follows the longer term climate as well as responding to rainfall in the shorter term. The second groundwater system wells (107 106 507) that appears to be affected by rainfall in the short term but having no overall long term and the third groundwater system which appears to be not responsive to rainfall in the short or the long term (well 101).

Groundwater surface water interactions

The interaction between the identified groundwater and the streamflow of the nearby Sloanes Creek is not well understood. There appears to be good correlation between the measured baseflow in the stream and the groundwater system measured in well 106 (Fig 15).

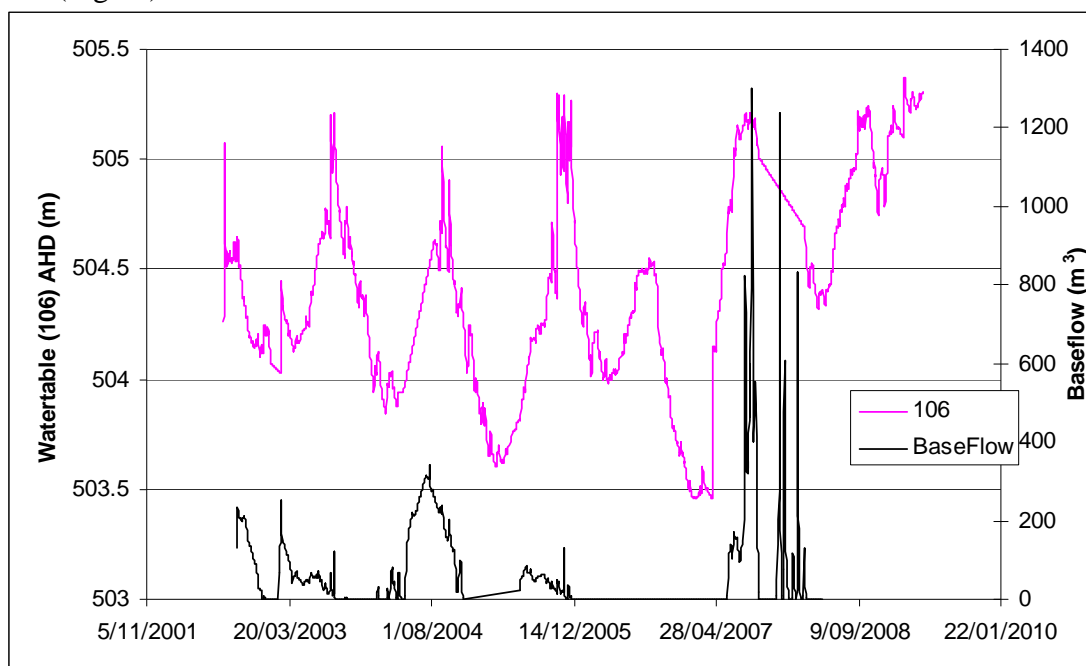


Figure 15 Surface groundwater interaction well 106 and baseflow in Sloanes Ck

Groundwater chemistry

Groundwater and surface water was sampled in over a period from December 2002 to April 2003 and analysed for the major ions. Samples were taken from a range of piezometers after pumping and sample of surface water was also taken. The sampled piezometers were selected to represent the spatial range of piezometers across the site. The samples were submitted to NSW DPI water testing laboratory for chemical analysis.

It was found that the average EC of the sampled groundwater was 3.9 dS/m with the highest recorded 6.9 dS/m at 602 and the lowest 1.8 dS/m at 612 (fig 9). Water was sampled from Sloanes Creek during baseflow conditions and the measured EC of 4.5 dS/m. Ground and surface pH ranged from 7.8 to 8.6 over all samples.

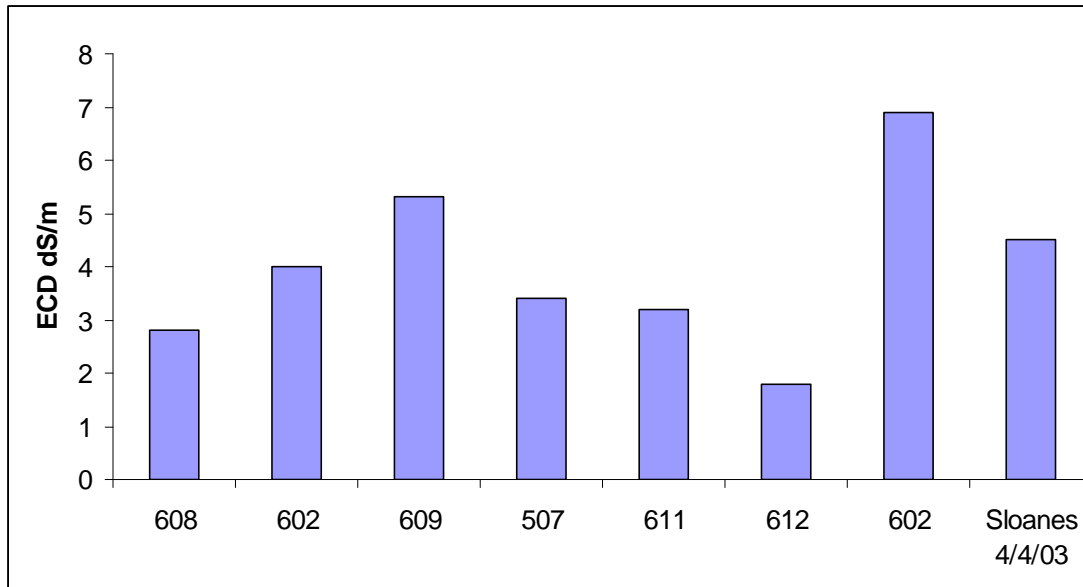


Figure 16 Electrical conductivity (dS/m) of selected piezometers at Sloanes Creek

Additional analysis of the cations and anions showed that sodium and magnesium were the dominate cations present at the site while the major anions were bicarbonate and chloride (fig 11).

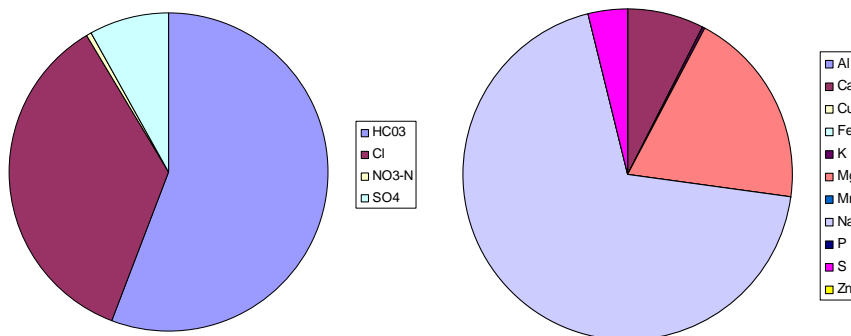


Figure 17 Proportion of anions and cations in groundwater

Projecting these results on a piper plot it can be seen that there was high variation in the chemistry of the groundwater samples (Fig 12). There appeared to be a number of grouping in terms of the groundwater samples. Piezometers 609 507 611 had similar characteristics and probably sit in the same groundwater system and are the most eastern piezometers (fig 10) that is the piezometers are towards the bottom of the catchment. The water samples from the piezometers 608 and 602 are similar and these piezometers are in close proximity and lie upstream and west of the main scald. The remaining group is in fact one piezometer 612 and is the most western location and highest in the catchment.

Piezometer 612 recorded higher percentages of bicarbonate however this is due to the low overall concentration of salts in the sample. The sample of surface water from the Sloanes Creek shows high level of Mg suggesting a source of water not measured in the groundwater survey.

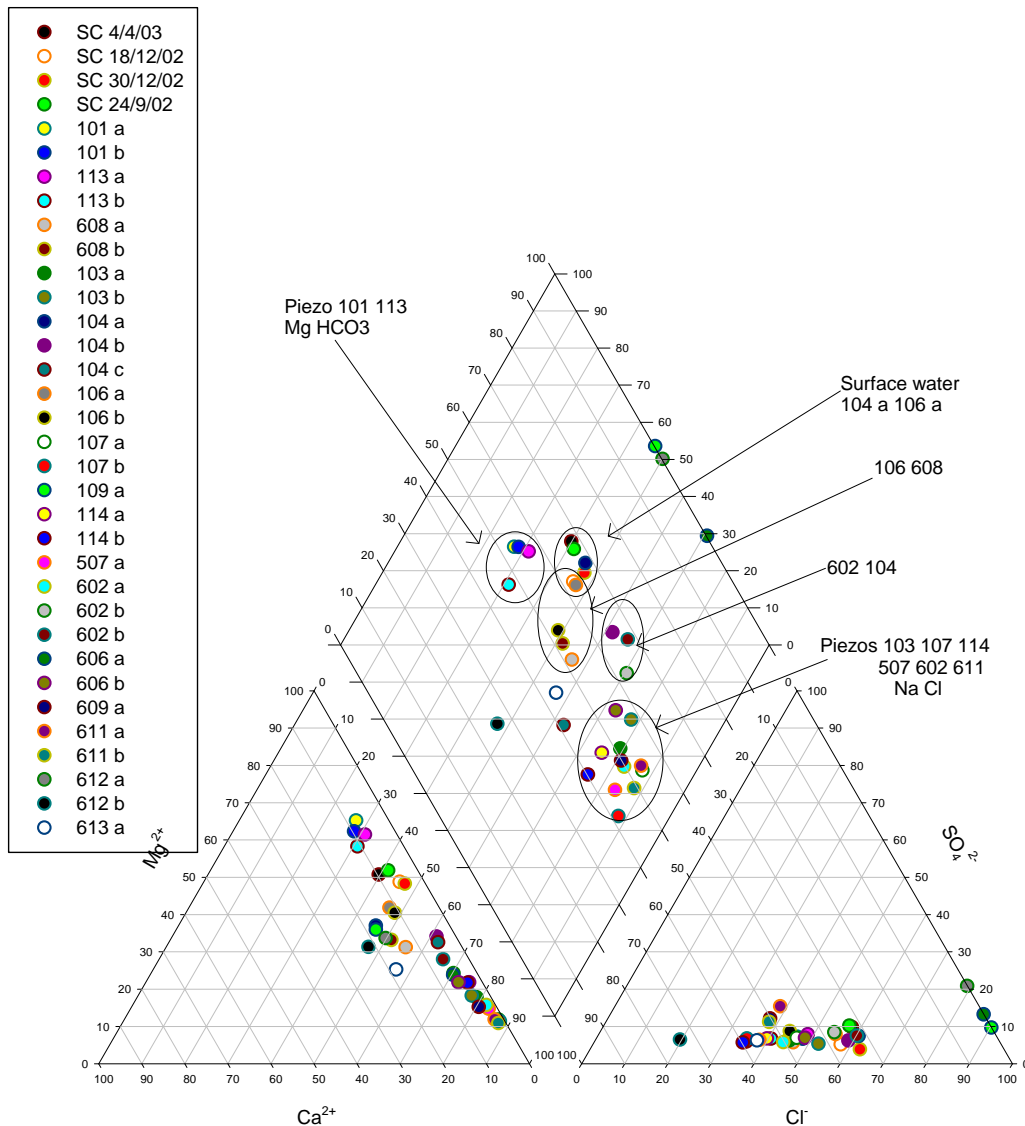


Figure 18 Piper plot of major ions Sloanes creek 2004

The spread of chemistry suggests that the groundwater system is not a single system as the spread in ionic composition is too great to propose that all water samples come from a connected system. On going research is required to assess if the water chemistry can be linked to a geological or anthropogenic changes.

Possible sources of the salts present at the Sloanes Creek site include weathering of the andesite porphyry to produce Mg, Na and Ca, while no limestone has been observed at the site there is limestone widely dispersed throughout the this area, presence of HCO_3 may be from limestone dissolution. Sodium and chloride could be originated as connate salts from marine shale and sandstone present at the site or as windborne cyclic salts that have been concentrated by evapotranspiration.

Evopotranspiration

Bowen ratio measurements commenced in February 2003 on a lucerne paddock and March 2003 on a phalaris paddock and completed in May 2003. Cumulative ET was approximately 25 mm higher than the cumulative rainfall and a 25 mm difference in soil moisture suggest that soil moisture was being depleted. Lucerne appeared to have a greater water use capacity than phalaris according to the ET data

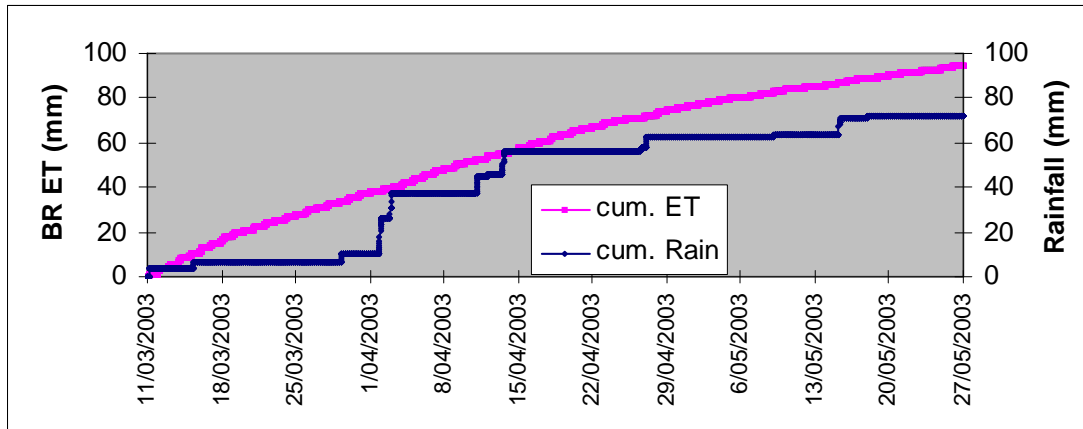


Figure 19 Bowen ratio Evapo-transpiration data for a Phalaris paddock at Sloanes Ck. (change in soil moisture for the period was approximately 25mm)

Water balance

The water balance for Sloanes Creek was measured from March 2003 until April 2004. Using the Bowen Ratio units to estimate evapotranspiration and neutron probe to measure soil water on a monthly basis a soil water balance was developed. Across the site there was high variation in the accounting of water. On sites 1-3 there was less than 5% discrepancy between the amount of water that was transpired and the amount of rain and change in soil moisture (table 3). However at sites 4-6 there was a large error in measurement. It is unsure why such large variations in the measurement of the water balance, however over summer when there are extended dry periods of low relative humidity large errors in the measurement of ET can occur.

Table 2 Water balance Sloanes Creek

Paddock	Record dates	Rainfall (mm)	Δ soil water (mm)	Available water (mm)	E.T. BR (mm)	Error (mm)	Error % ET
Lucerne (1)	Mar 03 – Apr 04	631	-102	734	706	27	4%
Phalaris/Cocksfoot (2)	Mar 03 – Apr 04	631	-93	725	696	28	4%
Wheat/weeds (3)	Apr 03 – Mar 04	570	-30	601	598	2	1%
Canola/weeds (4)	Jun 03 – Mar 04	493	0	493	659	-166	-25%
Phalaris/Cocksfoot (5)	Oct 03 – Mar 04	259	-50	308	247	61	25%
Lucerne (6)	Sep 03 – Mar 04	334	-234	577	451	126	28%

It was found that during the measurement period soil water declined at all sites except site 4 as the plants used stored soil water to meet evaporative demand. At site 4 an additional 166 mm of water was transpired than was available, it is unsure where the additional water came. At sites 5 and 6 less moisture was transpired than was available suggesting a non water limiting constraint was present. For lucerne this could be a presence of aluminium at depth that restricted root growth.

Streamflow

Stream flow and electrical conductivity has been recorded nearly continuously at the Sloanes Creek Site since September 2002. There is a 7 month gap in the data from December 2004 until June 2005. Since measurement commenced in September 2002 the creek has changed from what was anecdotally a perennial stream which ran continuously to an intermittent, stream and then through 2006 an ephemeral stream that ran in response to rainfall. Since 2006 the stream has run intermittently usually running from early winter until mid to late summer drying up over autumn and recommencing after rainfall in winter.

Since the beginning of streamflow measurement at Sloanes Creek there have been numerous periods of no flow (between 18-20). The stream was flowing when the gauge was installed in September 2002 but stopped flowing in late December 2002 and recommenced in February 2003 in response to a storm event. The stream flow ceased in late October 2003 but ran intermittently in response to summer storms from November 2003 to early December 2003. Storms in January 2004 made the stream run for a day or so until late February when the stream recommenced flowing and flowed consistently until the end of November 2004. There is a gap in the recorded data until early June 2005 when the data shows that there is a small flow in the stream which persisted until early December 2005. Modelled data shows that there were two runoff events during this period one in early December and one in early January.

No flow was recorded in the gauge at Sloanes Creek excepting a small storm flow in February 2006 until May 2006 which persisted until August 2006. There was a small flow event in November and December 2006 but effectively no flow until mid May 2007. There was low persistent flow from May to September 2007 and no flow was recorded until an extremely large flow event on 6 December 2007 when over 100 ML of water was recorded as draining from the site. The longest period of no flow occurred between June 2007 and late November 2007 a period of 170 days when no flow was recorded. During the drought of 2006 there were 279 days of no flow were recorded with the longest between the 1 May to the 10 July 2006. In 2003-04 there was around 45 days of no flow recorded with an average length of 20 days. In 2006 there was 279 days of no flow and in 2007 there was 170 days of no flow.

Streamflow in Sloanes Creek is highly responsive to rainfall particularly storm events. Over the period of monitoring (1800 plus days) there have been 10 days where the daily stream flow exceeded 10000 m³. The median flow rate for Sloanes Creek is around 50 m³ per day while 30% of the time there has been no recorded flow (fig 12).

All stream flow events were in response to rainfall, with typical the streamflow responding within 3-4 hours of rain. A peak daily flow rate was recorded on 5 December 2007 at 70529 m³, this corresponded to an instantaneous discharge of 23273 m³/hr on the same day. The highest daily salt export was 167t also on the 5 December 2007 with a peak flow of just under 60 t of salt exported on the same day.

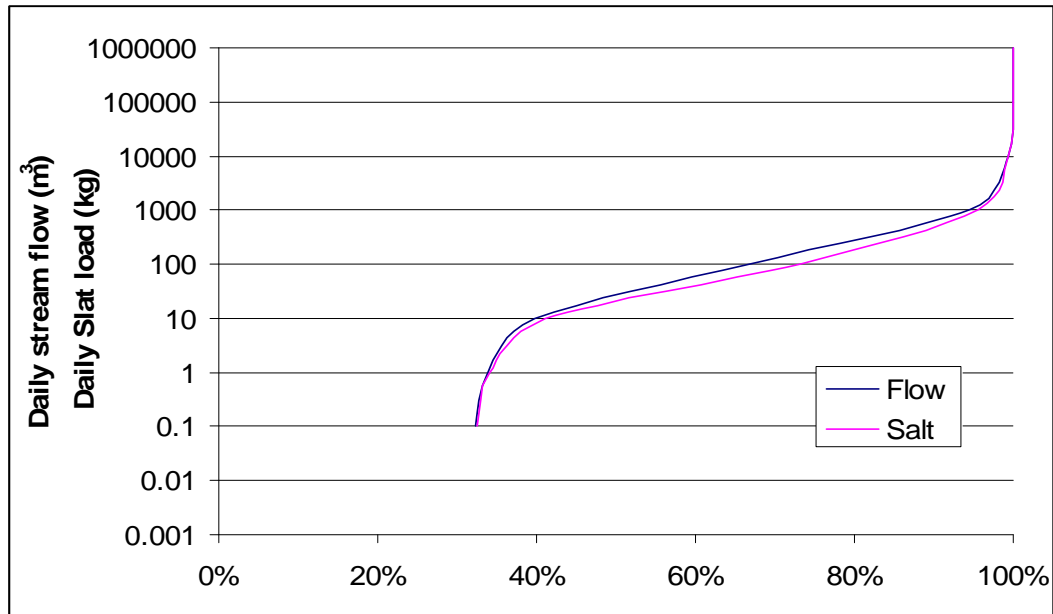


Figure 20 Flow duration and salt load exceedence curve

Seasonality of streamflow

Over the seven years of measurement, the seasonality of flow is driven by prevailing climatic conditions. During the early period of observation 2002-2004 the streamflow dominated by the winter spring months (June to October), which accounted for 84% of the volume of flow from 2002-2004. No data was recorded between November 2004 and June 2005 however in 2006 there was negligible spring flow (40 m³) and low winter volumes (1137 m³) as compared to autumn summer flows (2329 m³). In 2007 and 2008 winter spring flows accounted for 75% of the annual flow.

Along with the changes in stream flow (water yield) has been changes in the patterns of salt load specifically mobilisation and transport. The change in the nature of the stream can be seen as from 2002 to 2006, and from 2007 to the present date (2008). During the period 2002-2006 the stream ran most of the year excepting the dry summer and autumns.

Stream EC

Stream salinity recorded at the Sloane's Creek stream gauge has ranged from 50 μ S/cm to nearly 10000 μ S/cm with a median salinity of 302 μ S/cm. The mean flow weighted salinity for Sloanes Creek for the entire monitoring period was 1668 μ S/cm. The flow weighted mean salinity varied according to seasonal conditions, the flow weighted mean EC was around 2400 μ S/cm for 2002, 2007 and 2008, meanwhile the flow weighted mean EC for 2003-05 was around 500-600 μ S/cm. Very little salt was exported during 2006 due to very low flow that occurred during that year.

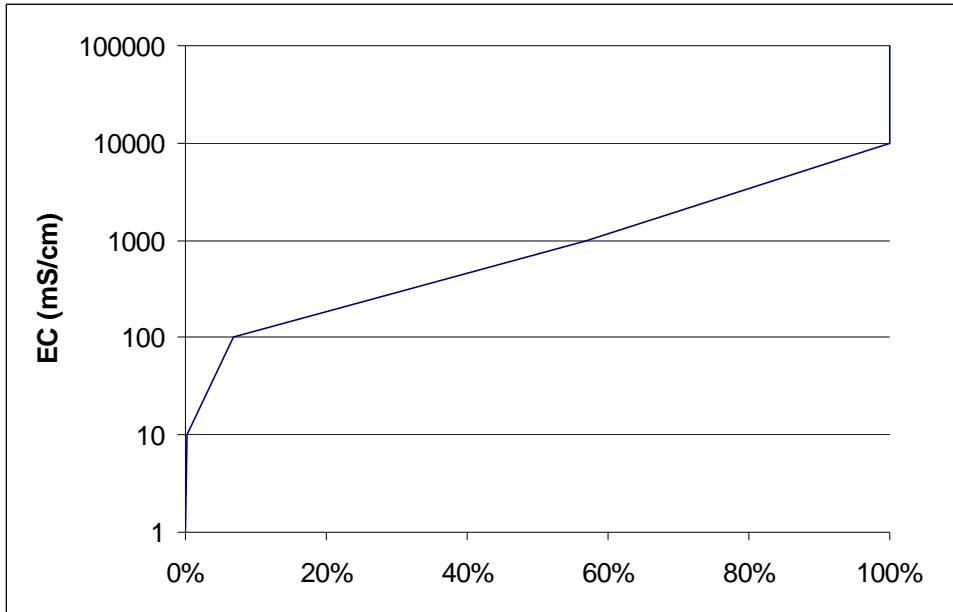


Figure 21 Exceedence Curve Stream EC Sloanes Ck

The exceedence curve for the measured stream EC for the observation period shows that while the median stream EC was 302 $\mu\text{S}/\text{cm}$ the upper limits (greater than 95%) were in the order of 3800 $\mu\text{S}/\text{cm}$ and the lower limits (less than 5%) was around 85 $\mu\text{S}/\text{cm}$.

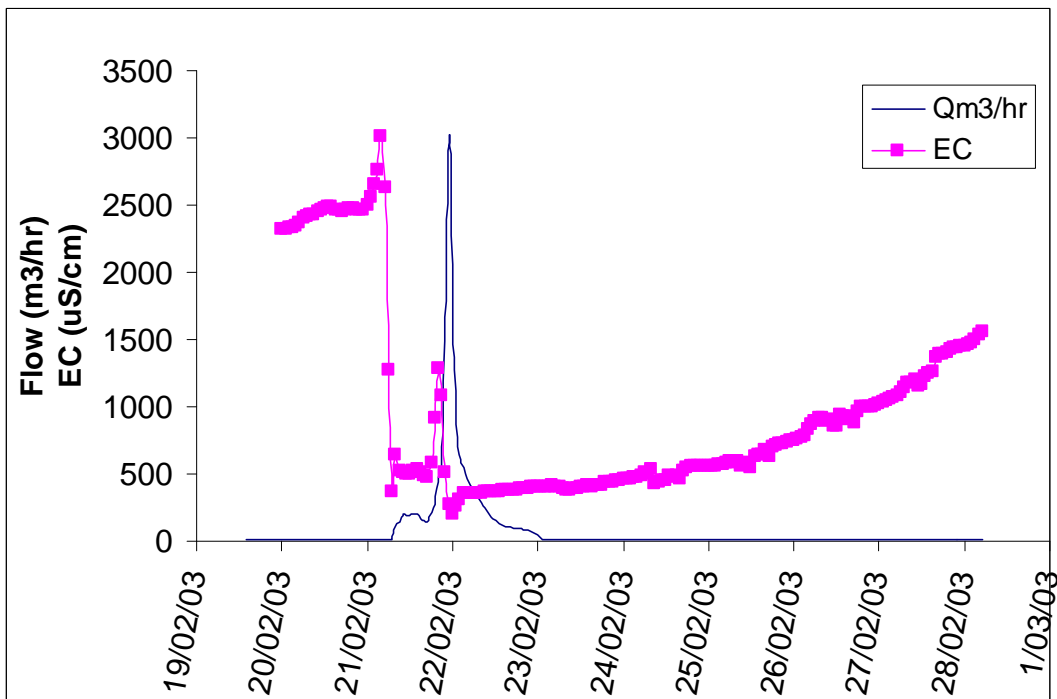


Figure 22 EC and stream flow from typical rainfall event

The EC of the stream responded very quickly to changes in flow regime with base flow averaging around 3000 $\mu\text{S}/\text{cm}$ and then dropping rapidly to about 500 $\mu\text{S}/\text{cm}$ due to dilution by event water then a rise back towards baseflow level of about 3000 $\mu\text{S}/\text{cm}$. The reversion to base flow was relatively slow usually taking between 10-15 days after each event. Towards the end of the observation period there spikes in EC

up to 10000 $\mu\text{S}/\text{cm}$ this may be caused by the drying out of the weir pool and the subsequent increase in salt concentration.

Cumulative stream flow and salt load

Since the beginning of the observation period in September 2002 over 600 ML of water has drained from the site and this has transported nearly 700 tonnes of salt. However it should be noted that nearly half this water and nearly two thirds of the salt was transported on one event in December 2007. Putting aside this one event the majority of salt and water was usually exported in during storms rainfall events in summer. Excluding the one large rainfall event of December 2007 it took the sum of 34 daily runoff totals to sum to 50% of the total runoff recorded for the observation period. In other words of the 1800 or so days of observation over half the runoff occurred in 34 of those days and 24 of those days were between November and February suggesting the importance of storm flow in not only generating runoff but also salt transport. The same 34 days it took to drain half the water from the site was responsible for transporting 44% of the salt mobilised over the observation period. It took an additional 1200 days to drain the remaining 50% of the water.

To separate the sources of water from storm events and groundwater the stream hydrograph was separated using a recursive digital filter (Lyne and Hollick 1979). Depending on the parameters chosen this filtering analysis showed that storm flow could account for between 70-90% of the flow measured at the Sloanes Creek site and 85% of the salt load.

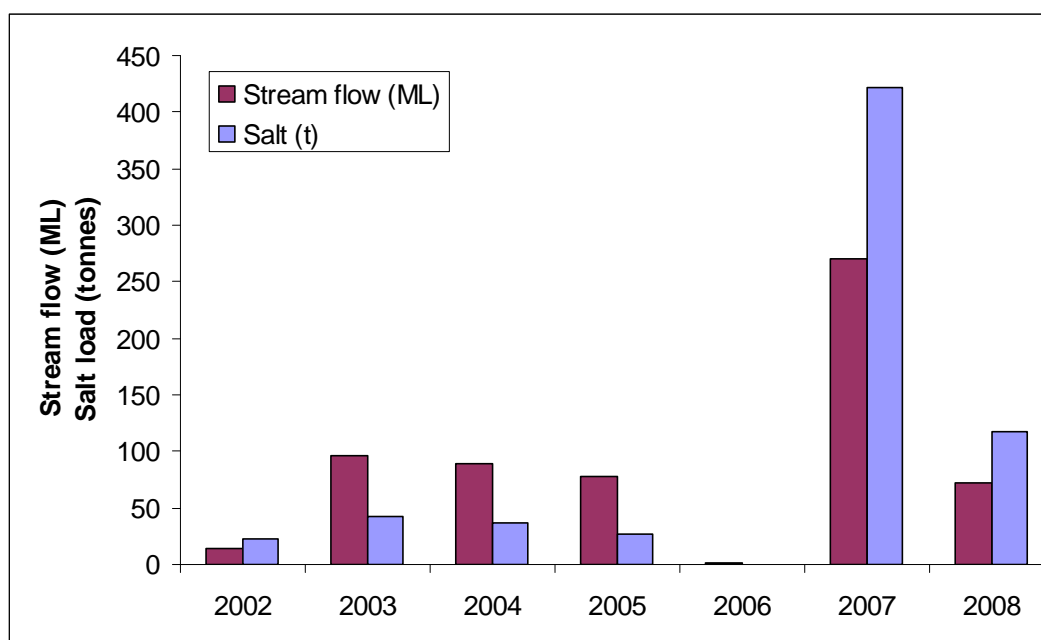


Figure 23 Water yield and Salt load from Sloane's Ck Catchment

The Sloanes Creek is a salt source catchment for the Bell River as it delivered similar or higher amounts of salt (t/km^2) than the Bell River itself (fig 16). Since 2002 the Bell River's average salt export was $3.81 \text{ t}/\text{km}^2$ as compared to the Sloanes Creek site which exported $16.5 \text{ t}/\text{km}^2$ of salt.

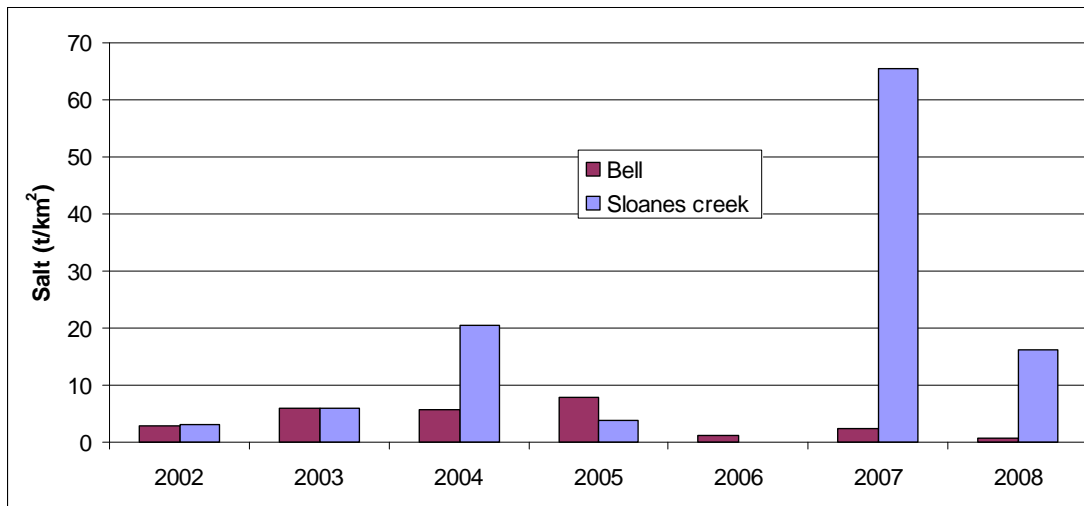


Figure 24 Comparison of salt export from Sloanes Creek and the Bell River at Newrea

Comparison of the salt and water export of the observation period with historical modelled loads.

The long term streamflow record was used to calibrate a rainfall runoff model (IHACRES). Streamflow from 2002 to 2004 was used to calibrate the model and stream flow from 2005-06 was used to validate the model parameters. Daily climate data from 1889 was used to generate daily streamflow from 1889 to 2004 (Fig). Assumptions in the model are that there was similar land use as that occurred in 2002-2004, that is a mix of grazing, cropping and native vegetation.

Streamflow

Annual average stream flow for the period was 144 ML however there was considerable variation in the volume. There was no flow in 9 out of the 117 years, and in 15 years the total annual flow was less than 10 ML. A peak flow of 1782 ML was simulated in 1950 which corresponded to the wettest year on record in which over 1500 mm of rain fell.

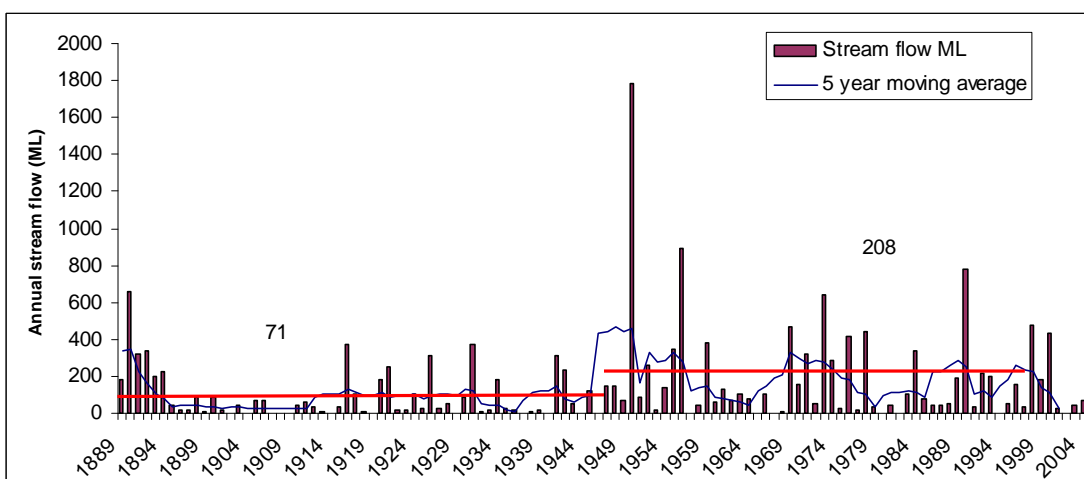


Figure 25 Historical modelled flow for Sloanes Ck

The highest daily flow was recorded on 24 February 1955 when just under 200 ML drained from the site, this corresponded to a daily salt load of just over 300 t of salt

draining the site. This was in response to a rain event that precipitated 147 mm on that day. The highest measured volume that drained from the site was 71 ML on 5 December 2007 with a salt load of 167 t draining from the site.

The runoff also shows inter decadal patterns that correspond to the variable rainfall. The annual average stream flow from 1895 to 1949 was 71 ML as compared to the corresponding period between 1949 and 1996 where annual stream flow average was 208 ML. This figure is highly skewed by a number of large events, however the annual median streamflow for these periods were 22 ML and 82 ML respectively.

Salt load

A relationship between daily stream flow and daily salt load was developed using the streamflow and salt load data measured since 2002 at the site (fig).

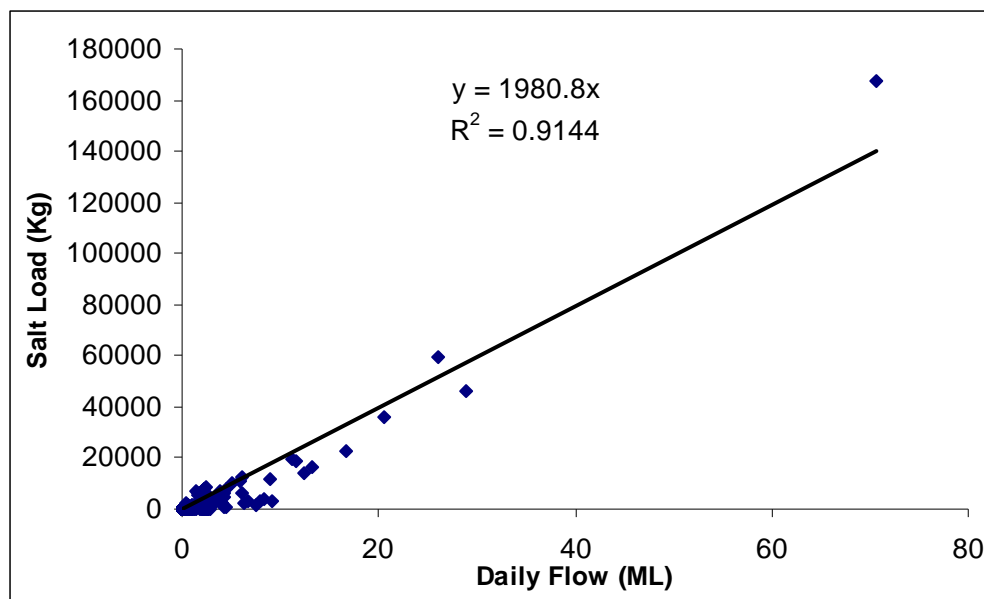


Figure 26 Relationship between measured streamflow and measured salt load for Sloanes Ck

This relationship was used to estimate daily salt loads from the modelled data.

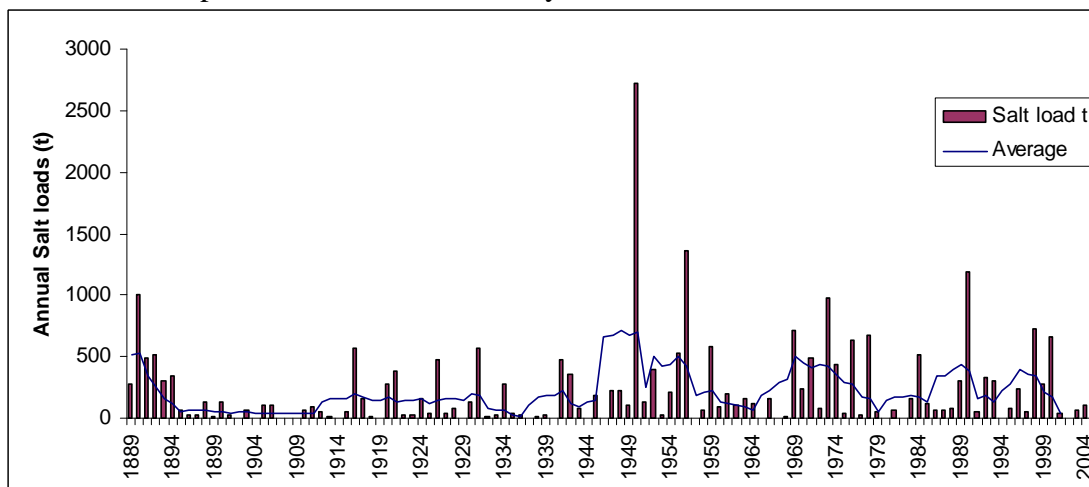


Figure 27 Annual salt loads (t)

Annual salt loads ranged from 0 to 2722 t per year, which coincided with the highest streamflow. Median annual salt load over the modelled period was 85 t/year, with the long term average salt load 220 t/year. This equates to the median long term salt export being just over 12 t/km²/year as compared to the Bell River's long term salt export is 3.81 t/km²/year. During the observation period the site's average salt export was 16.5 t/km² /year.

Digital Elevation Model (DEM)

The digital elevation model developed from the RTK GPS data shows the elevation decreasing from a high of 585 m on the western boundary of the catchment to 500 m on the eastern boundary. There is a roughly uniform slope across the catchment excepting areas on the western edge which corresponds to the ridge tops of the catchment boundary.

Sloanes Creek DEM

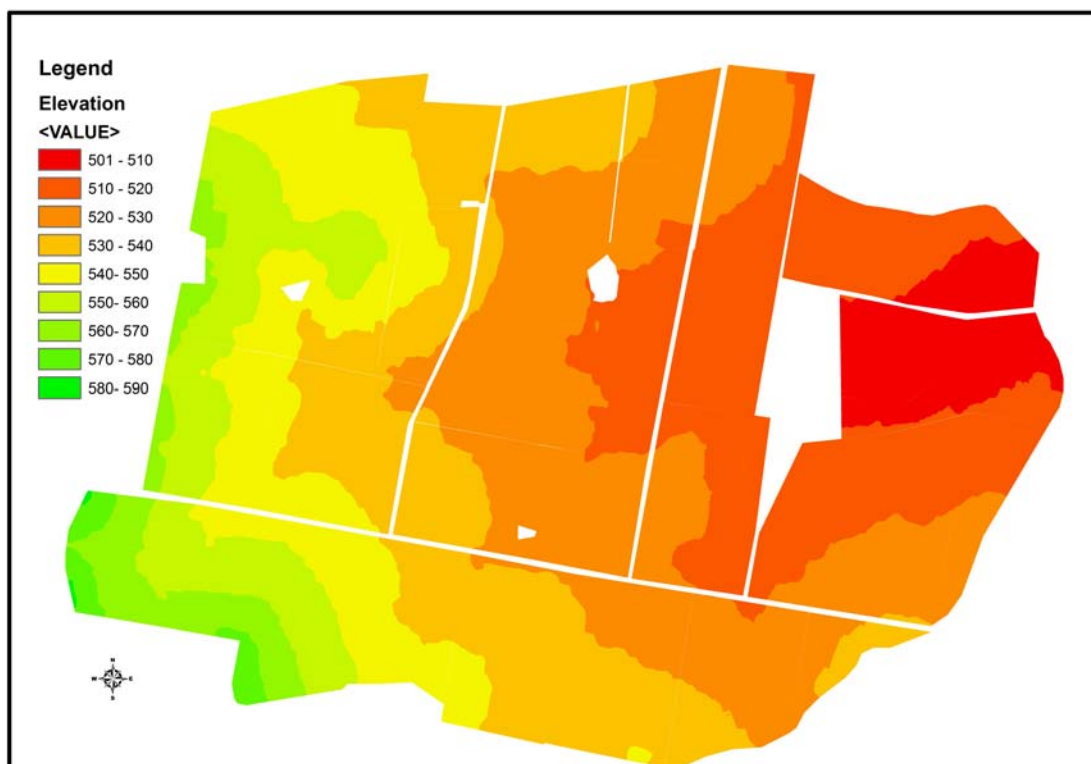


Figure 28 Digital Elevation Model Sloanes Creek

Fuzzy Landscape Analysis (FLAG)

Soil physical characteristics collected to date appear to be well correlated to 'FLAG lowness' and EM38/31 surveys, while piezometric head appears to be well correlated to 'FLAG upness'. Initial soil hydraulic conductivity measurements appear to increase as FLAG lowness index increases. Soil texture and depth appear to change nearer to flow lines (increasing FLAG lowness index) and hence the increase in conductivity was expected.

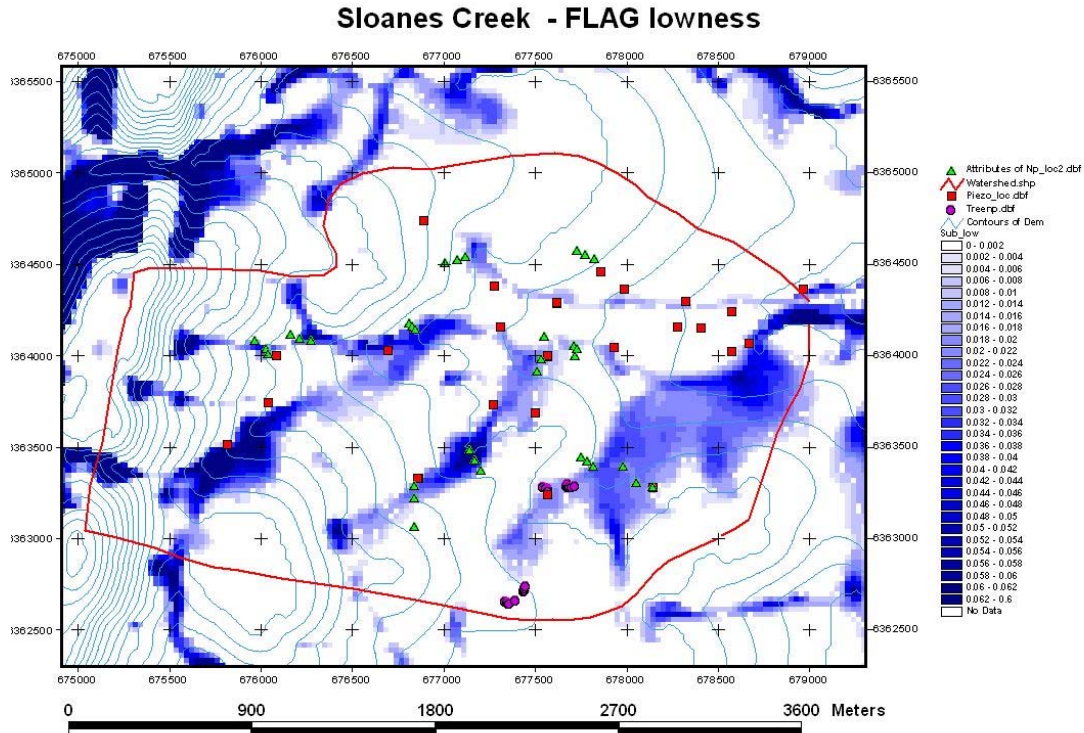
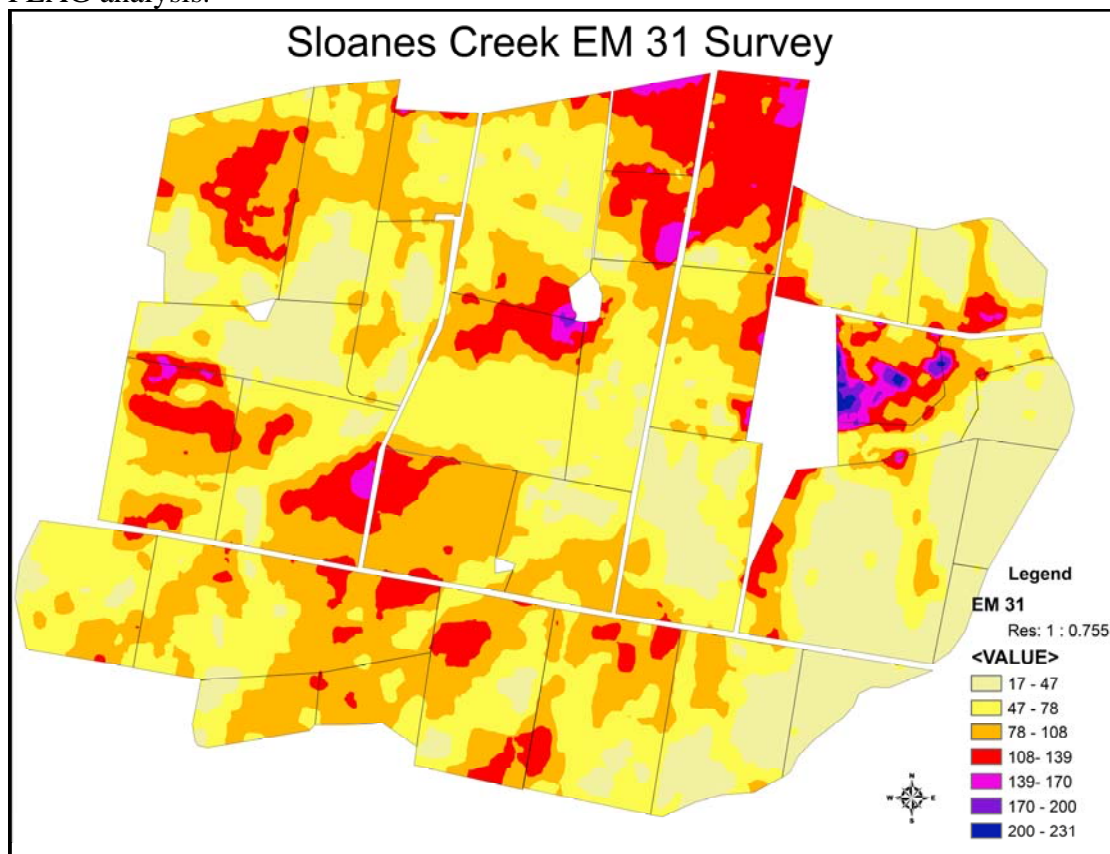


Figure 3. FLAG lowness modelling in the Sloanes Creek catchment and positions of instruments.

The electromagnetic induction survey of the site was undertaken in April 2003 under dry catchment conditions. The areas of high apparent electrical conductivity are related to areas of known salinity outbreaks and wetter areas as delineated by the FLAG analysis.



The majority of the area (90%) recorded an apparent electrical conductivity below 120 mS/m suggesting that there was little salt in the soil. This is assessed on the factor that the soil types have a predominantly clay loam texture which would then account for a majority of the electromagnetic response.

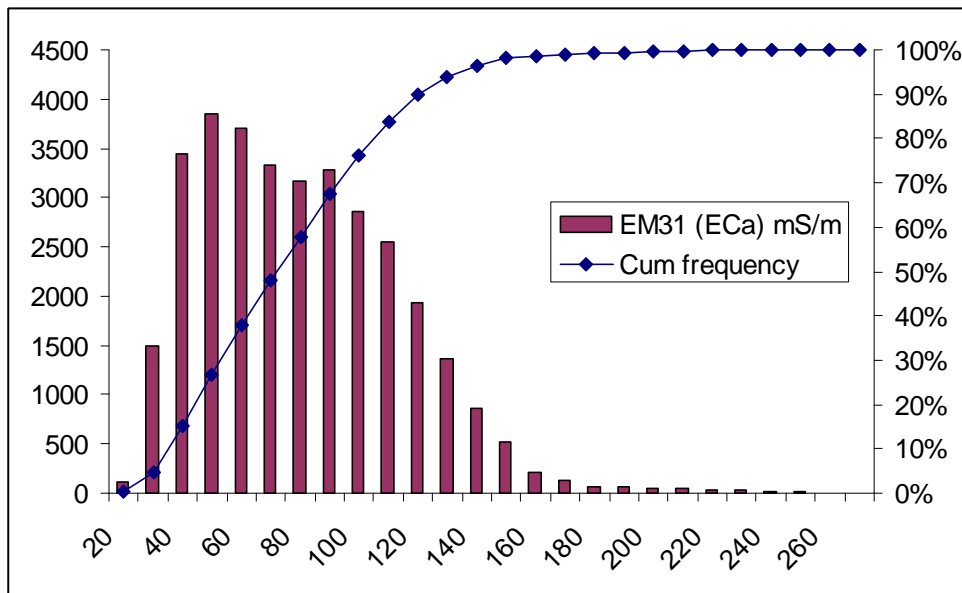


Figure 29 Frequency analysis of EM 31 survey

The areas of high conductivity are mostly areas of topographic lows suggesting that soil moisture may have been the major reason for the high response. The only area that has a high conductivity without the topographic low is the ridge area immediately north of the scald. This area possibly has high salt loads in the soil which may partly explain the presence of salt at the scald which is further down the catchment.

Conceptual model

Based on the monitoring and investigations a conceptual model of the Sloanes Creek Site is presented.

There appears to be a number of groundwater flow systems at the Sloanes creek site. One groundwater system appears to be at least one unconfined aquifer that is at the north western side of the scald. This aquifer is monitored by wells 103 and 113. This system's movement is highly correlated to the long term climate rising in response to above average rainfall and dropping in periods of below average rainfall.

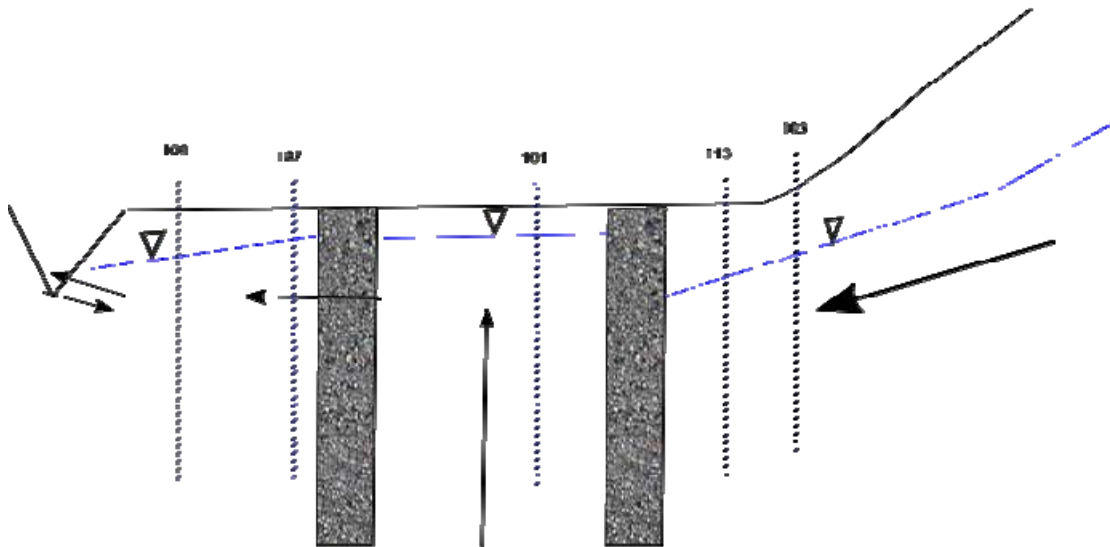


Figure 30 Conceptual model of the Sloanes Ck Catchment

The second groundwater flow system or at least the discharge zone of a GFS is evident in the middle of the scald. The groundwater flow system does not respond to rainfall as the watertable is usually close to the soil surface and has not dropped much over the observation period. This would suggest that this is discharge from a larger groundwater system. To confirm this, a nested piezometer is needed to be installed to measure the gradient of groundwater. The third groundwater system is on the south eastern side and is measured by wells 107, 106 and 507. This groundwater system appears to be a mixture of the above two. It is drawn down over time and also responds to rainfall however the draw down appears not to be related to rainfall as the groundwater system in the north western side there also appears to be interaction with the nearby stream. This is supported by the geochemical data that shows a wide scattering of chemistries within the groundwater. This data suggests that there is more than one source of groundwater discharging at the scald.

The streamflow has changed from what was anecdotally a perennial stream which ran continuously to an intermittent, stream and then through 2006 an ephemeral stream that ran in response to rainfall. Since 2006 the stream has run intermittently usually running from early winter until mid to late summer drying up over autumn and recommencing after rainfall in winter.

This suggests that the near stream aquifers that had been draining to the stream and providing base flow have dropped below the stream bed and have disconnected from the stream.

Conclusion and Future Directions

Conclusions

The groundwater discharge and subsequent saline scald and salt transport and mobilisation appear to be a predominately natural process. The groundwater discharge to the scald even under low rainfall conditions has not diminished over the last 7 years. The groundwater discharge causing the scald appears to be from a larger groundwater flow system that could be recharged from outside the catchment boundary. This leads to the conclusion that it would be uneconomic to and possibly unfeasible to identify the recharge zone and revegetate. The best option for this site would be to continue with the current management practices of keeping stock excluded, possibly with crash grazing if the vegetation (grasses) gets too thick.

The groundwater and the resultant discharge however is providing water to sustain a what appears to be a healthy groundwater dependant ecosystem. The scald itself while still bare in places is supporting a salt tolerant species such as tall wheat grass, Puccinella and salt bush.

Based on these observations it is concluded that fencing of and revegetation of the scald has improved the resource condition of the site, and is a model for best management practice for saline land in NSW.

Future

Continue to monitor surface groundwater and climate data at site

Continued investigations into the surface-groundwater interaction at the Sloanes Creek site will provide important understanding of how these processes occur and manifest. These processes

Continue to investigate the discharge zone in the scald to identify recharge areas

Monitor the effect of revegetation on the scald

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