*A case study of integrated hydrology research in the Namoi Catchment: Duri Catchment Key Site*

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Author: Dr David Mitchell, Technical Specialist Salinity Management, Salinity and Catchment Hydrology Unit, Orange Agricultural Institute



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Published by Industry and Investment NSW

First Published December 2009



Acknowledgements
This document has been compiled on the basis of discussion and contribution from many Industry and Investment NSW, DECCW and Namoi CMA staff and I would like to thank them for their time and effort. Peta Derham, Melisla Nies, Ian Daniels, Chris Lee, George Truman and Peter Regan.

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

## History

The Key Sites project was initiated in response to a recognised need to provide sound long term data to improve the scientific understanding of salinity and hydrology processes and subsequent conceptual and computer modelling tools. Officially the Key sites project started in 1st July 2005. However the origins of the project reside in the NSW Salinity Strategy and research activities that commenced between 2001 and 2004 under that strategy. In late 2003 applications to the NAP SWQ from then three state agencies (DLWC, NSW Agriculture, and State Forests NSW) were received to undertake hydrological research to better understand the effect of landuse on water and salt flow. Feedback during early stages of the assessment process indicated that one comprehensive multi-agency project focused on the hydrology needs of NSW was an appropriate means for this activity to be conducted. To that end a joint proposal was submitted with NSW DPI as the lead agency of a highly collaborative project that was jointly implemented with DIPNR. The subsequent project was independently reviewed (Webb 2005) and found to *"form a critical asset for generation of scientific knowledge required to underpin the ability of Government and the CMAs to evaluate salinity management options across NSW."*

## Site History

The Duri Key Site was initiated in May 2003, with the aim to better understand the role of landuse on salt and water movement in a typical northern farming dryland landscape. Specifically the Duri site was designed to determine the changes in deep drainage under various land uses, specifically perennial pastures.

This site was chosen due primarily to the extensive data set available on one of the major soil types within this sub-catchment. In previous years there was an extensive research project that investigated the impact of various grazing rates on lucerne's ability to utilize soil moisture (GRDC DAN-466).

## Site Location

The Duri Key Site is about 30 km m south west of Tamworth on the Werris Creek Road. The site is approximately 620 ha in size and encompasses six privately owned properties. The Timbumburi Ck is an ephemeral creek draining into the Peel River, a major tributary of the Namoi River catchment, flows through the middle of the sub-catchment, in a south-north direction.

The Duri Key Site is located east of the Werris Creek Rd (31°13'S, 150°49'E), bounded on the north by Duri-Dungowan Rd (31°13'S, 150°51'E) and to the east by Tamworth-Gowri Rd (31°15'S, 150°51'E). The southern boundary (31°14'S, 150°48.5'E) is defined by the topography, though not distinct, a gentle change in slope.

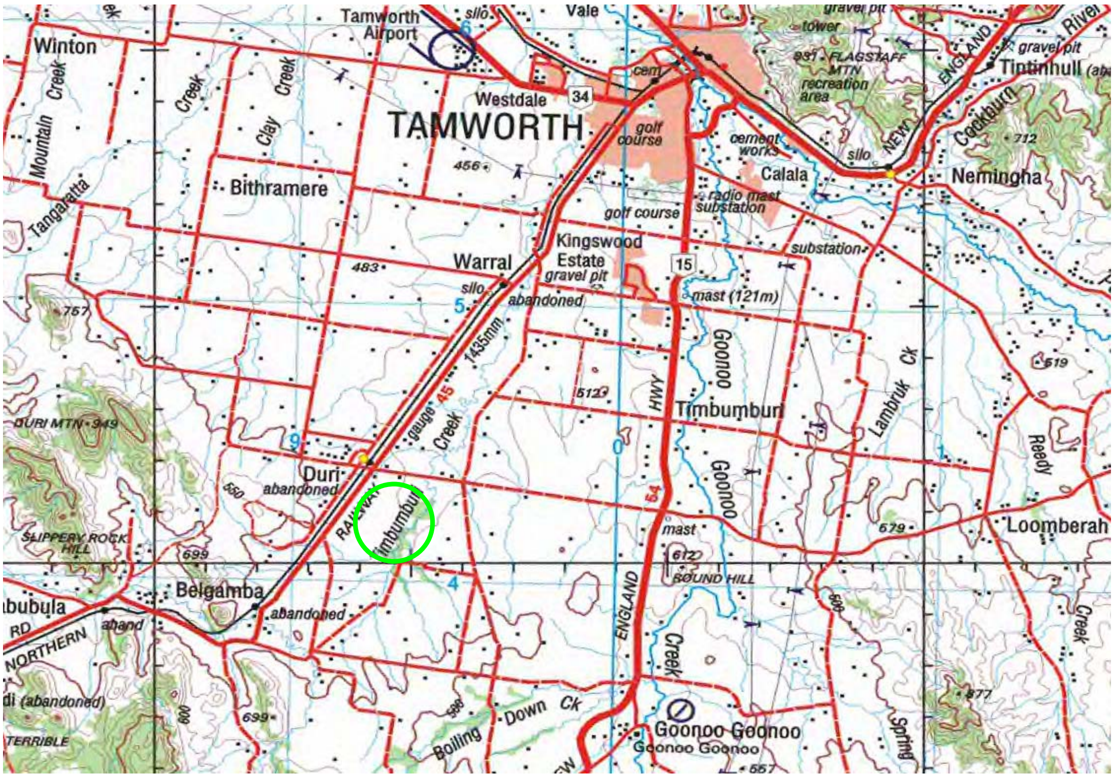


**Figure 1 Duri site location (green circle is indicative of the location but does not delineate site boundary)**

The site is characterised by the low undulating hills and red texture (chromosol) contrast soils and black clay soils (vertosols) along the creek line. The red soils are low in organic matter and fertility which underpins the main biophysical constraint in these landscapes, which is soil management. The sub-catchment has isolated salty deposits but stream electrical conductivity and salt load previous to the present study have not been monitored.

## Physiography

Within the Peel catchment the site sits in the middle to lower Peel which is described as a low to moderate relief landscape dominated by meta-sediment geologies occupying an area between Tamworth and the Melville Range that extends from upper Goonoo Goonoo Creek in the south to Borah Creek in the north. It is a mixed denundational/ aggradational landscape with gently to moderately inclined hillslopes and rounded ridge crests. Valley floor widths are generally between 50 to 200 metres, but can be up to 2000 metres along the Peel River. Due to the gentle hillslopes, relatively small amounts of sediment are delivered to the streams with most sediment stored in local sinks, though these can be subject to reworking, especially when disturbed. Stored sediments along the major streamlines have been largely sourced from the upstream rugged meta-sediments landscape unit. Although hillslopes are gentle, the relatively thin regolith/soils mean that runoff rates can be relatively high resulting in peaked and variable stream discharges.

## Soils

The soils in the Duri area have been extensively mapped in a report by Banks (2001) and the present study draws heavily on this report for the descriptions of the pedogenesis and soils within the study site.

Soils at the Duri Site are a contained within the “Warral Station” and “Duri” soil landscapes as defined by Banks (2001). The Warral Station soil landscape is transferral soil landscape, which is described as landscapes that have deep deposits of mostly eroded parent materials washed from areas directly upslope. Stream channels are often discontinuous and slopes are generally concave. These landscapes include footslopes, valley flats, fans, piedmont alluvial plains and piedmonts (Banks 2001). The Duri soil landscape is a residual soil landscapes which is dominated by sites where deep soils have formed from in situ weathering of parent materials. These soil landscapes typically have level to undulating, elevated landforms which include some summit surfaces, plateaux, terrace plains, peneplains and old ground surfaces and stream channels are usually poorly defined (Banks 2001).

The main soil present at the Duri Site is a Mottled Eutrophic Red Chromosol (Isbell 1996). This soil is described as one with a strong texture contrast between A horizons and B horizons and in which the carbonate is evident only as a slight to moderate effervescence in 1M HCl, and contains less than 2% soft finely divided carbonate, and have less than 20% hard carbonate nodules or concretions with a mottled B horizon (Isbell 1996). This soil landscape as having widespread gully and sheet erosion risk, with localised; water logging, poor drainage, high run-off, shallow soils, and the potential risk of both recharge and discharge areas (Banks 2001). The other soil grouping is described by Banks (2001) as a Self Mulching Black Vertosol. Isbell (1996) describes the concept of a Vertosol soil as a clay soils with shrink-swell properties that exhibit strong cracking when dry and at depth have slickensides and/or lenticular structural aggregates. Additionally the soil has a surface that is moderately to strongly self-mulching.

This soil is found along the flood plains and as a result is more prone to localised water logging with widespread run-on and flood risks. Again there are widespread risks of erosion, with localised permanently high water tables and poor drainage. This soil type also has the potential for both recharge and discharge areas (Banks, 2001).

**Geology**

The underlying geology is Carboniferous, Devonian in age falling under the Tangaratta formation, made up of mudstone and feldspathic arenite (consolidated rock with the texture of sand). There is Gowrie sandstone member on the northern edge of the site running along the Dungowan-Duri Rd. A significant feature of this research site is the fault that dissects the north east corner. There is also a syncline that runs through the middle of the sub-catchment in a north-northwest direction. In the south-eastern corner of the sub-catchment there is a Tertiary igneous intrusion, the Warrigundi alkaline group. The geology dips to the west and is dominated by Werrie syncline and is part of the larger Western belts of folds and thrusts of the Northern Tamworth zone in the New England Orogen.

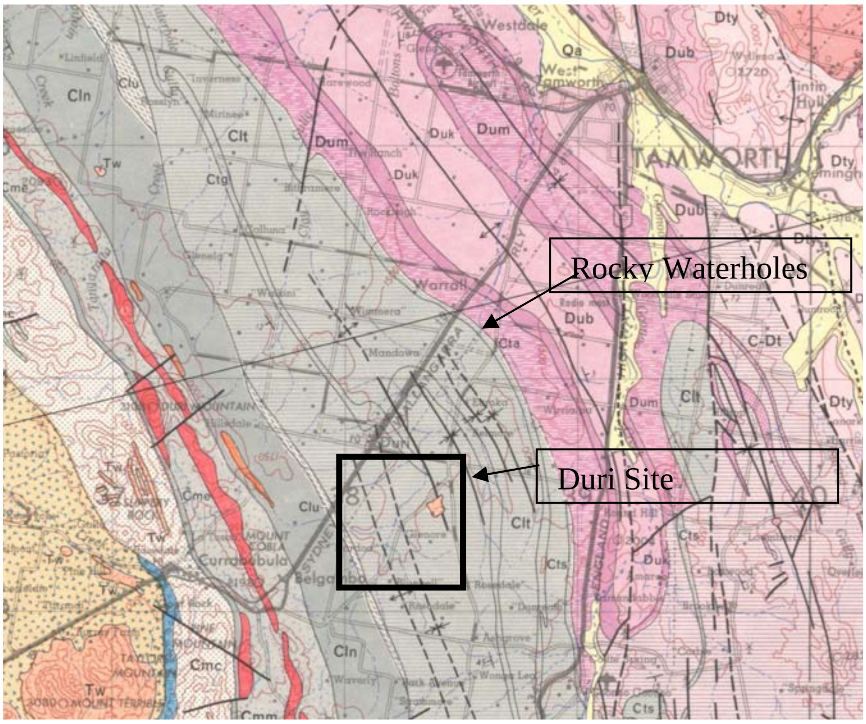


**Figure 2 Excerpt from Tamworth geology sheet showing Duri Key Site and Rocky Waterholes**

To the north of the site and underlying the Tangaratta formation is the Mandowa mudstone group, this geology was formed the Early Carboniferous Period (Tournasian age) under a near shore marine shelf environment (Mory 1982). It is suggested that the western margin of the Tamworth Belt was sub-aerially exposed with shelf muds being deposited to the east (Mandowa Mudstone) (Mory 1982).

## Groundwater flow systems

In the Namoi catchment a range of groundwater flow systems have been described (Smith and Blair 2002). These include a range of regional intermediate and local systems that are located in the Namoi catchment. The Duri site is located within the local carboniferous metasediments (system 11) groundwater flow system (Smith and Blair 2002). This system is characterised by fractured rock aquifer and variable weathered regolith, the aquifers are typically semi-confined and have high conductivity, moderate transmissivity, and low specific yield. The seasonal aquifers recharge under moderate annual rainfall, and groundwater can be moderately brackish.

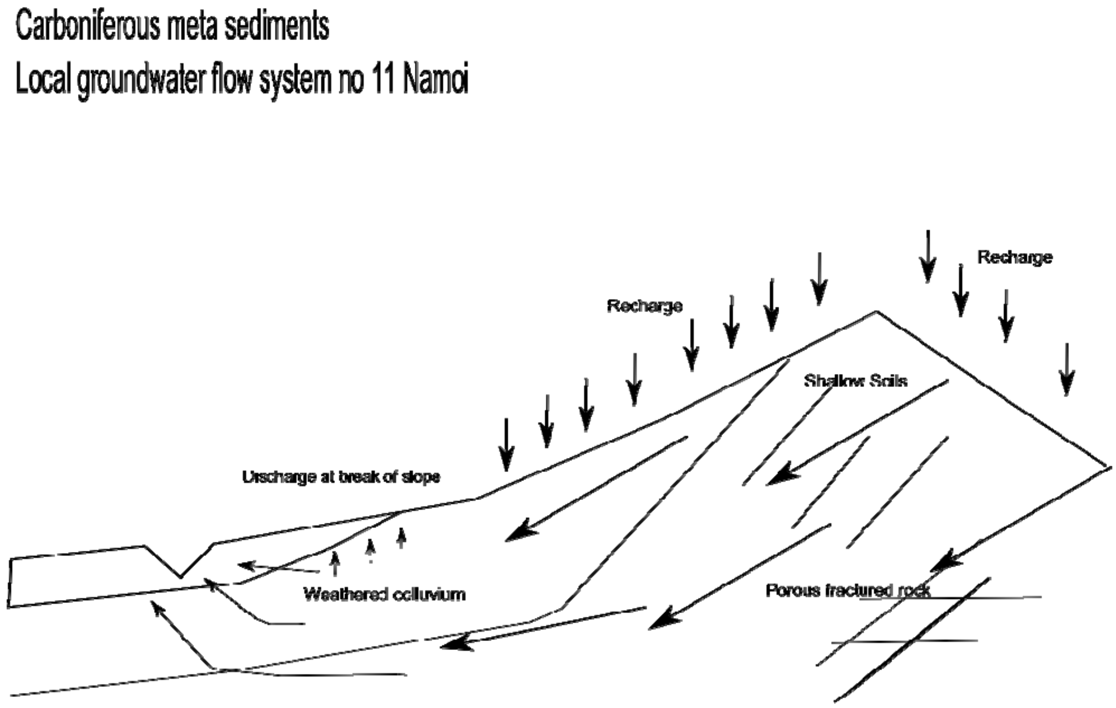


**Figure 3 Local groundwater flow system Carboniferous metasediment (no. 11) (from Smith and Blair 2002)**

Groundwater discharges at hillslopes, beak of slope and valley floors, additionally baseflow discharge is associated with termination of beds, faults and fractures with the land surface.

## Land use

The Duri Key site has an area of 650 ha of which at least 135 ha of remnant woodlot and another 150 ha of annual cropping, typically winter wheat, oats, barley, sorghum, vetch or sudax, all of which are used for fodder.  Excluding ~10 ha, which incorporates homesteads, dams and drainage gullies, the remaining 325 ha is covered with a variety of annual or perennial pasture.  Of this area, approximately 175 ha is a mix of unfertilised native grasses (including *Bothriochloa macra*, *Dichrnthium sericium*, *Stipa aristiglumas* and *Danthonia sp*.) and weeds.  There is an area of about 50 ha which is predominantly D. *sericium*. The remaining 150 ha incorporates fertilized mixed lucerne grass pastures, strip farming paddocks of lucerne or grass (with a variety of sub-clover types intermixed).

Lucerne has been predominantly sown on the heavier soil; this soil type is also used for cropping.  The lightered textured soils are dominantly covered with grass varieties and on the eastern side of the creek the upper slope has significant weed problems including eastern cotton bush (*Maireana microphylla*).

**Research questions**
The main research questions revolved around how salt and water move in these typical upland dryland agricultural landscapes and how will changes to management particularly landuse effect these processes.

The objectives of this project are:
- To define the water budget of the sub-catchment.
- To identify the hydrological processes within the sub-catchment.
- To evaluate the efficiency of the current land use systems on ground water recharge and discharge.

  - What are the paddock scale water balance components for current the enterprises?
  - Can the individual enterprise water balance be scaled up to the sub-catchment?
  - What is the groundwater recharge under current farming systems?
  - Can the effect of different spatial/temporal arrangements of farming systems on catchment recharge, salt export, and agricultural production be simulated?
  - What are the recommended land management practices for these landscapes?

**Methods**
To answer the research questions a series of one dimensional water balance experiments were setup on a range of typical landuses within the Duri Key Site. The individual water balances were then scaled to determine the subcatchment water balance including recharge to the groundwater and stream flow.

In a simple water balance the major input is rainfall and outputs include evapotranspiration, runoff, and drainage below the root zone. A significant amount of water can be stored in the soil profile as the soil contained in the root zone acts as a buffer between rainfall and deep drainage.

Additionally a physical site characterisation was undertaken to better understand the physiography of the site. This included:
- A sub 2cm Digital Elevation Model (DEM),
- Frequency domain electromagnetic induction (EM-31 & EM-38) survey,
- Fuzzy Logic Analysis GIS (FLAG) terrain analysis model output.

*Location of experimental sites in the sub catchment*
Six experimental sites were setup to monitor the water balance over a range of enterprises within the Duri site.
At each site a range of measurements were undertaken to calculate the water balance including, rainfall, soil moisture, and micrometeorological measurements to determine the Bowen ratio and estimate evapotranspiration.

*Rainfall*
Rainfall was measured with the use of automatic logging tipping rain gauges. A number of automated rain gauges have been installed in each catchment to measure the total amount of rain in each episode, and the rainfall intensity.

*Soil moisture*
Volumetric soil moisture content of the soil profile was measured by neutron moisture meters at a range of depths. The neutron probe was calibrated on all major soil types within the two research sub-catchments (R Young pers. comm.). Semi-permanent aluminium tubes for the neutron moisture meter were installed down to between three metres on crop and pastures sites, and six metres in areas where trees are present.

*Evapotranspiration*
The water use by plants as either transpiration or evaporation from the soil surface was measured using the Bowen ratio method (BR) (Bowen, 1926, Crosbie *et al.* 2007).

At four of the BR sites nine Neutron Moisture Meter (NMM) access tubes were installed. Each tube is spaced 50m apart in a square grid arrangement with one in the centre. At the central access tube there is a BR unit within 10m of the tube.

The fifth BR site was situated on a brown Vertosol and is bounded by contour banks. Neutron moisture meter access tubes were installed above, at the base of the contour bank both on the up slope and down slope side and further down slope from the contour bank.

The sixth BR site was situated on a degraded Chromosol where extensive erosion gullies have formed and there is a large amount of eastern cotton bush present. There are a total of 13 access tubes at this site. One has been positioned in an erosion gully and two have been position close to large cluster of eastern cotton bush.

*Runoff*
Streamflow was measured in the main drainage line Timbumburi Ck, an ultrasonic doppler (Starflow) velocity meter was installed at the top of the catchment and a depth sensor and an ultrasonic doppler (Starflow) velocity meter was installed at the bottom of the catchment to measure stage and discharge.

*Pasture*
Pasture biomass and leaf area index were measured monthly from random hand pasture cuts collected in $0.25m^2$ quadrats.

## Results

### Climate

Mean annual rainfall for Tamworth is 673 mm and ranges from 470 mm (Decile 1) to 912 mm (Decile 9). The rainfall is summer dominant with on average 52% of the rain falling between October and February; however substantial winter falls can occur. Evaporation exceeds rainfall year round with a mean maximum of 279mm recorded in December and a minimum of 60mm in June (BOM, Averages for Tamworth Airport). Mean maximum and minimum temperatures for the area are 31.9 and 2.9 °C for the months of January and July respectively.

*Rainfall*

The rainfall record for Tamworth commences in 1890, 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 rainfall Tamworth area has been experiencing has been below annual the average rainfall since 1993. However this period is still not the longest period of below average annual rainfall as that occurred from 1921 to 1948. There have been two periods of average annual rainfall from about 1898 to 1920 and from 1961 to 1993 and there was two periods of above average rainfall 1889 to 1898 and 1949 to 1960 (fig 4).

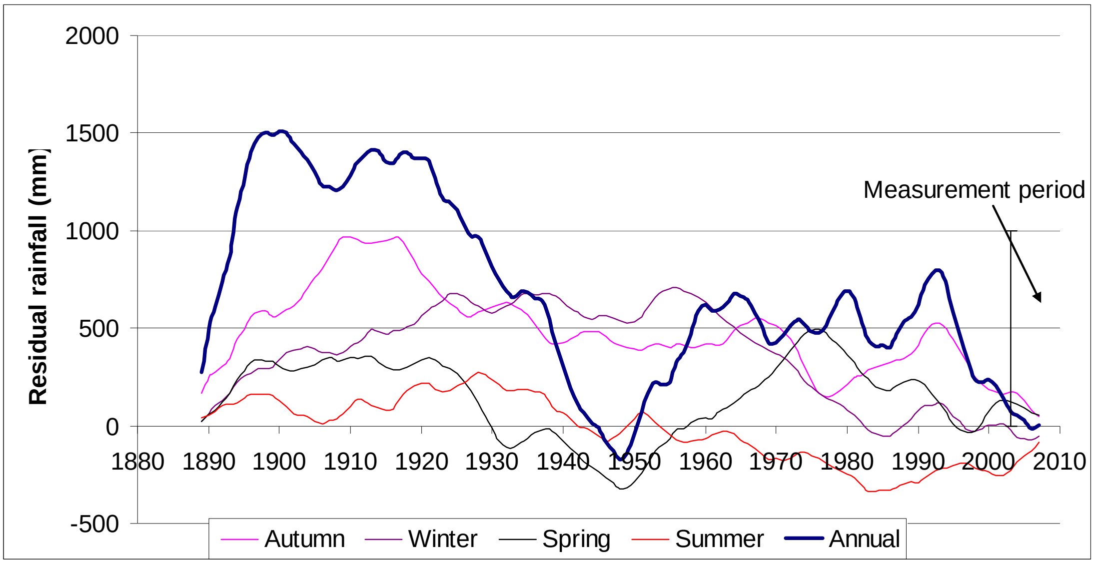


**Figure 4 Residual mass rainfall Tamworth Airport**

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, it can be seen that the current decline in annual rainfall has been due to decline in autumn rainfall since 1993 (fig 4).

*Results from the measurement period*

The total amount of rain received at the study site over the observation period (Jan 03 to Jun 08) was just over 3778 mm, which was above the long term average of 3196 mm. Over the 66 months of observation 34 months received above average rainfall and of those 17 were above the 75 decile and 14 were below the 25 decile. The variability of the rainfall was high with only 17 months receiving rainfall within the 40-60% centile over the observation period (fig 5, Table 1).

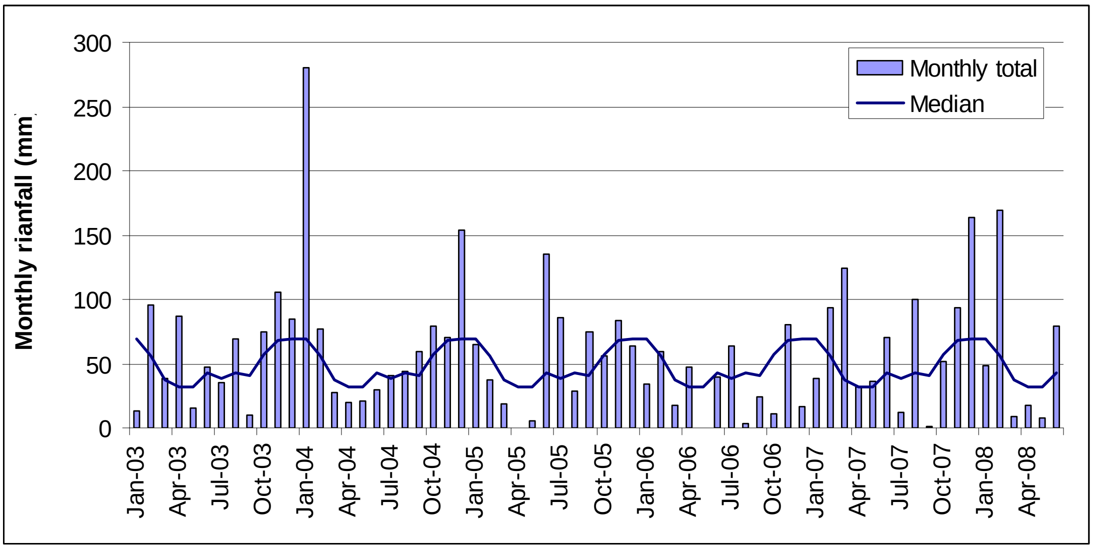


**Figure 5 Monthly rainfall Duri**

Seasonal rainfall

Rainfall received at the site over the observation period was considered to below average for nearly all the seasons. There was only three periods of median or above average rain falling for three consecutive months throughout the observation period. These were spring/summer of 2003 (Oct 2003 to Jan 2004) winter/spring 2004 (Jul 2004 to Dec 2004) and Autumn 2007 (Feb 2007 to June 2007).

**Table 1 Monthly rainfall totals Duri**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2003 | 13 | 96 | 39 | 86 | 15 | 48 | 36 | 69 | 10 | 75 | 106 | 84 | 677 |
| 2004 | 280 | 77 | 28 | 20 | 21 | 29 | 41 | 44 | 60 | 79 | 70 | 154 | 903 |
| 2005 | 65 | 37 | 19 | 0 | 6 | 135 | 86 | 29 | 74 | 56 | 84 | 64 | 655 |
| 2006 | 34 | 59 | 17 | 47 | 0 | 39 | 63 | 3 | 24 | 11 | 81 | 17 | 396 |
| 2007 | 38 | 93 | 125 | 32 | 36 | 70 | 12 | 100 | 1 | 52 | 93 | 164 | 816 |
| 2008 | 49 | 169 | 9 | 18 | 8 | 80 | | | | | | | 332 |
| Median | 69 | 56 | 38 | 32 | 32 | 43 | 39 | 43 | 40 | 57 | 68 | 69 | 678 |

Additionally there were four periods of below average rainfall that is rainfall that was below average for three consecutive months. These periods were autumn 2004 (March 2004 to June 2004), summer/autumn 2005 (Jan 2005 to May 2005), spring 2006 (Aug 2006 to Oct 2006) and autumn 2008 (Mar 2008 to May 2008).

*Site Characterisation*

Digital Elevation Model

A detailed digital elevation model (DEM) was developed for the Duri Key site using RTK GPS on a 4 wheel quad bike. Transects were driven every 25 m and this data was used to construct the digital elevation model.

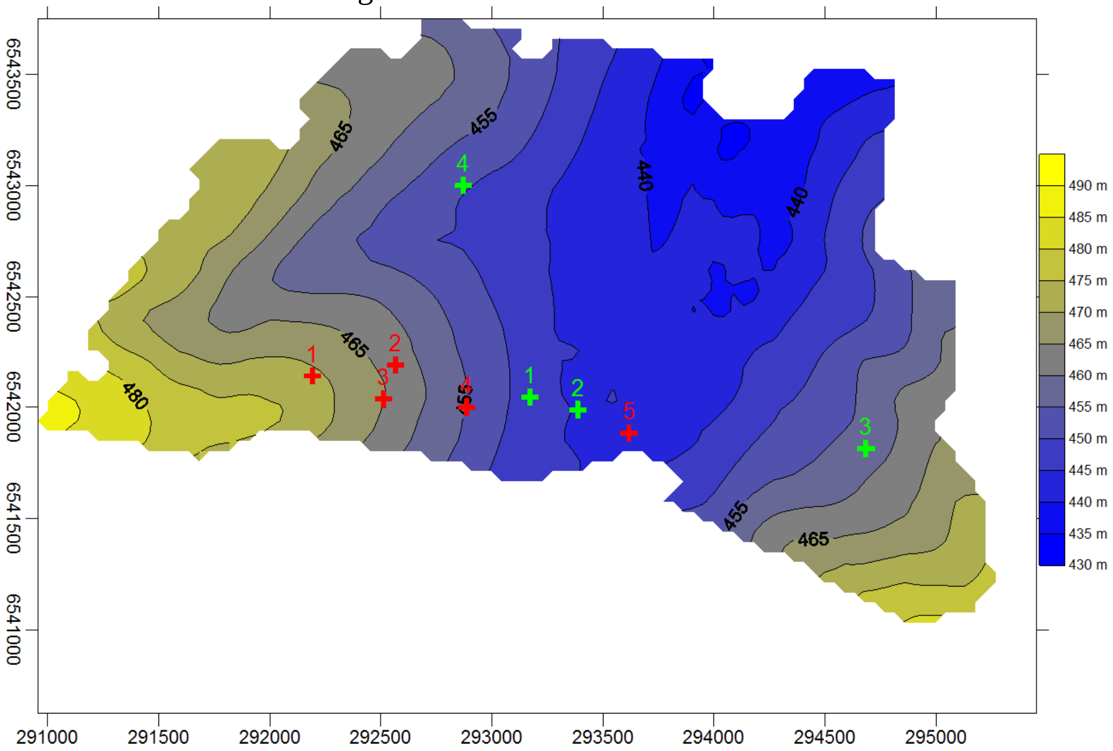


**Figure 6 Digital elevation model (DEM) of the Duri Key site (contour lines black 5m intervals; piezometer red crosses and numbers locations; BR units green crosses and numbers).**

Elevation varies from a maximum of 487 m on both the west side of the catchment with a low elevation of 429 m along the creek at the catchment outlet. The DEM shows the broad alluvial flats along either side of the creek. The median elevation for the site is 454 m AHD and there is an overall relief of about 40 m from the top of the hill to the creek line and the gentle northerly aspect of the site in general.

The DEM shows the Timbumburi Ck which is the main drainage line on the research site (fig 6) as well as a large area that is drained from the western side of the catchment towards the centre. Not as easily defined but also present are two drainage lines on the east flowing towards the Timbumburi Creek (fig 7).

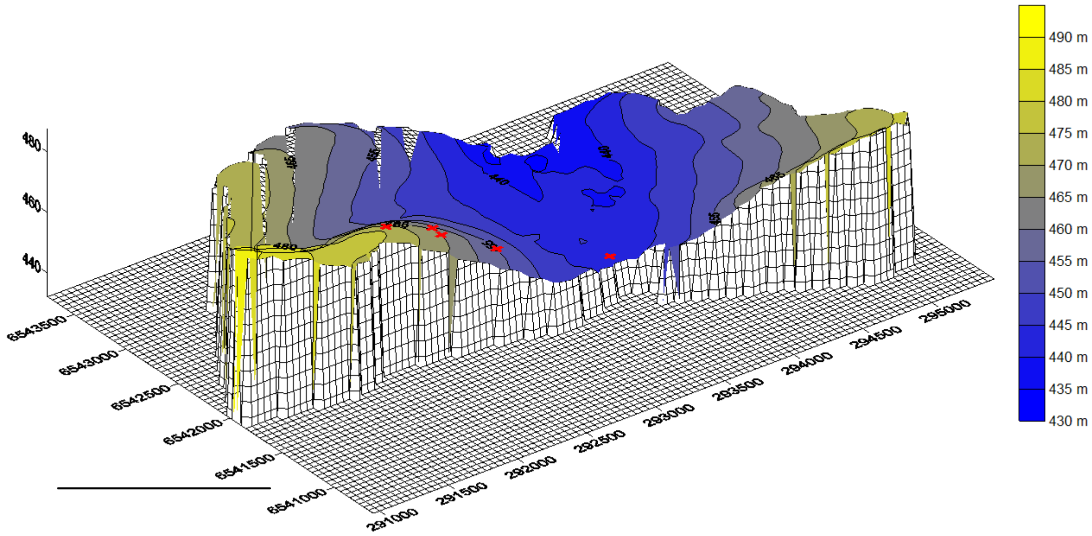


**Figure 7 Draped DEM (piezometers locations marked with red crosses)**

Additional to the site data, a broad scale DEM image covering Duri to Tamworth shows the broad regional drainage pattern and north south orientation of the valleys that the Duri Site (outlined at the bottom centre of fig 8) sits in (fig 6). The landscape slopes gently towards the north with a predominantly northern aspect. To the west the high elevation of Mt Cobla can be seen.

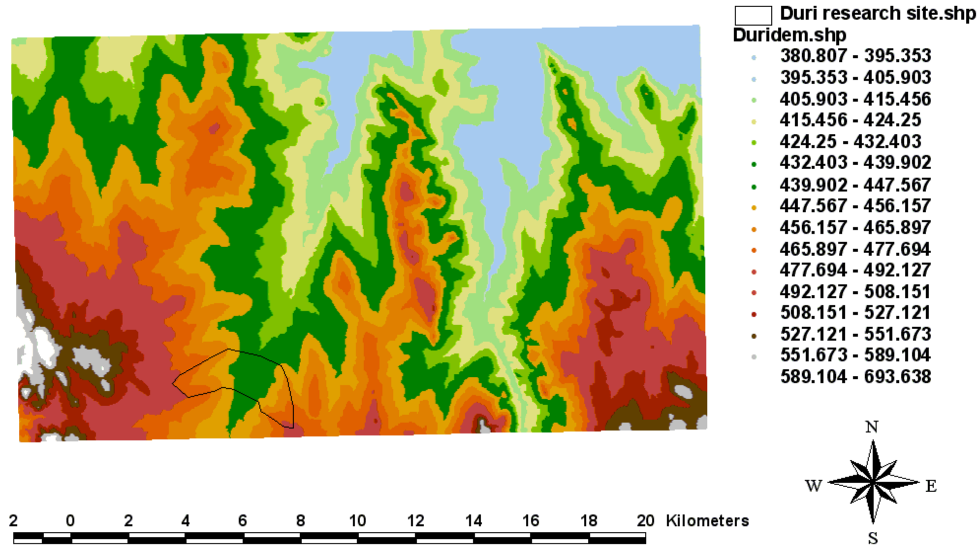


**Figure 8 DEM of the upper Timbumburi Creek (Duri Key Site outlined)**

EM 31 survey

An EM 31 survey completed by NSW DLWC (Gunnedah) in February 2002 was conducted to measure the near surface (0-4m) apparent electrical conductivity of the soil in February 2002. The survey was conducted on a quad bike with a Geonics EM 31 attached to a RTK GPS unit which logged the position and ECa every second which corresponds to a reading of roughly every 5 m.

The data was mapped using the SURFER mapping program and the countor levels where set in the $10^{th}$, $25^{th}$, $50^{th}$, $75^{th}$ and $90^{th}$ percentile.

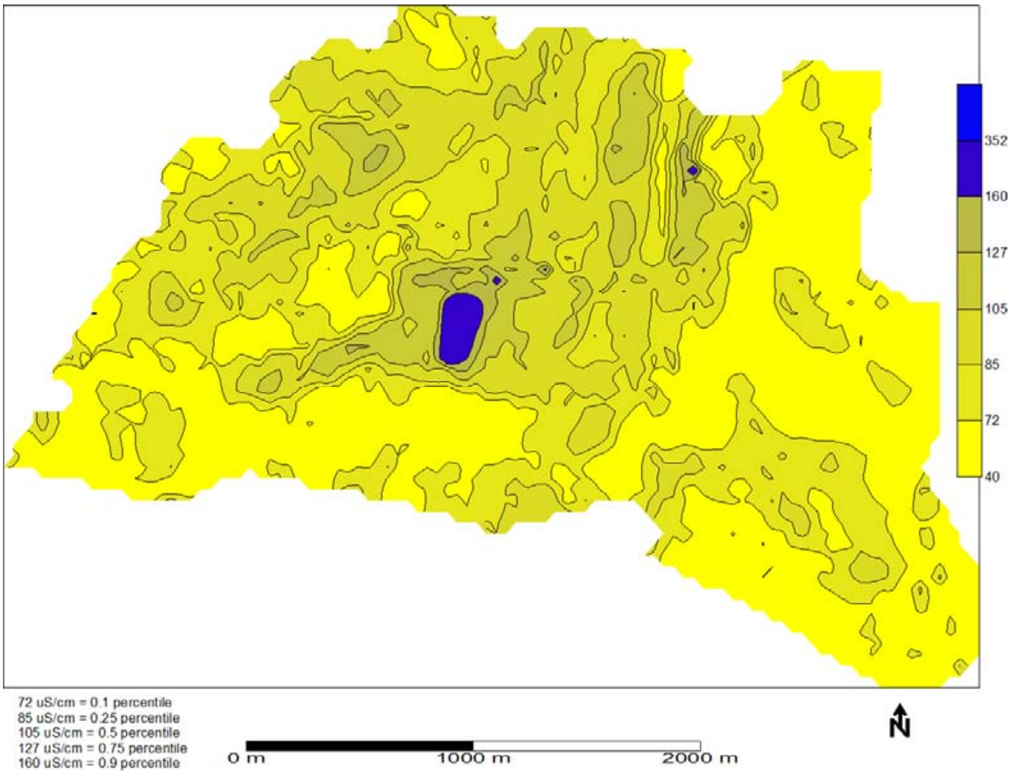


**Figure 9 EM-31 survey of the Duri sub-catchment.**

The survey collected just over 10 000 data points across the Duri Key site with easting, northings, elevation and ECa being recorded at each point. The range of ECa measured was between 44 and 402 uS/cm with the highest being measured in along a single transect composed of 12-15 points near the centre of the site (large blue shape in Fig 7). These higher readings are related to extensive fencing and metal equipment present in the research site which are by their nature conductive and have skewed the data. The data was reanalysed with these data points omitted and this edited data set will be discussed.

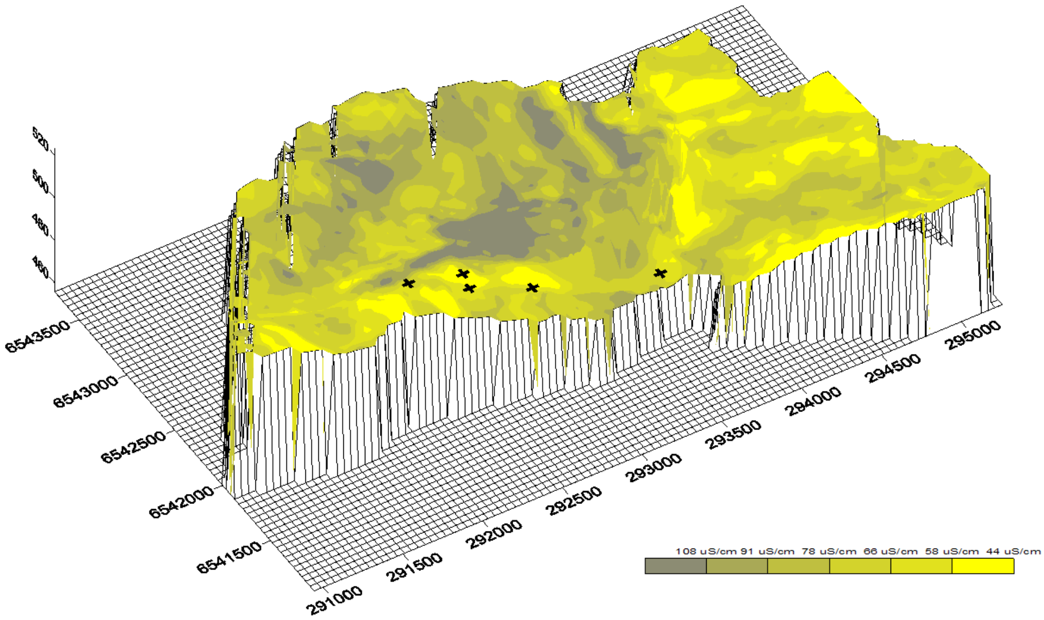


**Figure 10 EM-31 survey draped over DEM of the Duri sub-catchment (black crosses show piezometer locations).**

The conductivity data set was overlayed on the elevation data to identify if there was ant spatial relationship between conductivity and elevation (fig 10).

There is a broad area of high ECa (greater than 127 υS/cm) in the centre of the survey that appears in the maps as a large grey area and this corresponds to the black alluvial plains and on the eastern side large areas of low conductivity soil which relate to the lighter textured redder soils in the catchment. There appears to be no coherent spatial pattern to the data excepting the broad relationship between the elevation and ECa.

The frequency distribution of the ECa data shows that ECa data is nearly normally distributed around a central modal value of 80 uS/cm. The histogram shows a secondary peak at 125 uS/cm however this is due to the change in scale of the histogram.

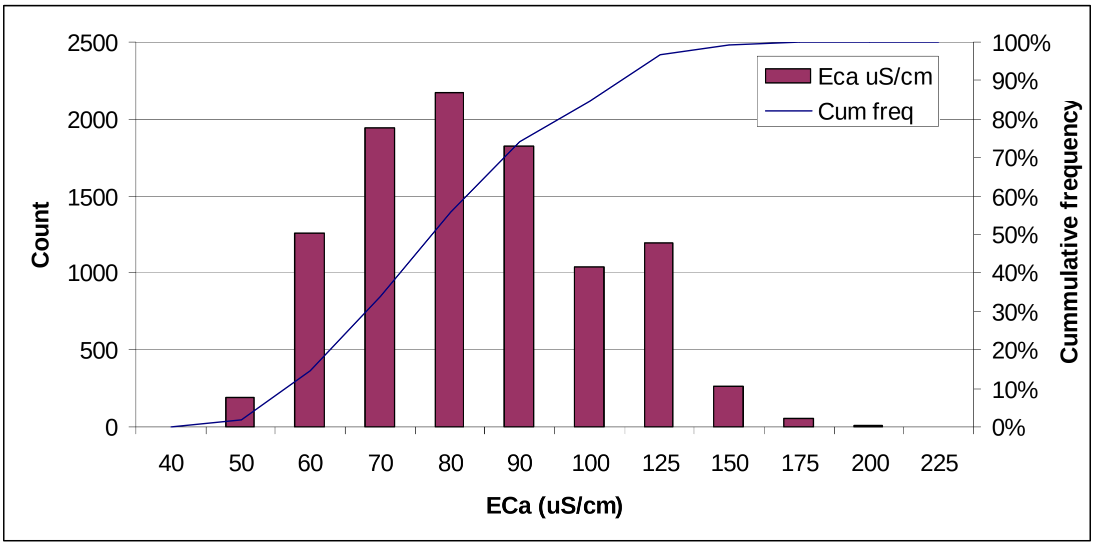


**Figure 11 Frequency distribution of ECa data at Duri Key site.**

At the time of the survey (Feb 2003) the soil was relatively dry, and the range of recorded soil texture is between loamy clay and light clay (Baker, Banks). From the range of measured ECa this suggests that there is little salt present in the soil with most of the ECa response coming from the texture of the soil rather than soil moisture or salt content.

Soils

The soils in the Duri Key site are generally capable of sustaining annual crops and pastures however the eastern side of the Timbumburi Creek has been extensively cropped over time and now as a consequence of this, these shallow chromosols have been degraded and have very poor soil structure. One of the consequences of the relatively long cultivation history is the extensive nature of erosion. There are significant erosion gullies, up to 1.8m deep and much of the landscape has experienced some sort of erosion. The western side of the creek has deep cracking brown clays and these soils are occasionally cropped, though currently the crops are predominantly for fodder.

Soil profile properties varied considerably across the site in the south east edge of the site the soil was shallow with a maximum core depth of 0.7m, impeded by a shale layer, and roots were found to this depth. East of the main creek line the soil depth was estimated to be 1.2 m also with roots were observed to this depth. Further away from the creek higher on the ridge the profile was underlain by shale and a maximum depth of roots was 1.2 m.

The soil profile on the alluvial plain 200m west of the creek was 3.7 m deep with roots observed to a maximum depth of 1.6m. Continuing west up the ridge the soil depth was 2.7 m and the top soil colour changed from grey-brown to red.

Alluvium fans on both sides of Timbumburi creek are derived from Permian and Carboniferous sediments. The area ranges from extensive undulating to rolling hills, underlain by Devonian and Carboniferous sediments. Further west of the cracking brown clays, moving back up the slope, the soil type moves back into the red-brown earths. Due to the extensive nature of erosion that has occurred in this landscape many of the soil profiles contain layer of colluvium or are relic subsoils left over from erosional processes. Over the past 50 to 100 years many gullies have formed and have refilled with sediment from upslope refilling the gullies. The resultant soil landscape is a mix of sediments and soils that has loosely classified as Chromosols soils however on inspection of the particle size many of the soils profiles sampled lack the texture contrast to be truly classified as a Chromosol and are more likely to be Kandosol or Dermosols.

Reclassification of soils at the Duri Site

The soils were classified using the profile descriptions and particle size analysis presented in Baker (2004), using the Australian Soil Taxonomy (Isbell 1996). Chromosol Site 1 in Baker (2004) has no significant texture change at depth with clay through the solum ranging from 37% at 0.2 m to 42% at 1.0 m. The soil texture, determined using the soil texture triangle, of the top 0.5 m was a clay loam, similarly the texture for Chromosol Site 2 was also a clay loam. This suggests that the proper classifications for these soils are a Red Mesotrophic Kandosol. Soil descriptions and particle size for the two “Overlap sites” suggest that these soils could be classified as Brown Kandosol. The two Vertosol sites remain classified as Vertosols.

**Bore log records**

A number of existing bores are present in and around the Duri Key Site, of which ten had logs recorded in NSW DWE groundwater database. The bore logs show that the soil depth varies from 0.6 to 4.5 m, underlying the soil is an extensive shale layer. The shale layer slopes gently down to the north east following the orientation of the identified syncline in the regional geology sheet. The shale layer has a varying depth and lies between 1.5 and 38 m below the soil surface. The slope of the shale layer is a appears relatively uniform dipping towards the north east, however a large minority of the site sits on a relatively flat lying section of the shale layer. Two bores located towards the north of the site (GW 052199, and GW062448) the shale layer has a thickness 10 m underlying that is a thick layer (10 m) of basalt at between 435 and 420 m AHD. No basalt was recorded for the other eight bores located through the site. The deepest bore penetrated the shale to a thickness of 68 m (379 m AHD) under which compacted shale was recorded.

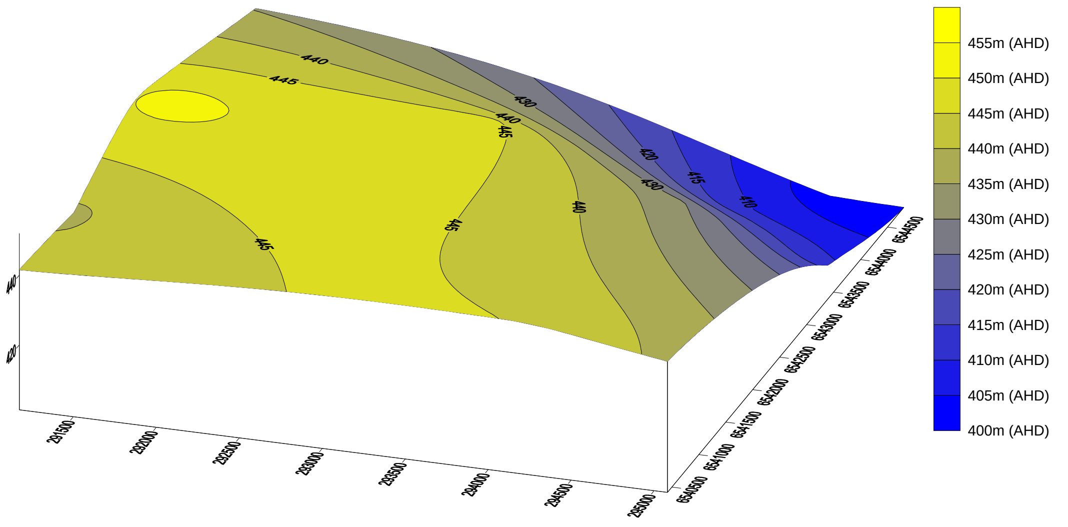


**Figure 12 Draped contour map of shale depth**

## Soil Hydraulic properties

At the Duri Site soil hydraulic properties specifically saturated and unsaturated hydraulic conductivity were measured by at several locations (Baker *et al.* 2004). Slow to very fast hydraulic conductivity rates (2.8->1000 mm/hr) were measured on the surface of the lighter soils, while at depth (0.4-1.3m) the conductivity was slower (0.003-0.5 mm/hr).

Groundwater

To better understand the connection between surface and groundwater systems data groundwater data was collected at the Duri site. Groundwater was measured nearly continuously at 5 locations across the Duri Key Site since the end of 2003. There are some small gaps in the data due to logger malfunction. The data presented here is from 5 piezometers located around the Duri Key Site.

The piezometers where located in a transect down the western slope of the Duri Site, spaced 500 m to 1000 m apart. Piezometer 1 was located on the crest of the slope on the edge between a cultivated paddock and an area of remnant vegetation (mainly trees). Piezometer 2 was located in the middle of the remnant vegetation block, and piezometers 3 and 4 were located in cultivated paddocks following the slope down towards Timbumburi Ck. Piezometer 5 was located near the edge of Timbumburi Ck and about 1200 m away from Piezometer 4 Amongst remnant riparian vegetation while landuse for piezometers 1, 3, and 4 was a mix of annual cropping and pasture.

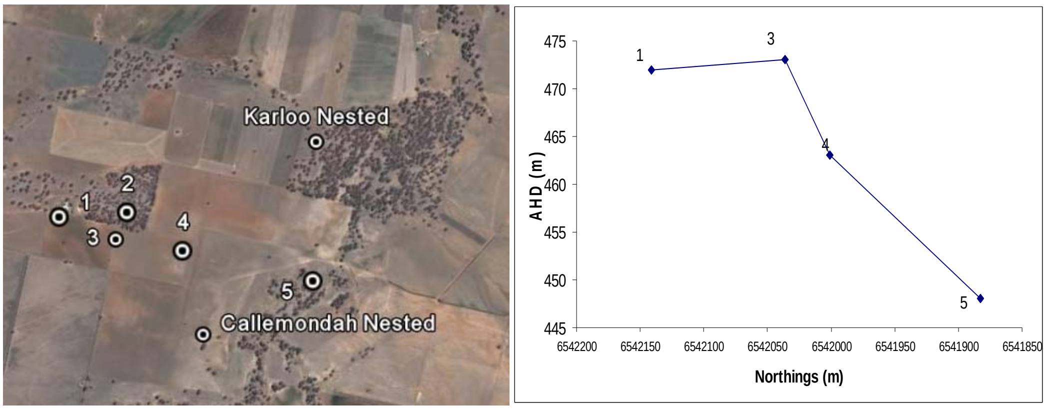


**Figure 13 Location of piezometers at the Duri Site, and hill slice showing heigts of the piezometers above AHD**

The groundwater data shows that there are periods of recharge, (rises in the hydrograph) followed by periods of depletion (falls in groundwater). Four of the five piezometers (2-5) appear to follow a similar pattern of recharge while piezometer 1 appears not be responsive to climatic condition. There does not appear to be any relationship between landuse and recharge as piezometer 2 is located within an area of remnant vegetation yet still shows that recharge is occurring after significant rainfall.

As piezometer 1 is located to the west of the other piezometers it may be in a different groundwater flow system that is not as well connected to the surface as the GFS that the other piezometers are located in. Further investigation into this piezometer using the barometric efficiency as an indicator of connectivity to the surface area is being undertaken.

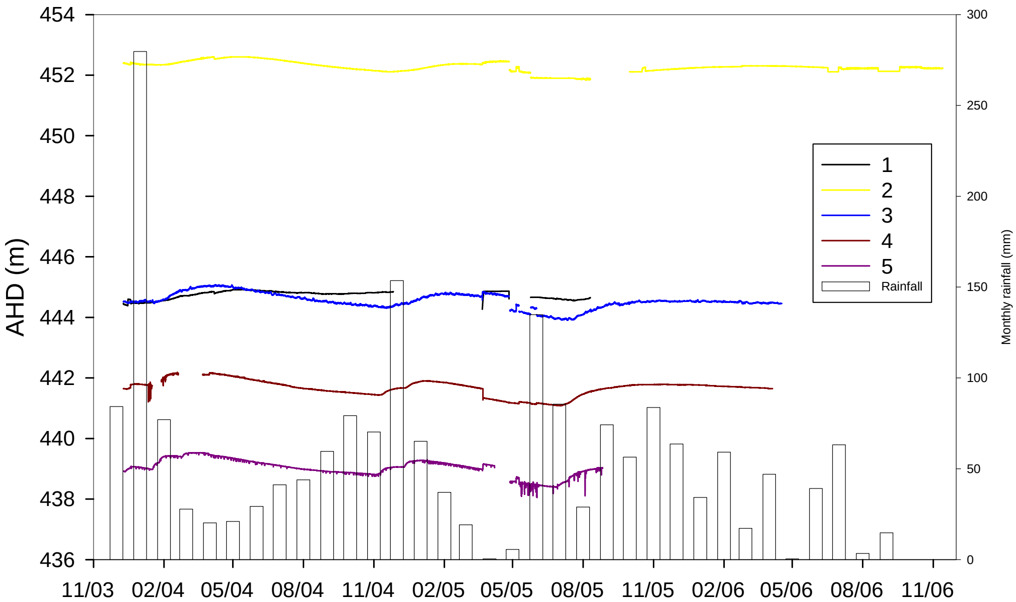


**Figure 14 Groundwater hydrographs from the Duri Key Site**

By plotting the water levels with a smaller scale it can be seen that the piezometers 2, 3, 4, and 5 appear to be responding to rainfall. There appears to be a delayed reaction to rainfall with a lag between rainfall and watertable response being between 1 to 2 months. To quantify the lag and verify the watertable response the groundwater hydrographs were plotted against daily cumulative residual rainfall for the study period (fig. 16).

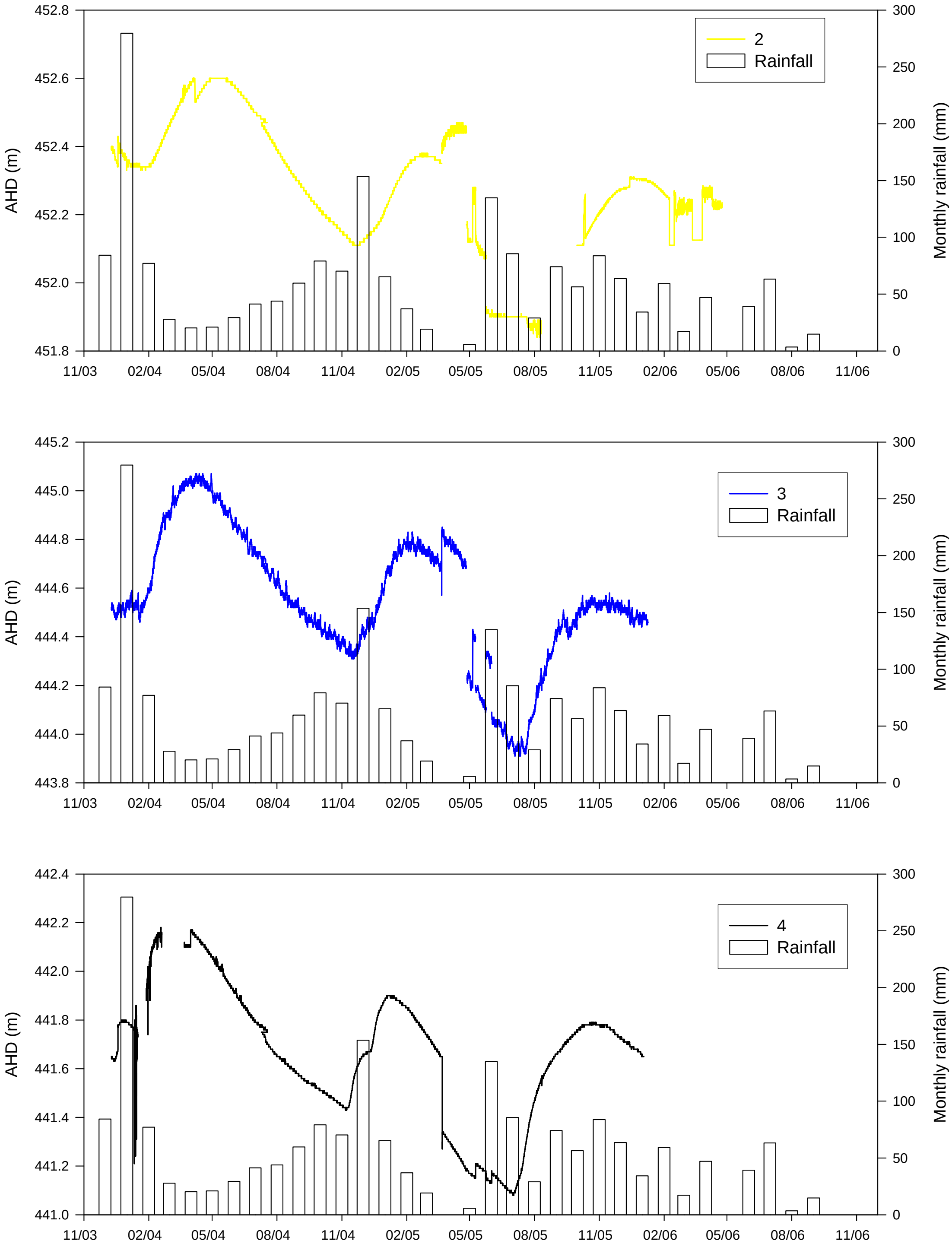


**Figure 15 Groundwater hydrographs and monthly rainfall**

The cumulative residual rainfall matches closely the dynamics of the groundwater hydrographs for piezometers 1, 4 and 5 (fig 16). It appears that the rises and falls within the groundwater flow system is due to changes in rainfall. The groundwater flow system that the piezometers are measuring appears to be well connected to the surface and is responding to periods of above average rainfall by rising. Also the groundwater dissipates during periods of below average rain suggesting that there is a discharge zone.

The calculated lag time between the rainfall event and the subsequent watertable response was between 10 and 22 days, and the average standing water level for piezometers 1, 2, 3, 4, 5 was 27.3 m, 29.7 m, 28.4 m, 21.4 m, 9.0 m below ground surface respectively. Additionally there is a relatively thick layer of soil above the groundwater and at the surface this soil has low hydraulic conductivity (see soil section). This suggests that the process of recharge to the groundwater from the rainfall event was relatively rapid and given the distance the water would have travelled (between 8 and 28 m) it either must be via preferential flow through possibly fractured rock or the groundwater is responding to a pressure response as a piston displacement flow. The type of recharge occurring at the Duri Key site could be characterised as translatory flow (Hewlett and Hibbert 1967). This type of flow allows for rapid subsurface response as the groundwater responds to piston displacement or preferential flow through larger non capillary pores (Sophocleous 2002).

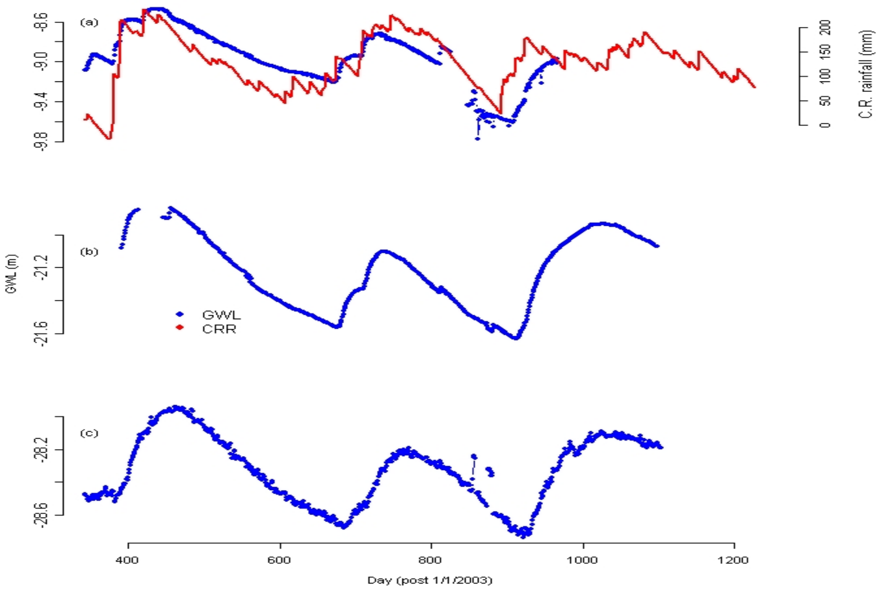


**Figure 16 Groundwater hydrographs (blue) and cumulative daily residual rainfall (red) for Duri Key Site (a) peizo 1 (b) peizo 4 and (c) peizo 3**

This rapid response of groundwater suggest that despite the relatively thick layer of soil (21-29 m) and low hydraulic conductivity of the surface soil, either groundwater recharge must be via preferential flow through possibly fractured rock or the groundwater is responding to a pressure response as a piston displacement flow. The type of recharge occurring at the Duri Key site could be characterised as translatory flow (Hewlett and Hibbert 1967). This type of flow allows for rapid subsurface response as the groundwater responds to piston displacement or preferential flow through larger non capillary pores (Sophocleous 2002). If the described characteristics of this groundwater flow system are correct then the observed aquifer has a high hydraulic conductivity, medium transmissivity and low specific yield. These characteristics then suggest that although water can be transmitted very rapidly through the aquifer due to the limited pores space (low specific yield) then not a lot of water is required to change the groundwater elevation and this additional water would then slowly dissipate and discharge. The analysis of the groundwater hydrograph shows that there is direct evidence of recharge is occurring at the Duri site, and that this recharge is episodic that is in response to rainfall events but the actual processes of recharge and the location of the recharge zone is unknown. However the landuse directly above the piezometers appear not to have effect on the groundwater dynamics. As the range of land use activities is from native remnant vegetation to annual cropping and pastures yet the same groundwater response was observed in four piezometers. The implication is that even though there is a direct and rapid link between the surface water and groundwater systems there is no effect of landuse.

This implies that land management activities that increase the risk of deep drainage may also increase the risk of groundwater recharge and inturn the discharge of saline water to streams.

The location of the recharge zone for piezometers 2-5 is unknown as the mechanism of recharge, and the discharge point for this groundwater flow system. The discharge zone may be located downstream of the Duri Site at “Rocky Waterholes” a permanent waterhole about 2 km north of the Duri Site along the Timbumburi Ck. This is based on the description of the groundwater flow system that suggest that the groundwater baseflow discharge is associated with termination of beds, faults and fractures with the land surface. Rocky Ponds is also located on the transition between the Tangaratta and Mandowa formations (Fig 2).

The analysis of the groundwater hydrograph shows that there is direct evidence of recharge is occurring at the Duri site, and that this recharge is episodic that is in response to rainfall events however the actual processes of recharge and the location of the recharge zone is unknown. However the landuse directly above the piezometers appear not to have effect on the groundwater dynamics. As the range of land use activities is from native remnant vegetation to annual cropping and pastures yet the same groundwater response was observed in four piezometers. The implication is that even though there is a direct and rapid link between the surface water and groundwater systems there is no effect of landuse.

If the described characteristics of this groundwater flow system are correct (section 1) then the observed aquifer has a high hydraulic conductivity, medium transmissivity and low specific yield. These characteristics then suggest that although water can be transmitted very rapidly through the aquifer due to the limited pores space (low specific yield) then not a lot of water is required to change the groundwater elevation and this additional water would then slowly dissipate and discharge.

Soil moisture

Soil moisture has been monitored at the Duri Site in some cases for eight years commencing in mid 1999. The data presented below is soil moisture measured using a neutron moisture meter down to 480 cm every 20 cm in a black clay soil (vertosol).

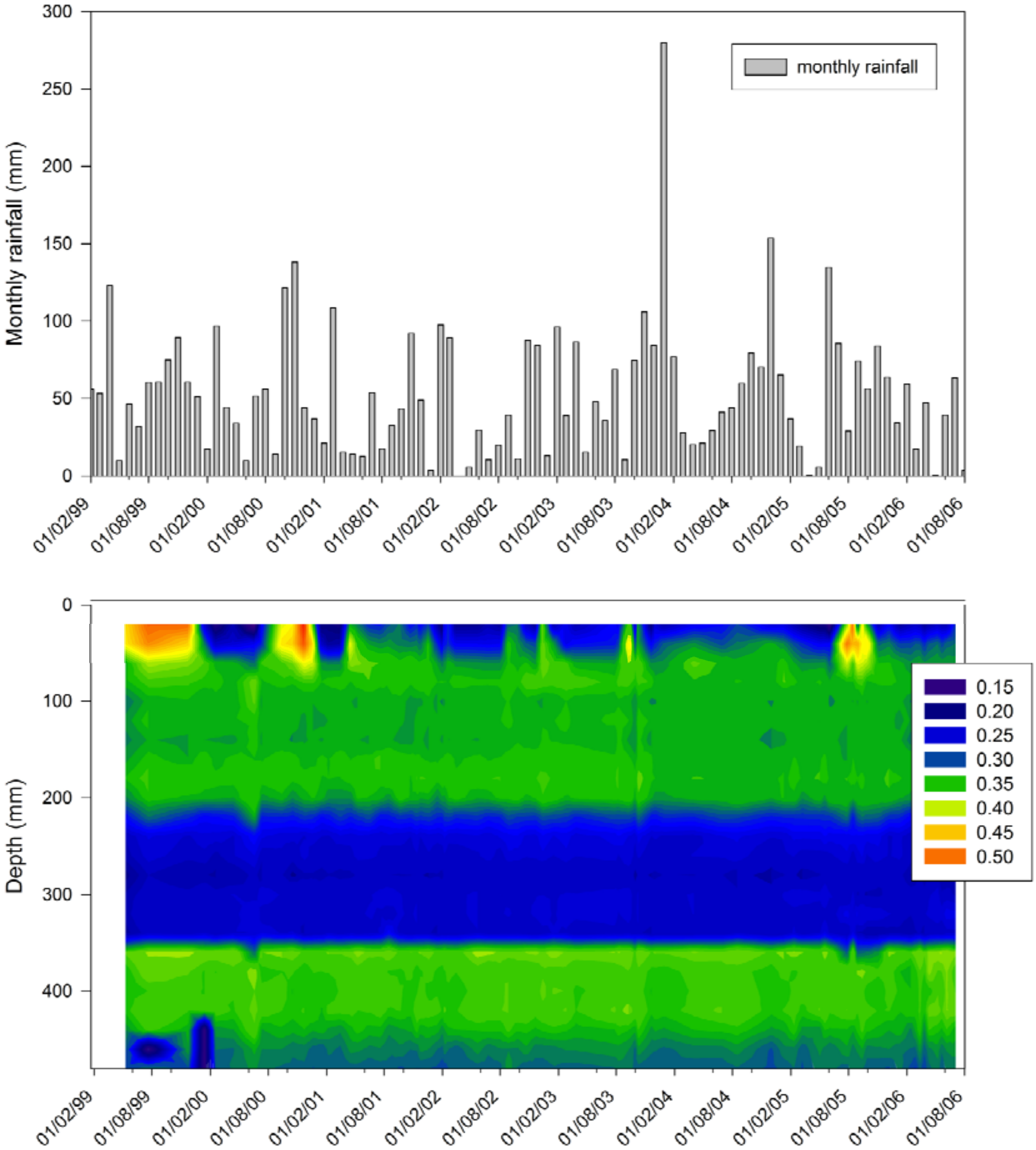


**Figure 17 Soil moisture and rainfall from tube 83**

There is little change to the soil moisture below 60 cm for the eight years of monitoring. In the top 60 cm there is record of rapid wetting after rainfall and the slow drying. The wetting appears to be confined to the top 40-60 cm with very little change to the volumetric soil moisture below this depth over the monitoring period. This suggest that most of the water the infiltrated the soil was either extracted by plants or evaporated, some of the soil moisture may have drained to depth but there does is no change in soil moisture at depth (below 80 cm) which in turn leads to the conclusion that there is little if any water draining below this depth and hence little deep drainage occurring on these soils.

**Evapotranspiration**
Evapotranspiration was measured at a range of locations covering the major landuses of the Duri Key Site from mid 2003. These landuses include grazing pastures such as lucerne, medic clover and native grasses; and winter cropping such as oats and barley. Mixed native grasses included *Bothriochloa macra* (Red Grass), *Stipa aristiglumas* (Summer Grass) and *Danthonia sp*.

| Plot | Date | Landuse |
|---|---|---|
| 1 and 2 | 14/6/03-1/06/04 | Lucerne mixed native grasses |
| | 2/06/04-15/11/04 | Barley |
| | 15/11/04-15/03/05 | Stubble and mixed native grass |
| | 16/03/05-06/12/05 | Oats |
| | 07/12/05-10/05/06 | Stubble and mixed native grass |
| | 11/05/06-2/12/06 | Barley |
| 3 | 9/9/03-14/12/06 | Mixed native grasses and medic |
| 4 | 31/12/03-4/12/06 | Lucerne with summer grasses |
| 5 | 27/06/03-4/12/06 | Mixed native grasses and medic |
| 6 | 30/12/03-20/12/04 | Queensland Bluegrass |

| | Plot 1 | | | Plot 2 | | |
|---|---|---|---|---|---|---|
| Date | ET | Rain | ET % of rain | ET | Rain | ET % of rain |
| June 03- June 04 | 667 | 611 | 109% | | | |
| June 04-June 2005 | 734 | 569 | 129% | 550 | 536 | 103% |
| June 05-June 2006 | 846 | 559 | 151% | 660 | 567 | 116% |
| June 06-Dec 2006 | 229 | 222 | 103% | 240 | 223 | 108% |
| | Plot 3 | | | Plot 4 | | |
| June 03- June 04 | 488 | 539 | 91% | 327 | 333 | 98% |
| June 04-June 2005 | 638 | 585 | 109% | 722 | 567 | 127% |
| June 05-June 2006 | 545 | 545 | 100% | 700 | 610 | 115% |
| June 06-Dec 2006 | 276 | 207 | 133% | 332 | 224 | 148% |
| | Plot 6 | | | | | |
| 2004 | 650 | 699 | 93% | | | |

Evapotranspiration was measured nearly continuously on four plots for over three years. It was found that consistently evapotranspiration exceeded rainfall over the same period suggesting that the Bowen Ratio was not sensitive enough to accurately close the water balance. Some of the causes of this over estimation have been due to hot, windy dry environment which causes soil moisture to be advected and invalidates some of the assumptions in the Bowen ratio method (Crosbie et al. 2008).

However using both the soil moisture that was conjunctively measured with the ET measurements some processes can be identified that may provide insights into the hydrology of these landscapes.

The measured soil moisture suggests that little deep drainage has occurred and all of the rain that infiltrated the soil was either extracted by plants or evaporated from the soil surface. The evapotranspiration data concurs with this assumption that all of the rainfall that infiltrates the soil is subsequently accounted for as evapotranspiration. However the water balance also includes rainfall that runs off and water that is not infiltrated into the soil, and as the calculated evapotranspiration exceeds this amount it is unsure how much of water is lost via this pathway.

Runoff

Three troughs were located at the Duri site to measure the amount of runoff that was generated by rainfall. Runoff was measured by galvanised runoff troughs that drained plots 120 $m^2$ (20m up slope x 6m wide) into a recording tipping bucket. The plots were defined by earthen walls at least 20cm high.  The slope of the three plots ranges from 0.008 to 2.43%.

Runoff was measured between October 2003 and June 2004 through that period 286 mm of rain fell and 9.5 mm ran off, with a runoff coefficient of 3.6%. However higher runoff coefficients were measured for individual events, these ranged from between 60% on 13/12/2003 and 16/02/04 to 45% on 26/01/2004.

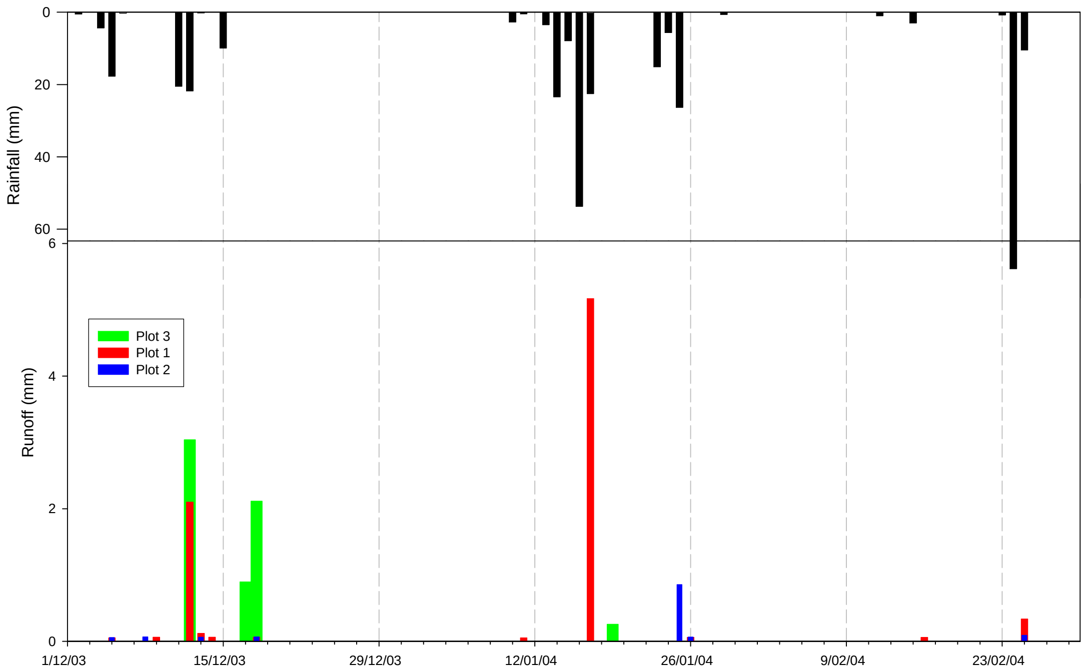


**Figure 18 Runoff plots**

## Streamflow

Two stream gauging stations were installed in January 2005 and recorded data until December 2006. The stations were located in the upper end of the Timbumburi Creek (Callemondah Station) and just upstream of a large road culvert where Timbumburi Creek exits the study area (Karloo Park Station). At each location cross sectional surveys have been compiled at the point of instrumentation (Fig. 4a and b).  At each site water pressure, temperature and conductivity were measured by a CTD350 (Greenspan Technology). Additionally another conductivity sensor EC350 and turbidity TS1200 Greenspan Technology sensors have been installed adjacent to the CTD350 sensor.

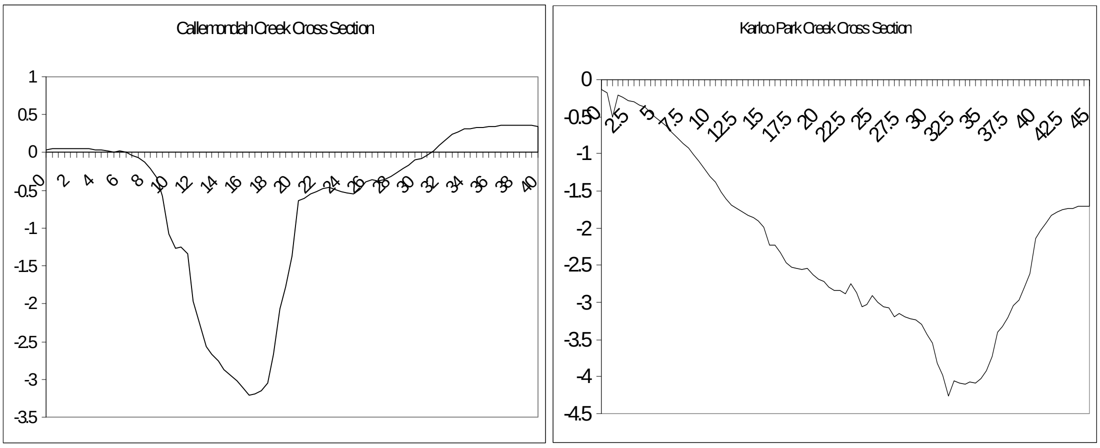


**Figure 19a, b** Cross sections of the Timbumburi Creek at run on site Callemondah, and out flow site Karloo Park

The creek is heavily incised which reflects the highly erodable nature of the soil and the extreme flow events that can occur in this area.

Over the observation period from there was only two observed flow events, which occurred in the 2005 winter. The low number of flow events possibly reflects the ephemeral nature of the creek and the below average rainfall that occurred during the observation period.

The creek bed is very sandy and highly erodable making stage relationships very uncertain. Combined with the highly ephemeral flow it has been impossible to provide an accurate measure of the flow down the creek. To overcome this estimates of the flow were calculated using Manning's equation and ongoing measurements of the stream cross section where the stage measure was located.

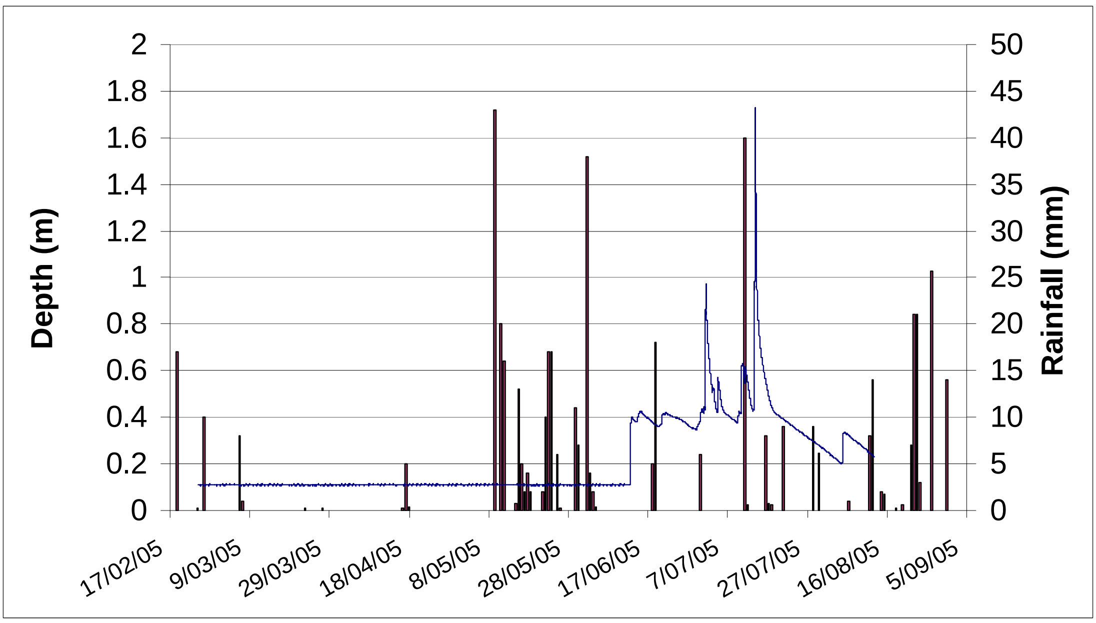


**Figure 20 Flow event 13/07/05 at Callmondah**

A peak flow depth of 2.3 m was recorded on 13/7/05 which resulted in a peak flow rate 0.24 $m^3$/s and an event volume of 11013 $m^3$ draining the site in just over 2 days.

This flow event was in response to a 38 mm storm that occurred on the 13/07/05. However prior to this event there was over 60 mm in the preceding 10 days which had wet up the site and allowed this additional rainfall to runoff.

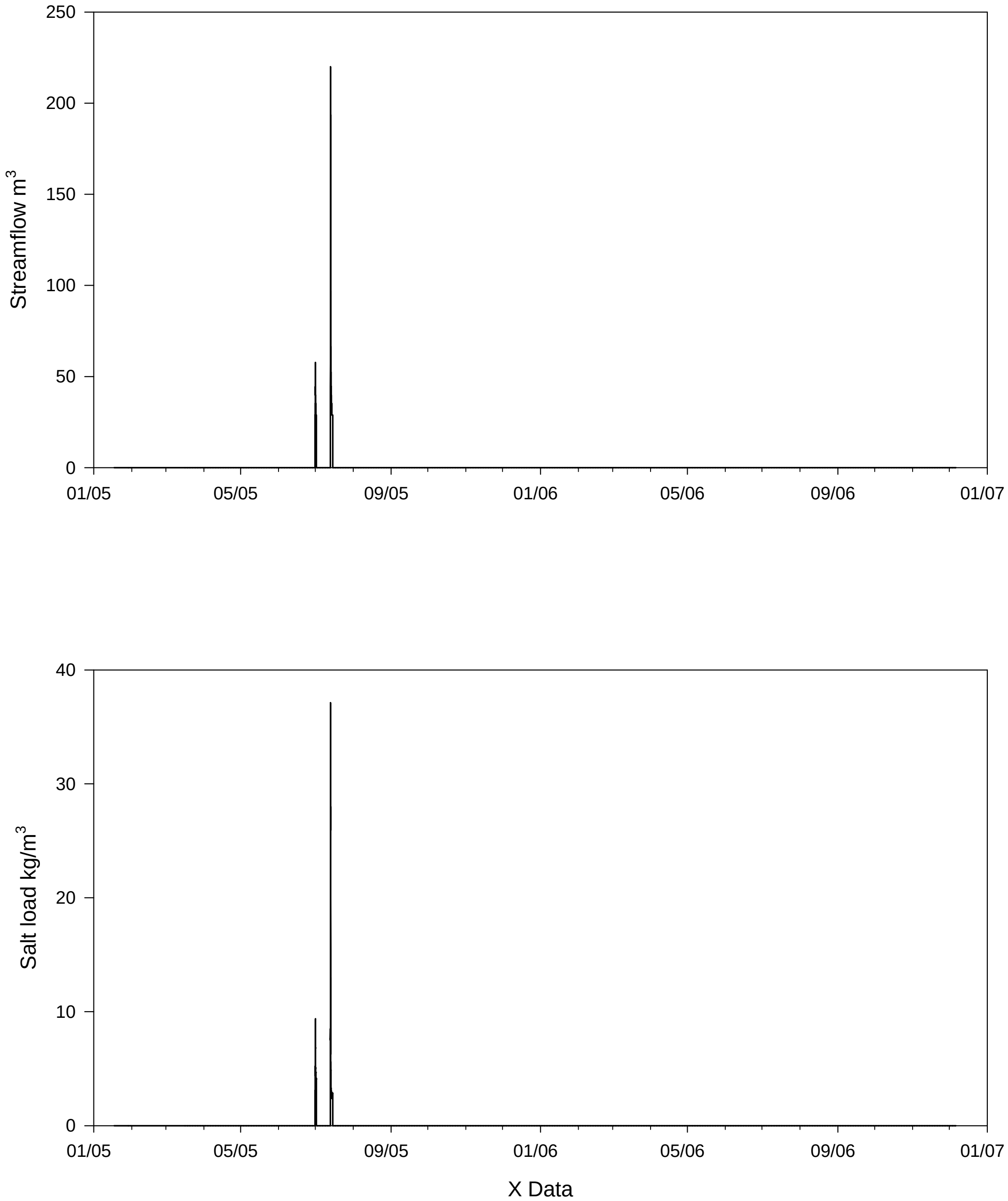


**Figure 21 Streamflow at Callomndah (top of catchment)**

**Development of conceptual model of Duri**

A physical conceptual model was developed for the Duri Key Site to identify possible hydrological pathways for salt and water movement in this landscape. The conceptual model was based on the existing spatial and hydrological data as well as observations at the site.

From the soil moisture, groundwater and ET data presented above it can be seen that there is little recharge or deep drainage and hence it can be conceptualised that there is little connection between the surface and the groundwater. There appears to be some interaction between the stream when it flows and the local groundwater system however this is very limited.

Two groundwater systems present at the site

1. Regional groundwater that is recharged outside the boundaries of the site. The recharge zones as yet are unidentified but possibly the Melville ranges.
2. A local system is characterised by fractured rock aquifer and variable weathered regolith, the aquifers are typically semi-confined and have high conductivity, moderate transmissivity, and low specific yield. The seasonal aquifers recharge under moderate annual rainfall, and groundwater can be moderately brackish.

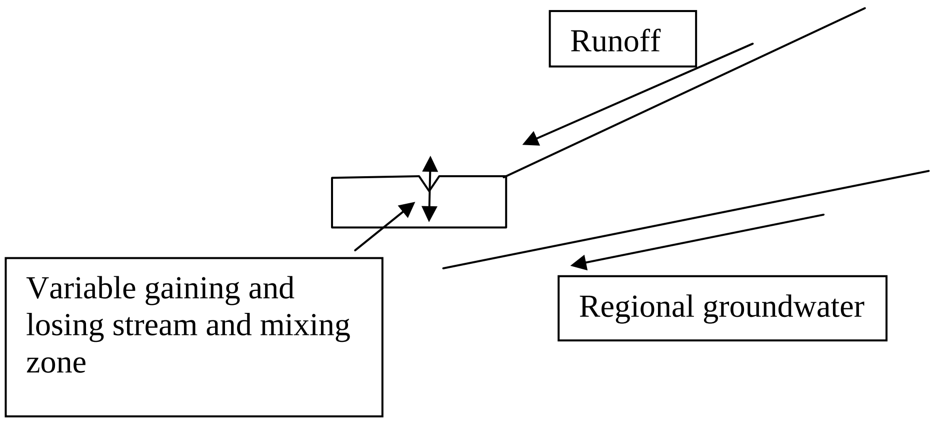


**Figure 22 Conceptual model for the Duri Key Site**

**Discussion**

This research site does not display any significant salty discharge or permanent waterlogged areas. However this research site is representative of the Upper Timbumburi Catchment within which there are significant areas of salt affected land.

This landscape has a high erosion risk due to the fragile nature of the soil. In the past moderate gully and sheet erosion has been observed in this catchment and there is evidence of soil degradation/aggradation processes occurring not only in the landscape but in the flowlines as well.

The salinity processes that occur in this landscape are not completely understood, however from the evidence discussed in this report it can be seen that there is localised recharge of the watertable after significant rainfall. The discharge point while not conclusively determined appears to be a local permanent waterhole several kilometres downstream of the site (Rock Ponds). It appears that landuse does not affect the groundwater response and that any changes to farming systems to minimise deep drainage and hence recharge would be misguided.

The erosion risk comes primarily from the lighter textured Chromosols. On the eastern side of the Timbumburi Creek, these soils have developed deep erosion gullies feeding into the creek. In the past these paddocks were heavily cropped and now they support grass pastures. The upper slopes, which have a shallower profile are infested with eastern cotton bush. This weed is less prominent on the lower slopes closer to the Timbumburi Creek.

Across the research site there are areas of prolonged waterlogging after heavy rainfall. The main area is located on brown Vertosol. This area has been identified by previous owners as an area of low productivity on the farm and is used as a wooded area which is grazed when underlying grasses can support stock. The soil moisture data showed that while localised waterlogging can occur the low hydraulic conductivity limited the infiltration of the water to 50-80 cm.

The ten soil profiles logged show soil depth varying from less than 1.0m to greater than 7.0m. Bore log records from bores in the catchment indicate a deep layer of fractured shale extending beyond 95m below the soil surface.

The EM 31 survey highlights fallow paddocks and a drainage channel. There is a paddock located centrally in Figure 4.3.4 which appears to have elevated results for the site. However the higher readings in this paddock are related to extensive fencing and metal equipment present in this establish research site.

**Outcomes**
The major outcome of this research has been to identify soil management as the major limit to sustainable and productive agriculture in this landscape. The soils in the Duri landscape are fragile, highly erodable and lack fertility. Farming systems need to be developed or implemented that encourage sustainable soil management for this area.

Additional to this is the hydrological conceptualisation of the Duri Site, which shows that there is rapid link between the surface and the groundwater however there does not appear to be a strong link between the land management and the rate of recharge.

Evapotranspiration exceeded rainfall over the three years of observations at the Duri Site. Evapotranspiration on a range of landuses was measured however little differences was determined between ET of the landuses. This method may not be suited to the hot dry climates that can be experienced in the Tamworth area and the on going use of this method may be questioned.

**Implications for NRM investment**
The groundwater and surface water systems appear to be highly connected allowing for rapid flow between the surface and the groundwater systems. However there appears to be little difference in the response to groundwater under a range of landuses. These include annual cropping to remanent vegetation. This leads to the implication that landuse has little affect on groundwater response and appears to be no reason to encourage NRM investment to change or managing landuse to affect groundwater.

Appendix
Publications arising from the Duri site

P. Derham, D. Berhane, M. Nies, C. Lee and D. Mitchell (2006) Losing Streams and Groundwater in Northwest NSW MDB Groundwater workshop 2006

P Derham, P Welsh (2006) Trial recommendations for the amelioration of a degraded chromosol landscape: Duri District, Northern NSW. AARES, January 2006

Friend J, Gallagher P, Hughes J, Derham P (2003) NSW Salinity Strategy Action 7.3 Interim Report NSW Cabinet Office, July 2003

Friend, J Regan P (2003) Research into land management practices and establishing model farms NSW Salinity Strategy Annual Report 2003/04 [final report]

Ag Today July article 2006 Duri Key Site

P Derham, M Nies, J Friend (2004) Evaluation of current farming systems on ground water recharge and discharge on a sub-catchment in northwest NSW. Bendigo

P Derham J Hughes, J Friend (2003) Research and develop land management practices that reduce and prevent discharge. Establish two research sites to evaluate new 'salt solution' farming systems. AGquip 2003

K Baker (2004) Hydraulic Conductivity Measurement using a modified well permeameter method at Duri NSW Honours Thesis UNSW 2004