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Investigation of the role of the Urella Fault and the impact of salinity development in the Nebru Catchment, Upper Arrowsmith

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Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Contents

Introduction

Nebru Catchment is a sub catchment of the Arrowsmith Catchment, located in its upper reaches. It is roughly bounded by Sunset Road in the North, the Kadathinni Hills to the east, Three Springs - Eneabba Road to the south and Reed Road in the west. It changes in elevation from 372m AHD near the intersection of Nebru Rd and the Kadathinni Hills to the east, to 220m AHD near the outlet of the catchment into the Arrowsmith River. The total area of the catchment is just over 7400 hectares.

The catchment straddles two different geological environments, separated by the Urella Fault, which strikes approximately north – south. To the east of the Urella Fault is the Irwin Sub Basin, containing a considerable portion of the Mullingarra Inlier. This is partially overlain by the proterozoic sediments of the Yandanooka Group, (Arrowsmith Sandstone and Arrino Siltstone in particular). Permian sediments (Holmwood Shale) are also found within the catchment. These have been found to lie unconformably on precambrian rocks, which may include the Mullingarra Gneiss (Playford et. al.1976). To the west of the Urella Fault lies the Perth basin. The fault separates the younger sedimentary rocks of the Yarragadee formation, deposited during the Jurassic, from the older precambrian rocks and proterozoic sediments to the east, Figure 1.

Salinity has occurred in the Upper Arrowsmith since the 1960's. However, the farmers of the Arrowsmith Focus catchment defined the extensive area of valley floor salinity as a prime area of concern for the catchment. The area extends south from the intersection of Hydraulic Road and the main creek line. Anecdotal evidence suggests that the area was always moderately damp, but was originally cropped, (there was evidence of working lines in the area). However, since the early 1960s (which were reasonably wet) the area has been seasonally wet and become too saline for cropping. The total area of mapped salinity is approximately 350ha (or 5% of the Focus Catchment area) Figure 2, which includes some seepage areas in the upper catchment, south of the main pod of salinity.

The upper catchment has an extensive area of sandplain on the western zones. An elongated seepage line has developed at the base (or eastern margin) of the sandplain, (i.e. where the sandplain thins over the heavier valley floor soils). The water seeping from the sandplain is reasonably fresh. Salinity concentrations from water samples were in the order of 233 mS/m in winter 1999. However, the concentration of salts increased in seepage water over summer and was recorded at 1184mS/m during summer 1998.

As stated, the catchment straddles the Urella Fault. The area of salinity is of concern to both the immediate farmers and the catchment as a whole. The water quality in the Yarragadee formation (west of the fault) is fresh and used to supply Three Springs town water. However, there has been a gradual decline in the water quality extracted from these bores since 1985. In the period between 1985 and 1994, water salinity in bore 2/75 increased by 50mg/L to a total salinity of 750mg/L, (unpublished reports Groundwater and Environment Branch, Water Corporation). This suggests that the saline water developing in the Nebru Catchment, might be 'leaking' across the Urella Fault. As part of the Focus Catchment process, the Catchment Hydrology Group of Agriculture WA undertook to investigate the causes of the salinity and the likely impact on groundwater resources within the catchment.

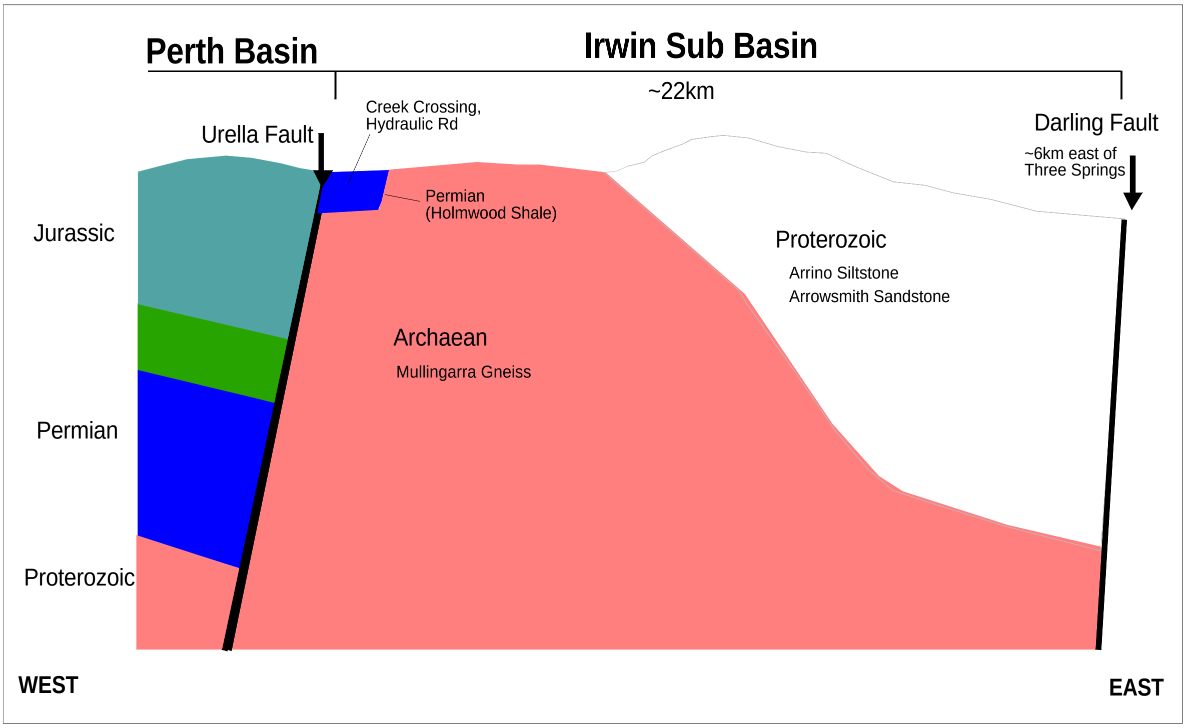

Figure 1. Solid geology cross section of the Irwin Sub Basin and sections of the Perth Basin relevant to Nebru Catchment. After Baxter & Lipple1985.

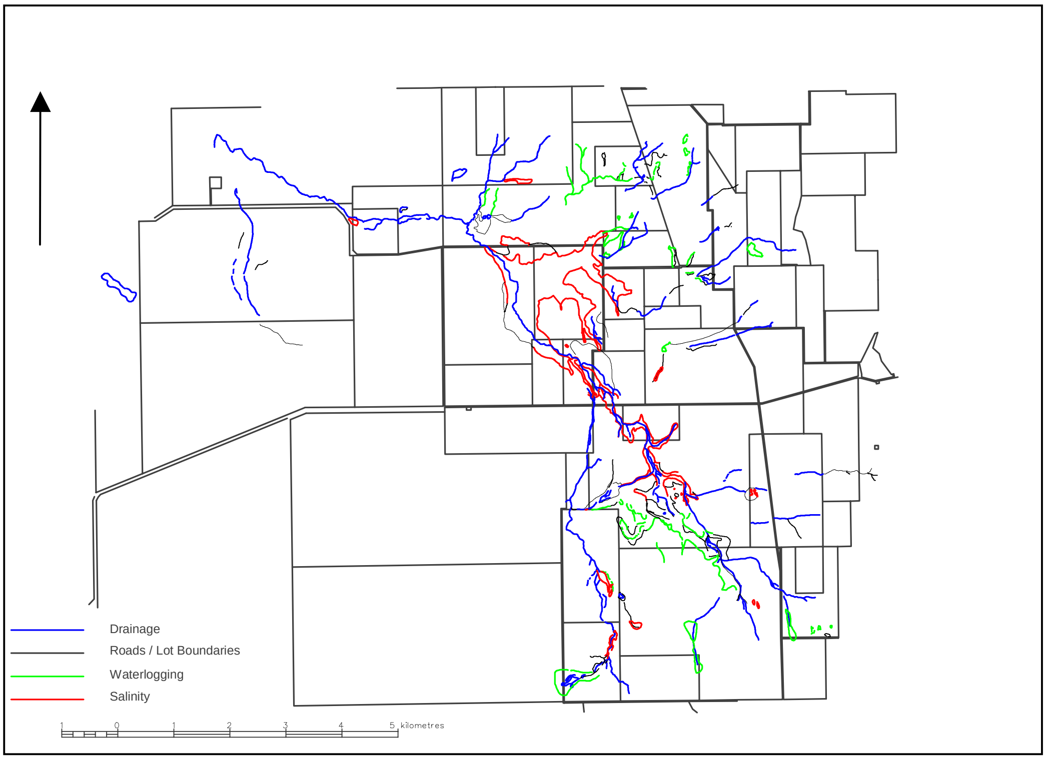

Figure 2. Salinity and waterlogging in the Nebru Catchment

Salinity in the Nebru Catchment.

Hydrological investigation was undertaken as part of the Focus Catchment Process in the Arrowsmith Catchment. The research was concentrated in the Nebru Sub Catchment (referred to as Nebru Catchment) located in the upper Arrowsmith Catchment. A significant area of salinity (approximately 5% of the Nebru Catchment) is affecting the main creek line and adjacent areas. The creek line is a tributary of the Arrowsmith river, however the salinity present in Nebru does not extend to the Arrowsmith River. The salinity appears to 'stop' at the intersection of the main creek line and Hydraulic Road. This area is in the vicinity of the Urella Fault, suggesting that the fault line may be an influencing factor.

The location of the salinity is controlled by a combination of the topography of the catchment, the current pattern of drainage through the north west of the catchment, and the location of the Urella Fault. Catchment topography is such that the areas of higher elevation are to the east and south, with drainage occurring in a northwest direction. Drainage exits the catchment in the vicinity of Hydraulic Road, eventually joining the Arrowsmith River. These factors, combined with seasonal rainfall fluctuation and clearing, plus the presence of the Urella Fault have determined the current location of salinity.

The occurrence of this salt/fault association, i.e. where salinity is found on one side of a fault, and appears to be confined by that fault, is not uncommon within the Irwin Sub Basin. Areas of salinity have developed in a number of locations along the western edge of the Irwin Sub Basin and terminate in the vicinity of the Urella Fault.

Comparison of the 1988 and 1996 satellite imagery suggest that salinity has not expanded substantially in the valley floor of Nebru Catchment over this period. The development of salinity has been more active higher in the catchment, where salinity extends back up the creek line or where seepage lines have developed in zones adjacent to the valley floor.

The build up salinity on the east side of the Urella Fault, and its disappearance on the west side of the fault is of concern. If groundwater is able to move across the fault then potentially high value, fresh water supplies might be contaminated with saline groundwater. The research was therefore aimed at trying to quantify if water was able to move across the fault, and if so, whether the volume was sufficient to cause the measured changes in groundwater salinity at the Dookanooka bore field.

Objectives

The objectives of this project were developed from a number of hypotheses relating to the potential movement of groundwater across the Urella fault. They include:

That there is a major offset of water tables east and west of the fault. This might produce an apparent underground 'waterfall' as the water 'falls' over the edge of the fault.

Water movement across the fault is unlikely to be uniform therefore, it is more likely that water moves across the fault in discrete zones, e.g. where the fault has been differentially weathered such as where the creek zone crosses the fault line.

That water movement across the fault is primarily in the surfical sediments above the fault zone. On the west side of the fault, permeable sediments allow rapid downward movement of water creating the apparent 'waterfall' effect.

Finally, there may be no groundwater movement through the fault zone, i.e. the fault is acting as a barrier to groundwater movement, causing the build up of groundwater in this region. Once at the surface, the groundwater crosses the fault as surface water. It may also be acting as a carrier, transferring water along its length to more permeable zones.

The mechanism is important in determining the volume of water and the rate of transmission across the fault. Large volumes of highly saline water will potentially degrade the quality of fresh water aquifers on the west side of the fault. Therefore knowing both the volume of water, and the mode of water movement, will assist identification of appropriate management options.

Based on these hypotheses, the objectives of the project were as follows: -

To investigate

- The role of the Urella Fault in relation to the occurrence of salinity.
- Groundwater levels and qualities east and west of the fault.
- Soil profiles and sources of sediment in order to suggest past climate and landscape.
- Quantify volumes of groundwater that move across the fault.

Methodology

Limited information on the geology of the region has been collated and presented in Geological Survey reports. This material was reviewed in conjunction with more recent information such as the Arrowsmith Groundwater Area Management Plan (Report No. WG153 Sept 1995, Water Authority), historic aerial photography and verbal histories available through farmers.

This data, along with farm visits, were used to determine the most appropriate sites for an exploratory drilling project. Satellite imagery was used to locate the Urella Fault as accurately as possible to assist in identifying possible drill targets. Sites were selected to provide a number of sections across the fault line. Some upper catchment sites were chosen to delineate the extent of salinity.

During February 1998 eleven sites were drilled and sampled. Drilling was conducted using a Rotary Airblast Rig. Drill spoil was sampled using collection trays at one-

metre intervals. Samples were analysed for pH, EC 1:5 (mS/m) and %Cl using standard laboratory procedures as described by Rayment & Higginson 1992[1]. Sample analysis has been completed and monitoring established. Groundwater level and quality are monitored at regular intervals.

A field survey was undertaken to map the extent of rock outcrop and areas prone to water logging and salinity. The maps were used to confirm the accuracy of the larger scale GSWA mapping, and to assist interpretation of results.

[1] (The exception being that samples were shaken for 30 minutes rather than the one-hour suggested in the text. Previous trials have shown that there is minimal difference to results when the shorter shaking time is used).

Results

Eleven drill sites were established in the Nebru Catchment. These comprised of two transects of bores crossing the Urella Fault, and several additional bores in mid to upper catchment areas. Bore details are shown in Table 1, with initial water level and water quality data collected on the 27/2/98.

Bore Name	**Date drilled**	**Elevation** (~ mAHD)	Casing Depth (m)	Water level below ground (m)	Water Quality (mS/m)	Piezometer/ Observation Well
AR01d	2/02/98	238.5	26.89	*8.45	5740	Piezo
AR01I	3/02/98		22.13	2.1	6080	Piezo
AR01ob	3/02/98		5.3	1.6	2900	OB
AR02ob	3/02/98	248.8	6.06	1.88	2260	OB
AR03ob	3/02/98	236.2	19.89	16.29	1518	OB
AR04d	4/02/98	247.2	11.7	1.2	1611	Piezo
AR04I	4/02/98		8.69	1.21	2190	Piezo
AR04ob	4/02/98		4.62	1.22	1558	OB
AR05d	5/02/98	237.3	20.21	Dry	-	Piezo
AR05ob	5/02/98		1.31	Dry	-	OB
AR06d	5/02/98	238.4	28.92	12.55	5050	Piezo
AR06I	5/02/98		11.75	9.89	3020	Piezo
AR06ob	5/02/98		1.86	Dry	-	OB
AR07d	9/02/98	257.6	11.87	0.92	314	Piezo
AR07ob	9/02/98		1.87	1.04	151	OB
AR08d	9/02/98	240.7	18.49	1.61	3580	Piezo
AR08ob	10/02/98		5.6	2.03	3710	OB
AR09ob	10/02/98	242.3	32.78	Dry	-	OB
AR10d	10/02/98	241.3	21.28	6.28	2850	Piezo
A/R11d	11/02/98	241.1	16.37	3.47	4000	Piezo
AR11ob	11/02/98		5.69	3.13	5330	OB

Table 1. Bore construction details. Note that AR03, AR05 and AR09 are all west of the Urella Fault and show much deeper water tables. Piezo = Piezometer OB = Observation Bore. (* AR01d did not fully recover post drilling until approximately June 1998).

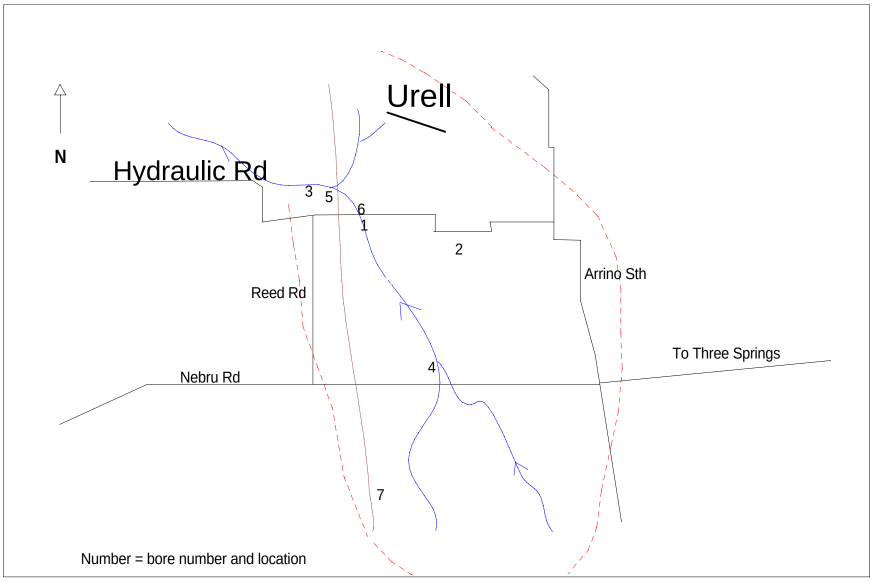

Figure 3. Bore locations in the Nebru Catchment.

Sample Analysis

All bores holes were sampled as previously described, and the texture, moisture and other aspects, such as ease of drilling, noted. The soil profile was bulked and sampled over one metre intervals and tested for EC (1:5) mS/m and pH.

Examples of four sites are shown in Figure 4. The results indicate that pH varies with both location and depth. The largest variation is seen in the upper profile, (top metre) which reflects different management practices. For example, AR09 on the edge of a pasture paddock, has a moderately low pH value at the surface (5.5) which becomes alkaline (9.5) by 1m below the surface. At this site, agricultural management may have caused a reduction in pH, changing an alkaline profile to an acidic profile in the first metre. AR10, which is located in a vegetated depression, had a neutral pH in the upper 1m. There has been no mechanical disturbance of the soil at this site, although there has been stock access. Surface pH (top 1m) ranges between sites from 5 – 8.

Sites on the east side of the Urella Fault generally showed higher EC values than those on the west side. The results for EC1:5 (mS/m) demonstrate that some sites had extremely high surface EC values, between 1000 – 1200mS/m, probably representing a concentration of salts by evaporation, rather than inherently saline surface soils. At AR11 there is a distinct salt bulge between 5 and 12m below ground, reaching a maximum salinity (EC1:5) of 800mS/m. This is similar to soil profiles under native vegetation where salt has accumulated around the tree root zone. Currently this salinity is below the root zone of most crops, however, should the salts be mobilsed with a rising water table, these levels would prevent crop growth[2].

The source of such high levels of salt is unlikely to be relate to the nearby Arrowsmith Sandstone and Arrino Siltstone both formed under marine conditions. Whilst weathering of these formations could release stored salts, which have accumulated in the weathered clay profiles of the valley floor and slopes, it would be more plausible if this occurred from the Holmwood Shale.

Weathered Holmwood shale was encountered at the base of most holes within and immediately surrounding the current area of salinity. Salinity levels of both the profile and groundwater were generally less within the Holmwood Shales than in the profile above. The low permeability of the Holmwood Shale might restrict downward leaching of the salts, causing the accumulation of salt above it.

Limited downward leaching combined with a low lateral hydraulic conductivity (due to the weathered clay profiles above the Holmwood Shale) may have prevented the salts from leaving the catchment. This scenario also suggests the possibility that the

[22] 50% yield reductions in wheat occur at soil salt levels of 161 mS/m on heavy soils and 72 mS/m on light textured soils, George & Wren 1985.

catchment was internally drained at some time in its history (probably post fault formation). The current surface drainage system may have evolved relatively recently.

On the west side of the fault, the EC readings at AR09 show little variability down the entire profile and are relatively fresh. Similar results were found at AR03. This contrasts strongly with the measured results in AR11, (east side of fault). AR09 is located in the Parmellia formation, which is a sandstone formation with little stored salt content. The majority of the Yarragadee formation, (of which the Parmellia formation forms the upper section) was deposited under fluvial conditions. However the upper sections (encountered in AR09) was deposited in shallow marine and continental conditions, (Playford et al 1976). Any salt store could potentially have been flushed through the upper sections of the coarse sandstone formation. This contrasts with the sites east of the fault, which have a weathered profile derived from gneiss and surrounding silt and sandstone sediments. With limited capacity for flushing or leaching of salts and the potential of internal drainage, salts have accumulated.

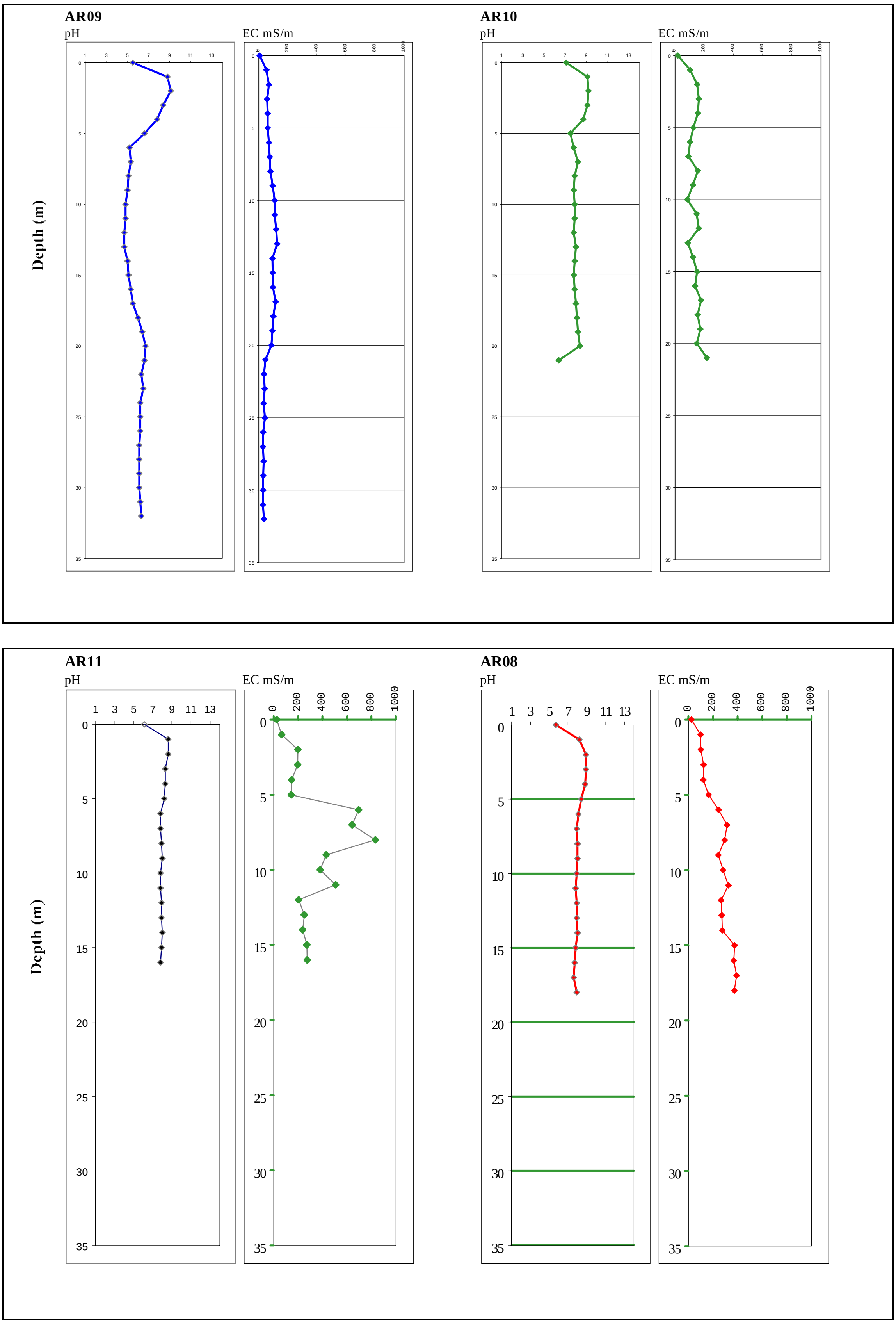

Figure 4. pH and EC profiles for selected bores from the Nebru catchment. AR09 is on the west side of the Urella Fault, while the remainder are either in the Fault zone, or to the east of the Fault.

Hydrographs

Hydrographs for bores that show water table fluctuation are presented in Figures 5-8. AR09 has been dry since February 1998, with the first intersection with a water table in AR05 recorded in August 1999.

The hydrographs presented vary between sites, however, a seasonal response to rainfall is observed. Water tables have risen in response to winter rains, and fallen the following summer. The summer water levels in 1998/99 were higher than the summer water levels recorded at the beginning of 1998, (generally 10 – 30cm higher). At the time of report compilation there was insufficient data to conclude if a rising trend exists in the water levels of the catchment. However, bore AR03 located on the west of the Urella Fault, has exhibited rising groundwater level throughout 1998/99.

Different responses for the piezometers and observation bore were recorded at site AR01, immediately south of Hydraulic Rd where the creekline intersects the road, (Figure 5). The deep hole (AR01d – a piezometer) was screened in the Holmwood Shale (screen depth 24.89 – 26.89m below ground level (bgl)). The water level took 6 months to stabilise in this hole, indicating the extremely low permeability of the Holmwood Shale. However, once the bore had reached equilibrium seasonal fluctuations were observed, of a similar magnitude to the shallow piezometer and observation well.

Seasonal response to rainfall is unlikely in an aquifer with low permeability. The rapid seasonal response suggests that the formation may be extremely fractured, or jointed, allowing preferential flow within the system. The recorded response may also be caused by non-sealing of the drill hole or the incorrect placement of the slotted pipe where the hole slumped before installation of the pvc pipe. However, the hole required 6 months to stabilise, suggesting the former rather than latter explanation for the observed seasonal response.

Site AR06 occurs downstream, on the north side of Hydraulic Rd. AR06i had a similar response to AR01i and AR01ob. That is, the groundwater level rose and fell in response to seasonal rainfall. However, by February this year (1999) it had not fallen to the levels of February 1998, (Figure 6). This pattern of groundwater rise and fall was characteristic of several sites including AR02, AR04, AR07, AR08 and AR11, (Figure 5). The observed response at AR10 was similar but subdued.

AR06ob is a very shallow bore (only 1.0m) and was dry during summer 1998. During winter a perched water table developed that had disappeared by December 1998. This has probably occurred through a combination of evaporation, evapotranspiration and possible drainage to lower aquifers.

The amount of water required to produce a perched water table varies, and is dependent on soil type, soil moisture and rainfall total. In 1998 there were substantial early season rains (approximately 70mm in May and 90mm in June). A perched water table had developed by the end of June 1998, which had dried out by the following summer. A perched water table developed again following high summer rainfall generated by Cyclone Elaine. Seventy-two millimetres of rain was recorded between the 19/3/99 and the 22/3/99 at Three Springs. The water table had disappeared by early May 1999, before the major winter rainfall.

A perched and deeper water table was first observed in AR05 during August 1999. The measured water quality in the observation bore was quite fresh (331mS/m) but was more saline in the deep piezometer (2570mS/m) (R. Speed pers. comm.). The water table in the observation well had fallen below the depth of the bore by September 1999.

AR07 is located in the upper catchment, above a sandplain seep. It was drilled through a thick band of silcrete into massive saprolite grits, predominantly quartz. Two aquifers, an unconfined sandplain aquifer, and a semi confined basal grit aquifer, were identified. At the time of drilling it was noted that the profile appeared saturated, (i.e. the seepage might not be perched). However, groundwater monitoring (Figure 7) has demonstrated a change in vertical heads between the observation and piezometer holes at this site. Suggesting that the lower system may be a basal grit aquifer that receives additional recharge from sources other than the sandplain immediately above it.

The remaining site is AR03 (Figure 8), which is located west of the Urella Fault. Water levels did not exhibit seasonal fluctuations, but rose steadily over the monitoring period. The depth of groundwater level appears to mute any seasonal impacts that might be expected in shallower bores with water. This is consistent with other bores in the Perth Basin. Groundwater levels rose approximately 30cm during 1998.

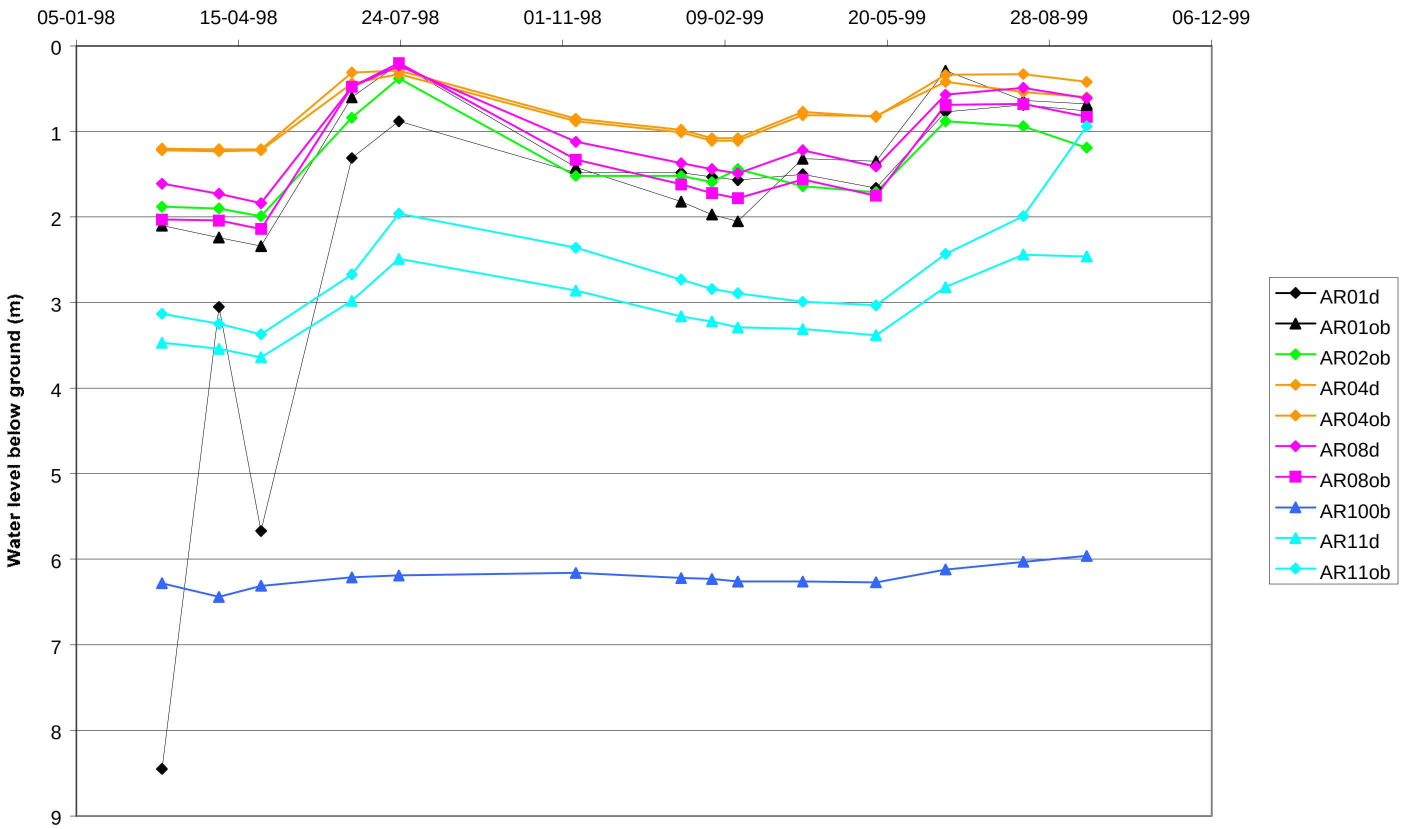

Figure 5. Hydrograph for all bores with seasonal trends.

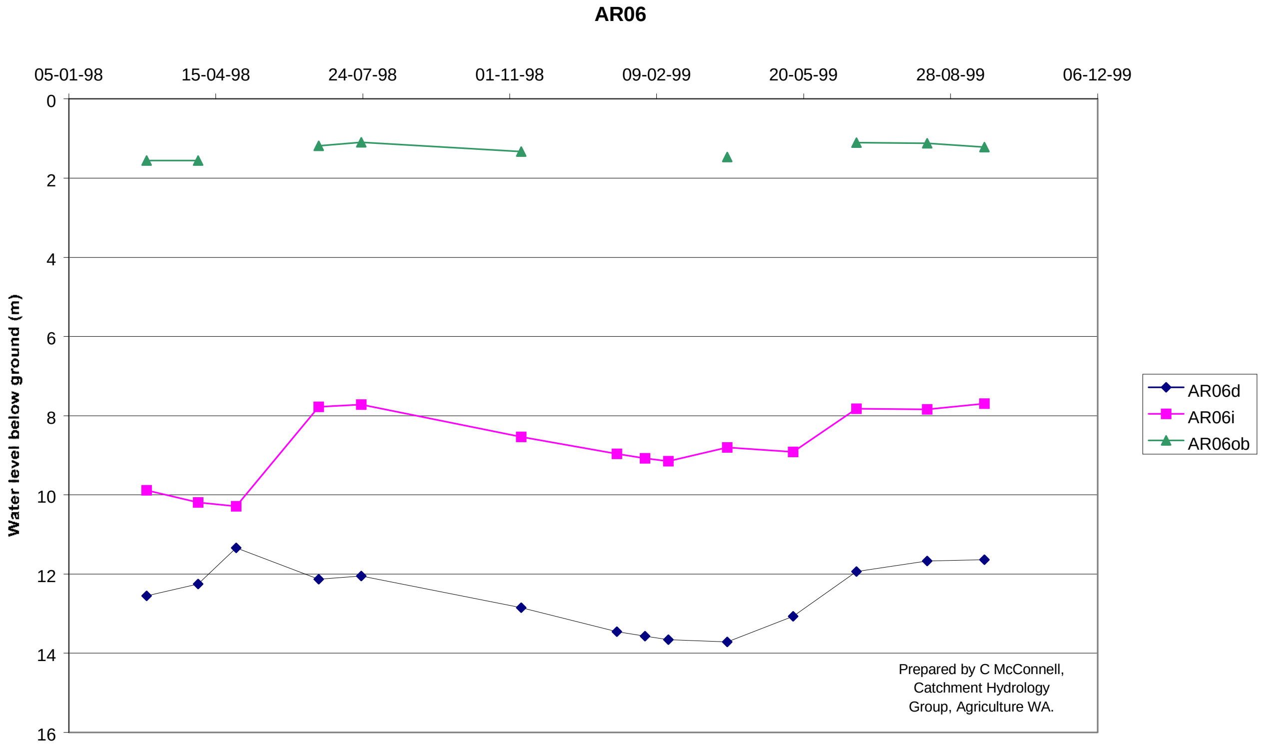

Figure 6. Hydrograph for AR06.

Data shows that for some of the winter period (eg. July 1998 or August 1999) that three separate groundwater systems exist.

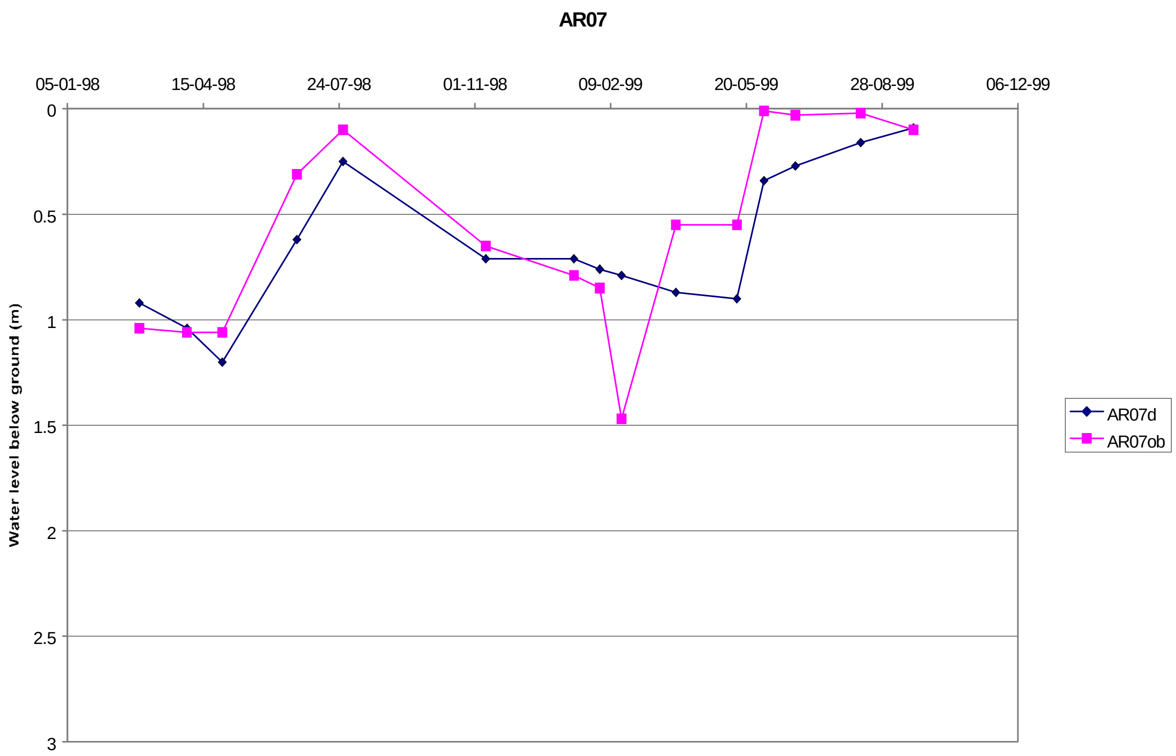

Figure 7. Hydrograph for AR07.

Note the change in vertical head during early March 1999. The water level in the piezometer is higher than the observation well. The situation remains until late August 1999.

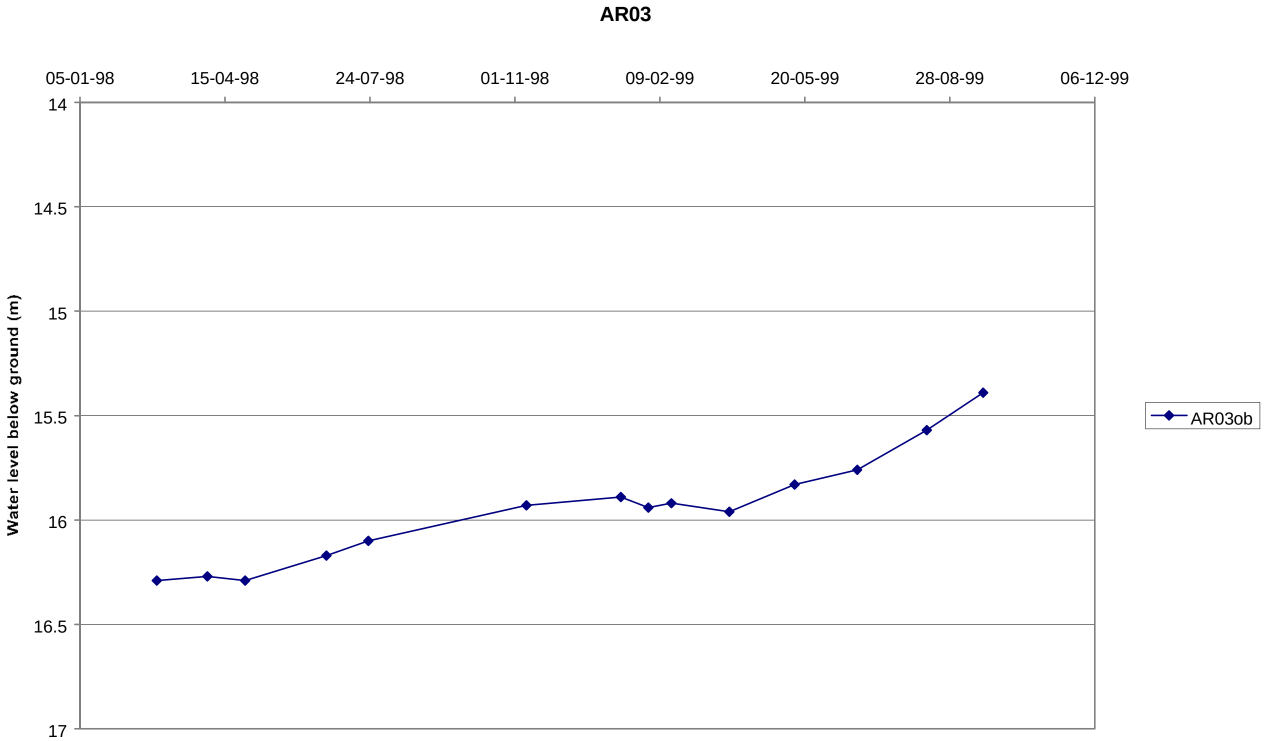

Figure 8. Hydrograph for AR03. Water levels are steadily rising.

Ground Survey

Rock outcrop and the extent of waterlogging were mapped during the winter of 1998. Most of the geological field investigation confirmed the accuracy of the 1:250,000 geological sheet (GSWA). Exposures of the Arrowsmith Sandstone were identified in the vicinity of Arrino South Road. Small sandstone outcrops were mapped along the entire length of the road within the catchment. Toward the southern end of the road, small weathered outcrops of Arrino siltstone were identified.

The Mullingarra Gneiss was located predominantly to the north and south of the catchment. In the south, the Dookanooka Reserve and adjacent areas had extensive outcrops of quartz and mica rich gneiss. The rock was highly fractured and in varying stages of weathering. The gneiss was prominent in the northwest – southeast hills that traversed Neil Reed's and John Illingworths properties to the north. The gneiss was quartz and mica rich and highly fractured. There was also some evidence of past mining operations, (copper exploration) on the eastern edges of the quartz ridges through Neil Reed's property.

On the western edges of the catchment there was evidence of Perth basin sediments, probably Yarragadee formation. The sediments comprised of

sandstones, shales and minor siltstones with well round gravels of quartz and were mostly capped with laterite. There were distinct gravel beds within the upper areas of the formation. The formation had a north northwest strike and dipped slightly to the east.

Other areas of the catchment were covered by reworked sediments and formed the majority of the valley floor and sides.

Evidence of waterlogging was apparent in the areas surrounding Arrino Sth Rd. The Arrowsmith Sandstone outcrops in a zone running approximately north south, just west of Arrino Sth Rd. The soils were comprised of chocolate coloured clay loams, with some gravels. Profiles appeared to thin out over the sandstone, with waterlogging occurring in areas immediately upslope of outcrops.

Several areas to the south west of the catchment indicate lake development and waterlogging of the surrounding soils. These lakes occur high in the catchment, below extensive areas of sandplain. The Mullingarra Gneiss outcrops in the adjacent reserve (Dookanooka Reserve). This combined with a sandier landscape suggests that the lakes may be formed by the 'filling or saturation' of the soil profile in sand filled basins above a bedrock surface of changing height.

Discussion

Prior to drilling, existing evidence suggested that salinity in the Nebru catchment appeared to be influenced by the Urella Fault. The fault, which was approximately located through interpretation of the Satellite imagery, appeared to be acting as a barrier to groundwater flow, causing water tables to build up behind it, resulting in surface salinity. A process very similar to salinity development behind a dolerite dyke, but on a regional scale.

The drilling project was planned to provide several groundwater monitoring sites either side of the fault zone. Additional sites were drilled to investigate other issues higher in the catchment.

Cross sections were constructed from the drillhole data to assist interpretation, (Figure 9 & 10). The cross sections show that the water table changes dramatically from east to west. In the east, it is at or near the surface, as expected with salt affected land. However, on the west side of the catchment, the water table ‘disappears’ to depths of greater than 33m at site AR09. Regional water tables are approximately 65m below ground level (225m AHD) at the Dookanooka bore site, (also on the west side of the Urella Fault). This elevation was intersected with AR09, which was dry to an elevation of 209m AHD. It is possible that the water table is either unconnected to AR09, or the gradient of the bedding plane controlling the aquifer has a similar gradient to the change in elevation between AR09 and Dookanooka Reserve (approximately 2.5%).

The cross sections show a water table gradient from east to west, (i.e. the water table slopes towards the west). The cross section from sites AR08 to AR09 indicate a gradual drop in water levels from AR08, to AR11, to AR10. The groundwater level then plunges dramatically to an undetermined depth below the drill hole at AR09. A similar pattern is observed in the second cross section (AR02 to AR03). Watertables remain close to the surface east of the fault, between AR02 and AR01, but drop between AR01 and AR06, before ‘plunging’ over the fault.

The cross sections would suggest that the fault is the dividing point between two areas of different composition, rather than a barrier to flow. On the east side of the fault, the soil profile consists of the weathered products, clays and sands, produced by the weathering of the Mullingarra Gneiss, Arrowsmith Sandstone and Arrino Siltstone. Hydraulic conductivity (K) is likely to be low, although gravel beds encountered during drilling might provide localised areas of higher conductivity. Estimates of K from weathered granitic profiles from the eastern wheatbelt suggest K values of 0.005 to 0.85 m/day for sediments, (George 1992). On the west side of the fault, sandstone, sands and gritty earths were the predominant lithologies. These were mostly dry (excepting the lower profile at AR03). Due to the coarse size of sediments in the profile, the likely hydraulic conductivity is probably several orders of magnitude greater than on the east side of the fault.

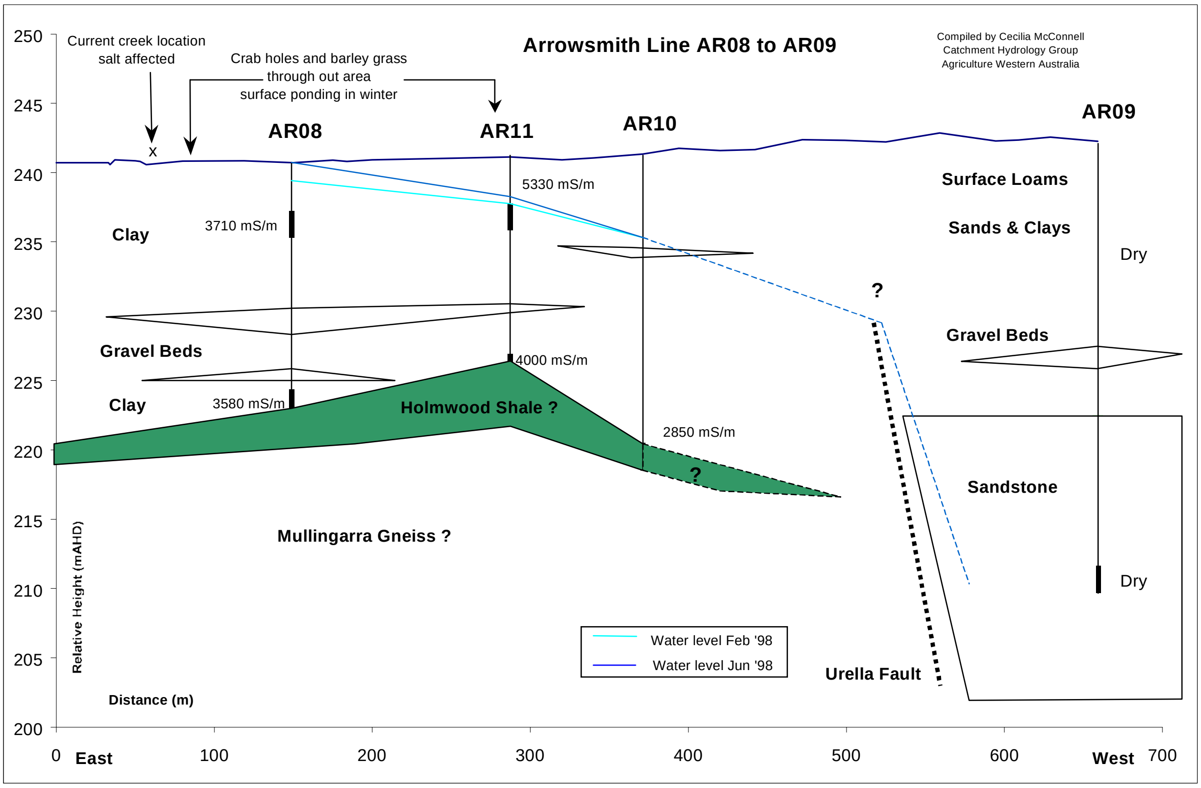

Figure 9. Cross section between AR08 and AR09 constructed from drill and other data.

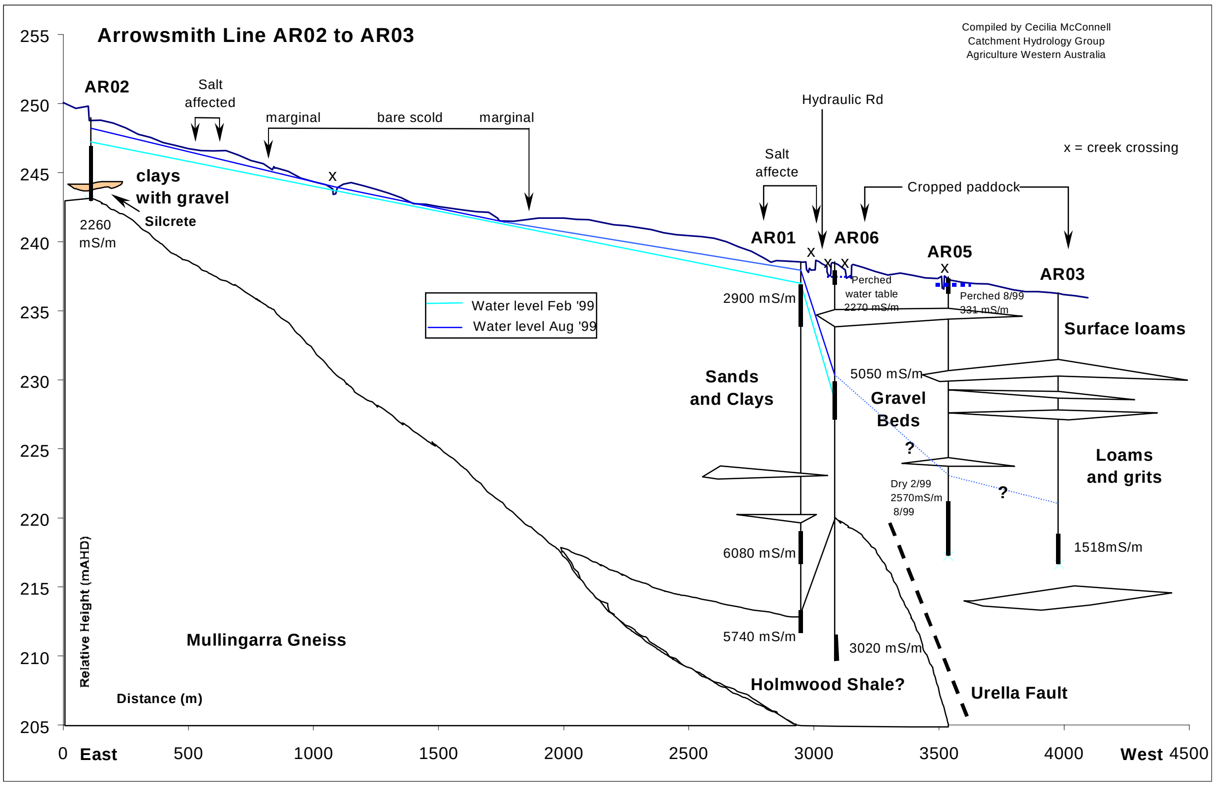

Figure 10. Cross section constructed from drill results and geological knowledge.

The groundwater gradients suggest that the Urella Fault is not a barrier but simply a dividing zone between two areas of very different soil profiles and hydraulic properties. The gradient indicates groundwater may be leaking from the zones of low hydraulic conductivity to areas of high hydraulic conductivity. Estimates of the velocity of flow, combined with the cross sectional area of the leakage face, could give an indication of the volume of water leaving the Nebru area. Darcy's equation can be used to estimate flow. In its simplest form:

$V = Ki$,
(V = velocity of flow (m/day), K = hydraulic conductivity (m/day), and i = slope or groundwater gradient (m/m))

The measured groundwater 'slope' between AR02 and AR01 was ~0.003 and the groundwater slope between AR01 and AR06 ~0.05. Using the estimates for weathered granitic profiles (see above) and the measured groundwater slopes, V could range from 1.5×10^{-5} - 2.5×10^{-3} to a maximum of 4.2×10^{-2} m/day with the rate of flow limited by the slowest component.

Cross sectional area of the leakage front was estimated using drilling information. The depth of aquifer was determined from the cross sections. All sections to the east of the Urella Fault, (except AR02 (shallow bedrock), AR04 (siltstone) and AR07 (sandplain seep/shallow bedrock)) intersected shale at depth. The shale has a low permeability and could be considered as an aquitard to water movement or the lower boundary of the unconfined aquifer. The hydrograph for AR01d which is screened within the shale, showed a long recovery time (6 months) after drilling, suggesting that permeability within the shale was extremely low. This is also suggested in the explanatory notes of the GSWA Perenjori 1:250,000 hydrogeological sheet, SH50-6, Commander & McGowan 1991. However, rapid seasonal responses were observed in the hydrograph data for this site. Given the extended recovery period observed for this bore, this response probably results from seasonal transmission of hydraulic pressure through the shale. However, it also suggests that either preferred flow zones might allow rapid movement of water within the shale itself, or, less plausible, that the bentonite seal on the piezometer is not fully sealing and the fluctuations are reflecting the profile above the shale.

At both AR06 and AR10 (on the edge of the fault) the shale was encountered at around 20m below ground. An aquifer thickness at the point of exit of 20m has therefore been used.

Drilling was not extensive enough to determine the length along the fault, through which the water table may be leaking. Higher in the catchment, toward AR07, the fault is in close proximity to the Mullingarra Gneiss. At the time of drilling AR07 the profile appeared fully saturated. Groundwater monitoring has shown there is a distinct change in vertical heads between the observation and piezometer holes at this site suggesting that two aquifers exist, an unconfined sandplain aquifer and a semi confined basal grit aquifer. The basal grit aquifer potentially recharged from additional sources to the sandplain immediately above it, e.g. the gneiss to the southeast. It is also possible that leakage from at least the basal aquifer may occur in a west direction across the fault. However, further evidence would suggest that water is not moving west across the fault.

The water from AR07 and surrounding seeps are slightly more saline than water extracted from the Dookanooka Bore reserve. AR07 measured 151mS/m in perched system and 314mS/m (end of summer 1998) in the deeper system. The seeps on the Stokes property measured 219 – 233mS/m in winter 1999. Dookanooka Reserve measured 137mS/m in 1994, (Water Corp Unpub). The topography of the site and the location of the seepage on an east facing slope, suggests that groundwater movement in at least the perched system is in an easterly direction. This would suggest that this water is not crossing the fault line at this point in the catchment.

Sources of saline water appeared to be related to the location of sediments eroded and reworked from the various sedimentary formations. Therefore, the contact zone between the Mullingarra Gneiss and overlying sediments might define the southern boundary of the leakage face. This assumes that there is limited water movement within the Gneiss. AR04 encountered siltstone at a shallow depth (~8m). Arrino siltstone is believed to be deposited over the Arrowsmith Sandstone, or directly over the Mullingarra Gneiss, (Playford et.al. 1976). The total depth of the formation at this point (AR04) is not known, however its existence at AR04, and absence at AR07, helps delineate the southern edge of the formation as occurring between AR04 and AR07. Nebru Rd runs east – west roughly dissecting these two sites. Therefore, if the zone of saline leakage is correlated with the recent sediments, (weathered and reworked), then the length of the saline leakage face can be estimated from approximately Nebru Rd (south) to at least the creek crossing at Hydraulic Rd (north).

There is no drilling data for the area north of Hydraulic Road, on the east side of the fault. However, ground truthing across the properties immediately north of the road (Illingworth and Reed) showed that the hills to the north are quartz rich (i.e. further exposure of the Mullingarra Gneiss). The hillslopes run approximately northwest, southeast, and would appear to intersect the fault line in the region of Sunset Road. Shallow hand auger holes on the south slopes of the Illingworth property revealed a shallow duplex soil of chocolate rich clay loam over a gravel/grit, that made water (winter 1998). The hills provide both the topographic and groundwater divide for this area. It was assumed that the leakage face did not extend to the top of these hills, but that it was probably present on the lower slope areas. A northern limit of the leakage face could be estimated as approximately half way between Hydraulic Rd and Sunset Rd. Most leakage is likely to occur from the deeper profile of the valley. The leakage face was assumed to exist approximately one km north of Hydraulic and extend south to Nebru Rd, a distance of approximately 4.5km.

Estimates of total volume are shown in the table below with a range of values, to indicate the sensitivity of data used. Velocity is clearly the limiting factor, and that increasing the flow rates by an order of magnitude significantly changes the

volume of water that might cross the fault. The estimates vary considerably with the most optimistic being approximately a third of the estimated annual production of the existing groundwater scheme at Dookanooka Bore Field.

Depth aquifer (m)	Velocity (m/day)	Estimated length (m)	Estimated total volume (m^3/yr) (kL/yr)
20	1.5×10^{-5}	1000	109.5
20	1.5×10^{-3}	1000	10,950
20	1.5×10^{-3}	3000	32,850
20	1.5×10^{-5}	5000	547.5
20	1.5×10^{-3}	5000	54,750

Table 2. Estimates of the volume of potential through flow from areas east of the Urella Fault.

Further work is required to determine both appropriate hydraulic conductivity values, (via either pump or slug tests) and estimates of the leakage face. Slug tests should be conducted in at least AR01, AR06, AR10 and AR11 to give an indication of hydraulic conductivity on the east side of the Urella Fault. However, these figures indicate, that unless the lowest estimated K is realistic, then considerable amounts of water are potentially crossing the fault zone.

If leakage is occurring, particularly at the higher rates suggested above, (for either 1km or 5km), it might be expected that water quality on the west side of the fault should show an increase in salinity. Unfortunately, whilst three sites were drilled west of the fault, (AR03, AR05 and AR09), only one, AR03 intersected a water table at the time of drilling. In August 1999, a water table was intersected in AR05D and 5OB. The water quality in the AR05D was 2570mS/m, at a level of 14.59m below the surface, whilst the shallow observation bore had a water quality of 331mS/m, at a level of 0.94m below ground level. The observation bore is associated with winter waterlogging which would be expected to be fresh. The deeper piezometer is reflecting water qualities in the regional system.

The quality of the observation bore probably reflects the large amount of surface water flushing that has occurred due to the above average rainfall in the early months of the 1999 growing season. However, the water level and quality of the deep piezometer is of concern. The rapid development of a 5m head suggests massive recharge or episodic recharge in the area. This might result from rapid movement of water through gravel beds. Whilst not as salty as the water at AR01 or AR06, its quality suggests that the saline water from east of the fault may have contributed to the high salinity levels at AR05d.

During spring and autumn, when the creek is at low flow rates, the creek water frequently ‘disappears’ between AR06 and AR05, (i.e. the surface flow doesn’t reach AR05), as it infiltrates into the creek bed. At AR05 extensive gravel bands were encountered from 7m to the base of the hole at 20m. In particular the last 6m were comprised of 'thin bands of white clay interlayered with coarse grits to fine gravels. Some gravel up to 10-12mm, predominantly well-rounded quartz'.

Interestingly, gravel beds occur at the same AHD level (~223mAHD) in AR01 and AR05, but were not intercepted in AR06. The possibility exists that there is some connection between the gravel beds in the surficial sediments on either side of the fault, allowing for the rapid transfer of water across the fault zone. Similarly, the gravel beds in AR05 may have some connection to the creek bed, which could facilitate rapid groundwater movement across the fault zone at rates much more rapid than those suggested above. The rate of drainage of AR05 will give some indication to the connectiveness of AR05 to the surrounding aquifers. Rapid drainage would suggest high hydraulic conductivity in surrounding profiles. Slower drainage might suggest that either the profile is now full preventing downward drainage, or that drainage away from AR05 is slow.

Gravels beds were encountered in over half of the drill sites, and were found on both sides of the fault. The gravels were of mixed geology comprising quartz, gneissic and rock of volcanic origin. Quartz gravel beds were noted in the ground survey, occurring in exposures of Jurassic sediments to the northwest of the fault. It is difficult to determine the source of the quartz and gneissic gravels as the composition of the Mullingarra Gneiss is similar to the gneiss on the Yilgarn Block, (Baxter & Lipple 1985). The same study has suggested that the Mullingara Gneiss is an inlier of the Archaean rocks of the Yilgarn. The presence of the gravels on both sides of the fault suggest that the environment of deposition occurred across the fault boundary, and possibly extended to the Yilgarn Craton, east of Three Springs.

The gravels found in drill samples, and the observed gravel beds in the exposures of Jurassic sediments, were well rounded. Rounding occurs in high-energy environments where rock fragments can be regularly moved and worn down, e.g. this might result from a fast moving creek or river, or from a beach environment where waves have sufficient energy to move and 'wear' rocks. It has already been mentioned that the Arrowsmith Sandstone was formed in shallow marine conditions, with the 'well rounded grains indicating prolonged traction', (GSWA Bulletin 124, 1976), and that the 'gravels are comprised of well rounded feldspar and lithic fragments'. The source of the gravels found in the drill samples is probably from the reworking and redistribution of the weathered Arrowsmith Sandstone, with the original source of sediment for the Arrowsmith Sandstone being the Mullingarra Gneiss and/or the Yilgarn block. The rounding of gravels occurring during the formation of the sediment, as opposed to more 'recent' reworking of sediments which has redeposited the gravels in their current locations. Reworking would appear to post date fault movement, as gravel beds were found in drill holes on both sides of the fault line.

Geophysical logging of the bore holes will give some indication as to similarities between gravel beds and hence the potential for connectivity between gravel beds encountered at different sites. Slug tests in AR05 – which is screened entirely in gravel beds, may help quantify the hydraulic conductivity in some of the gravel beds in this catchment.

A significant factor, not yet discussed, is a splinter fault, suggested by Barnett, 1970 and the GSWA in the Perenjori, 1;250,000 hydrogeological sheet. This fault splits from the Urella fault in a north-northwest direction, approximately half way between Hydraulic & Nebru Roads, (Figure 10). This creates a small groundwater cell, with a northern opening. Any water leaking across the Urella Fault, north of this splinter fault, is potentially moving into this small groundwater cell and may not be in direct contact with the Dookanooka Bore Reserve. More investigation is required to 1) determine the role of this minor fault, but as importantly, 2) determine the quantity and quality of water moving across the Urella Fault, in the zone south of the splinter fault.

A salt balance can be used to determine if the increase in salinity levels in the Dookanooka Reserve are comparable to the suggested amounts of salt leaking over the Urella fault line. Water Corporation records (unpublished) show that water quality in bore 2/75 has increased by ~9mS/m (50mg/L) since 1985. Average annual extraction from the bore field is 169,000 kL/year. An increase of 50mg/L equates to a total salt weight of 8.45tons/yr (50/1000/1000 (kg/l/yr) x 169,000x1000 l/yr). (Location of bores shown in Figure 11).

It was assumed that the splinter fault was a barrier preventing any water moving across the Urella Fault from mixing with water south of the splinter fault – i.e. mix with the borefield aquifer. Water sampled at AR04d measured 1611mS/m. The volume of water moving across the fault was taken over a 1km length (the section of the leakage face south of the splinter fault) for the two hydraulic conductivity's used in Table 1. This produced a minimum estimate of 0.9tons/yr to a maximum of 93 tons/yr. Therefore from the salt balance, the suggested leakage across the Urella Fault is well within the parameters required to cause the observed salinity increase in the bore field.

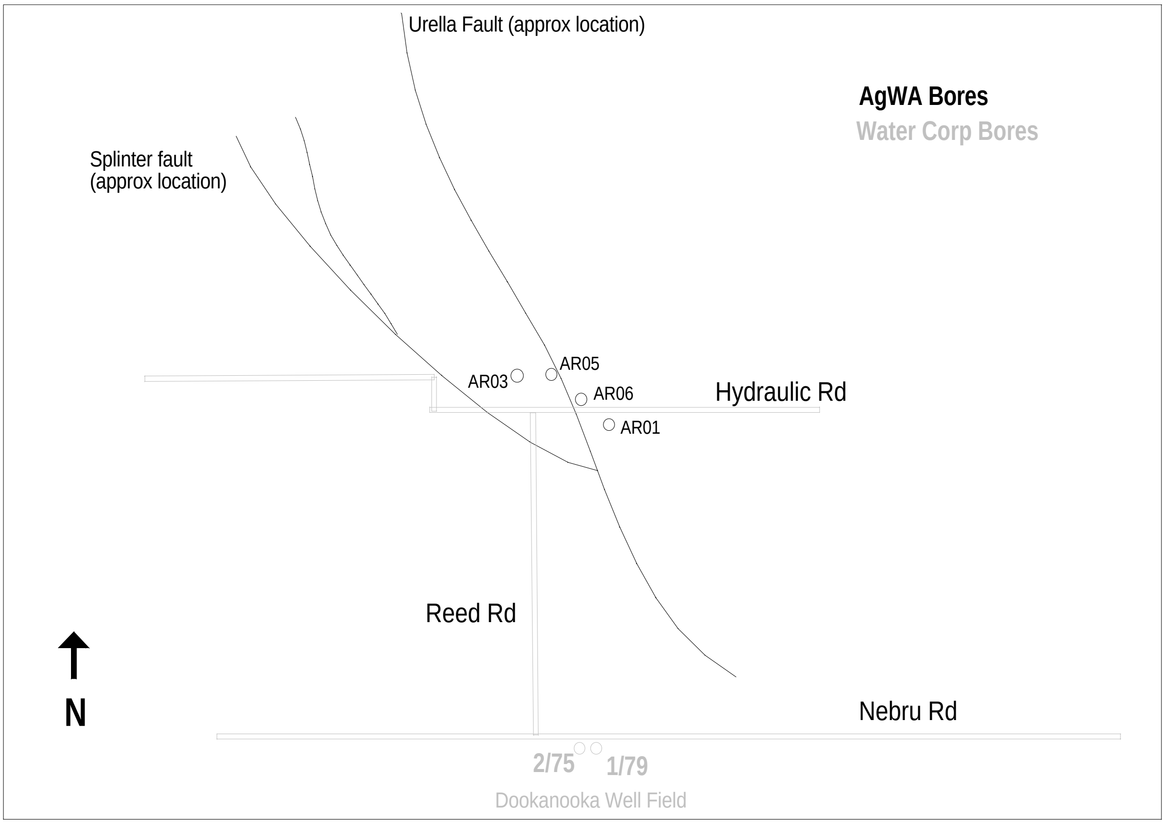

Figure 11. Approximate location of the Urella Fault and splinter fault. The Dookanooka Bore Field locations area also marked.

The recorded salinity of the water from the Bore field was 137mS/m (Water Corporation Unpublished). However, the measured salinities of AR03 (1518mS/m) and AR05 (2570mS/m) were significantly more saline than the bore reserve. The additional salinity could have resulted from leakage across the fault in this zone. The soil analysis showed a relatively low salinity profile for AR03 and AR05, when compared to those sites east of the fault, (both less saline than AR09, also west of the fault). If water movement was by matrix flow, higher soil salinities could be expected. However, if preferential flow, for example, through gravel beds, was a significant process, higher groundwater salinities, and lower soil salts might be expected. There is some evidence for this in the EC1:5 profile for site AR06. A slight bulge in the measured EC values correlates with a zone of clay and ironstone grits. (See Appendix). There is less evidence in the profile for AR05, however there is slightly higher EC levels within the lower profile occupied by clays and gravels.

Initial examination of the water table depth show some inconsistencies with this conclusion. The water depth at AR03 was at 220mAHD in June 1998. At the same time and depth, (i.e. June 1998 and 220m AHD) there was no water table at site AR05. This suggests that there is an apparent gradient from AR03 to AR05, (i.e. from West to East). If this is correct, it is unlikely that saline water from east of the fault has contaminated the water in AR03. However, a water table was first recorded in August 1999 in AR05 at levels higher than in AR03. This, if connected, suggests a slight east west gradient.

The pattern of groundwater rise is quite different between the two sites. AR03 has steadily risen since first drilled. AR05 has been dry until the 3 week period between readings in June and August 1999, when a rise in the piezometric head of 6m occurred. The profile at AR03 was quite different to AR05. AR05 was consistent with AR09, showing bands of grits/gravels and white pink clays. AR03 had more red, brown and yellow earths with some gravels. It is probable therefore, that AR03 is unconnected to AR05 and possibly represents a different aquifer system.

Outcomes

The outcomes for this report are limited by the need for further fieldwork. If slug tests and geophysical logging were undertaken the range of possible conductivities could be reduced considerably.

The project has delineated that the Urella Fault does not appear to be acting as a barrier to groundwater flow in the upper regolith. The fault is the dividing line between an area of extremely low hydraulic conductivity and an area with substantially higher conductivity. Water movement out of the Nebru catchment will be limited by the hydraulic conductivity of the sediments within it.

Water flow from the Nebru catchment, across the Urella Fault and into the Perth Basin, potentially occurs along ~4-5 km length, spanning from Nebru Rd to north of Hydraulic Rd. Outflow may be as much as half of the current capacity of the Dookanooka Borefield. Actual figures of hydraulic conductivity, and a better estimate of the leakage face need to be obtained before any major management decisions can be made. If the lowest estimates are more realistic, then this leakage is not an issue for the water supply.

The role of gravel beds has been suggested to be significant in the rapid movement of groundwater from west to east of the fault.

There is limited evidence that not all of the water crossing the Urella Fault is moving directly into the Perth Basin. A splinter fault exists in the immediate vicinity of Nebru catchment, creating an additional groundwater cell for water storage to the west of the Urella Fault. This cell is not necessarily connected to the groundwater reserves from which the Three Springs Town supply is drawn. Current data is insufficient to determine the role of this fault, but it is likely that groundwater from Nebru is filling this groundwater cell and not necessarily affecting the groundwater supplies at the Dookanooka Bore Field. If this fault is a barrier, there may be a lesser risk of contamination by salinity of the Dookanooka Reserve, therefore changes in management may not be required. (Management changes might be advisable for other reasons, e.g. further expansion of salinity in the Nebru Catchment).

There has been some investigation of the major seepage line in the south western areas of the catchment. This seepage may have potential to provide additional water supplies for farm use, and/or irrigation for a higher value crop. This would assist viable changes in management, e.g. adoption of alley systems etc. Investigation should look at potential volumes of water and groundwater properties to develop better management strategies.

Recommendations

Recommendations derived from this investigation are:

1) It is seen as a priority to attain estimates of hydraulic conductivity. Initial estimates should be easily obtained by undertaking slug tests at existing bore sites. These are necessary to delineate the volume of water moving across the Urella Fault.

2) It is suggested that geophysical logging of boreholes occurs. This may provide evidence to support the hypothesis that gravel beds are able to rapidly transmit water across the fault zone. Slugs tests should also be undertaken to assess the rate of water movement.

3) Further investigation should look at:
the role of this splinter fault – barrier or other?,
water chemistry analysis, including sources of salt, in each groundwater zone (i.e. Nebru Catchment, - Irwin Sub Basin, the splinter basin, and the Perth basin). This might assist tracking the movement of water.

Acknowledgments

I would like to acknowledge the considerable amount of time and effort of Russell Speed and Dick Kelly who undertook the drilling and monitoring for this catchment. In particular, Russell who has provided ongoing comment and challenged ideas during the development of this work.

Also Dr Neil Coles and Ben Whitfield who helped review the paper.

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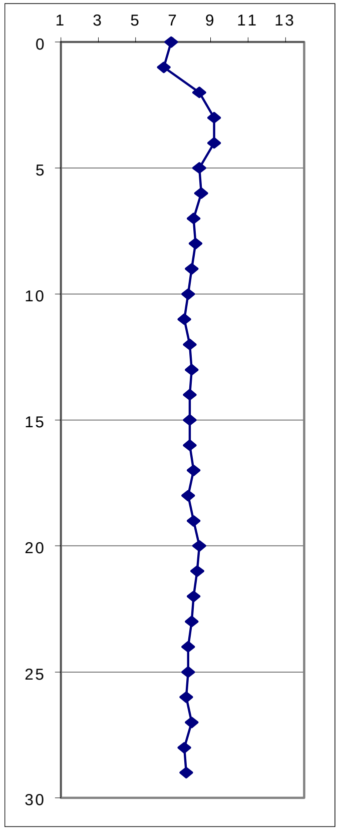
Appendix 1.

Drill Logs for the Nebru Catchment Project

Bore ID	**AR01d**	**Total Depth from Tube top (m)**	26.89
Date Drilled	########	**Tube Top agl (m)**	0.3
Driller	Speed/Kelly	**Length of slots (m)**	1
Property Location	N. Reed	**Piezometer/Observation**	Piezo

Depth bgl (m)	Description
0	Orange/brown sandy loam
1	Orange/brown loamy sand
2	Brown clay, minor grits, moist
3	Grey clay, gritty to red/brown sandy clay
4	Grey clay, gritty
5	Grey/brown silty clay
6	
7	
8	Clayey sand
9	
10	
11	Sands
12	
13	
14	
15	Gravel beds
16	
17	
18	
19	Blue/grey clay
20	
21	Red fine sand
22	Blue/grey clays
23	
24	Gravel beds
25	Blue/grey clay
26	
27	
28	
29	Shale (Holmwood?)
30	
31	
32	
33	

pH



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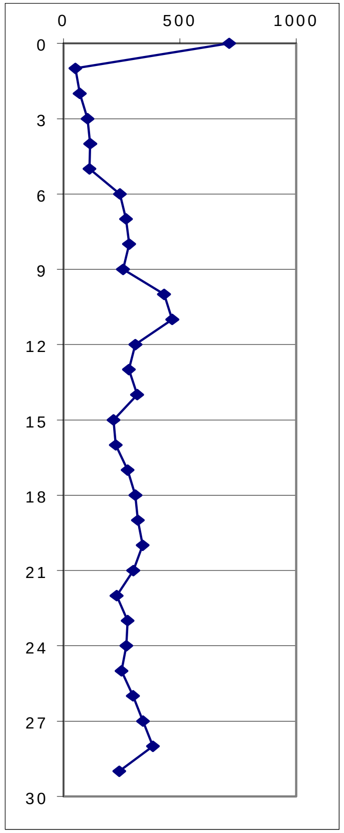
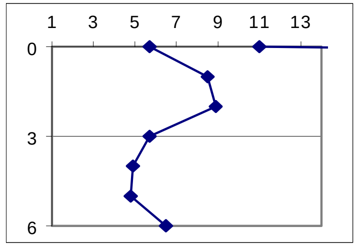


Bore ID	**AR02**	**Total Depth from Tube top (m)**	6.06
Date Drilled	03-02-98	**Tube Top agl (m)**	0.3
Driller	Kelly/Speed	**Length of slots (m)**	3.7
Property Location	N. Reed	**Piezometer/Observation**	Obs

pH



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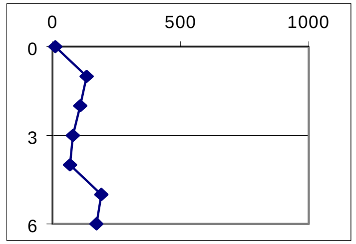

Depth bgl (m)	**Description**
0	Brown/Red gravelly clay loam
1	Brown/Red gravelly clay loam
2	Yellow heavy clay
3	Red heavy clay with ironstone gravel
4	Yellow clay (dry), Silcrete (3.5-3.6), hard ironstone gvls
5	Red clay, damp to sticky
6	quartz grits
7	
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Bore ID	**AR03**	**Total Depth from Tube top (m)**	19.89
Date Drilled	03-02-99	**Tube Top agl (m)**	0.3
Driller	Speed/Kelly	**Length of slots (m)**	2
Property Location	N. Reed	**Piezometer/Observation**	Ob

Depth bgl (m)	**Description**
0	Brown silty loam
1	Brown sandy earth
2	Lt grey silty earth, gravel bed 2.8
3	Red/brown gritty earth
4	
5	Grey, weakly cemented earthy sand, gravel bed 5.4
6	Brown earth sand, moist
7	Lt grey silty clay, gravel bed 7.3
8	Lt grey silty clay, gravel bed 8.6
9	Grey, gritty earth
10	Alternating brown and grey gritty earth
11	
12	Lt grey clayey sand
13	
14	Brown/yellow clayey sand
15	White clay
16	Grey Clay
17	White clay
18	Red/brown earth
19	
20	Gravel beds 20.5-22.8
21	
22	
23	Brown gritty clays
24	
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27	Brown gritty clays
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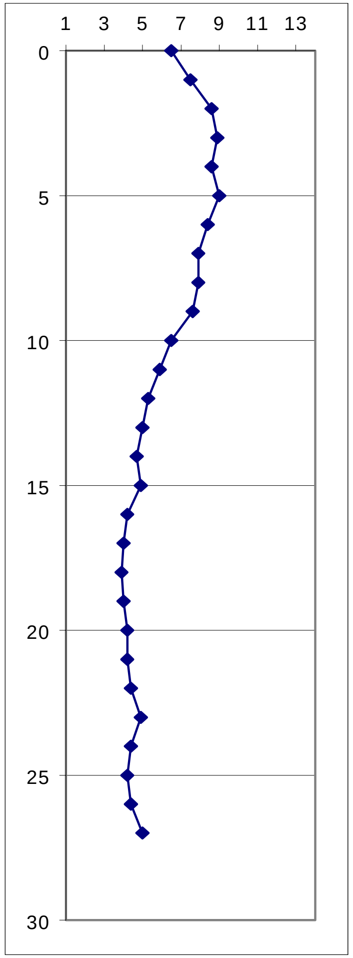
pH



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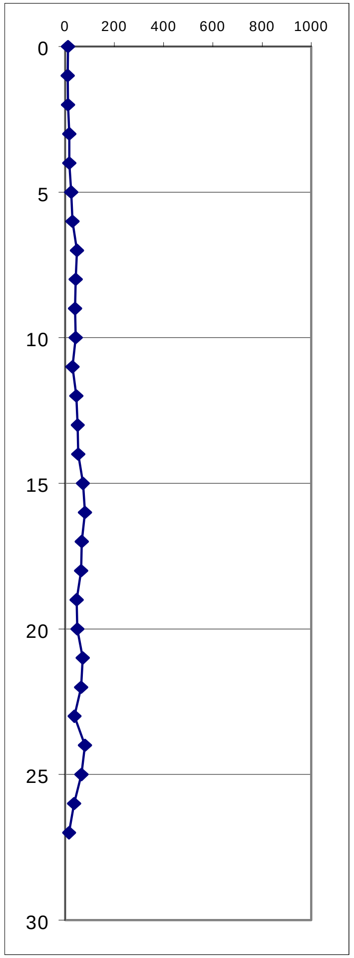

Bore ID	**AR04**	**Total Depth from Tube top (m)**	11.7
Date Drilled	04-02-99	**Tube Top agl (m)**	0.3
Driller	Kelly/Speed	**Length of slots (m)**	1
Property Location	M. Stokes	**Piezometer/Observation**	Piezo

Depth bgl (m)	**Description**
0	Red/orange sandy clay loam
1	Brown sand - brown clay
2	Dk Green Clay with Ironstone grits
3	Green sandy clay, wet
4	
5	Silcrete
6	Soft silcrete
7	Hard silcrete
8	Hard silcrete with some gravels
9	Silstone (used rock roller)
10	
11	Silstone (used rock roller)
12	
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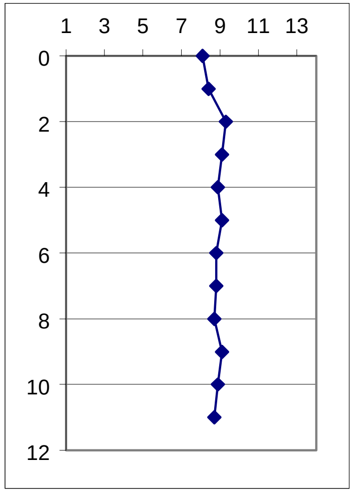
pH



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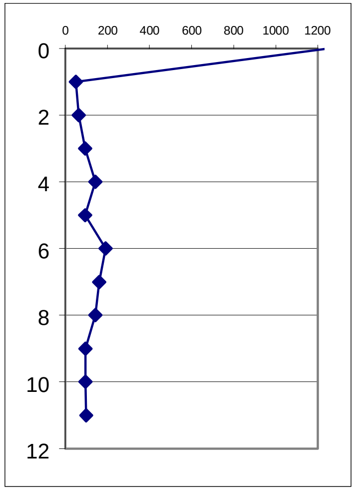

Bore ID	**AR05**	**Total Depth from Tube top (m)**	20.21
Date Drilled	05-02-99	**Tube Top agl (m)**	0.3
Driller	Speed/Kelly	**Length of slots (m)**	3.75
Property Location	J. Illingworth	**Piezometer/Observation**	Piezo

Depth bgl (m)	**Description**
0	Brown sandy loam
1	Brown Loamy clay
2	Gravel beds rounded qtz
3	Grey/brown gritty clay, moist
4	Brown sandy clay
5	Red/brown loam
6	Gravel beds rounded qtz 6.6-7.3
7	Fine red loamy sand
8	Gravel beds
9	Yellow/brown loamy sands
10	Pink/brown gritty earth
11	Rounded qtz grits
12	White clay
13	Pink/brown gritty alternating with white clays
14	Lt brown coarse sand
15	White clay bands interlayered with grits/gravels
16	
17	
18	
19	
20	White clay bands interlayered with grits/gravels
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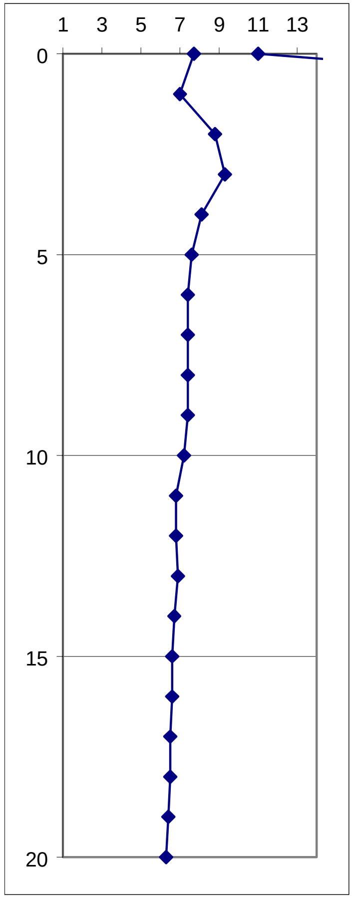
pH



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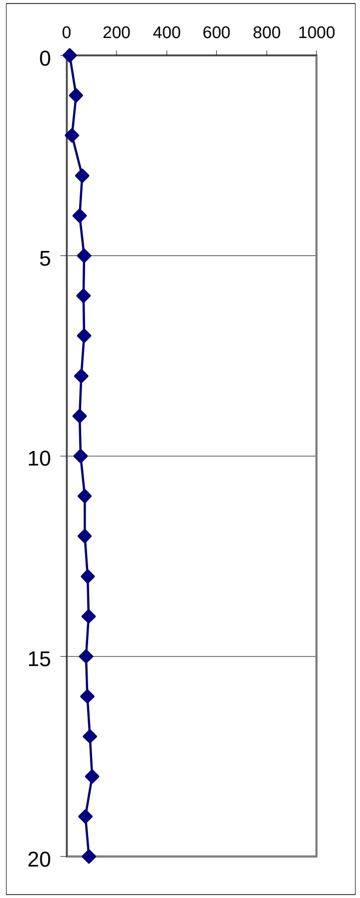
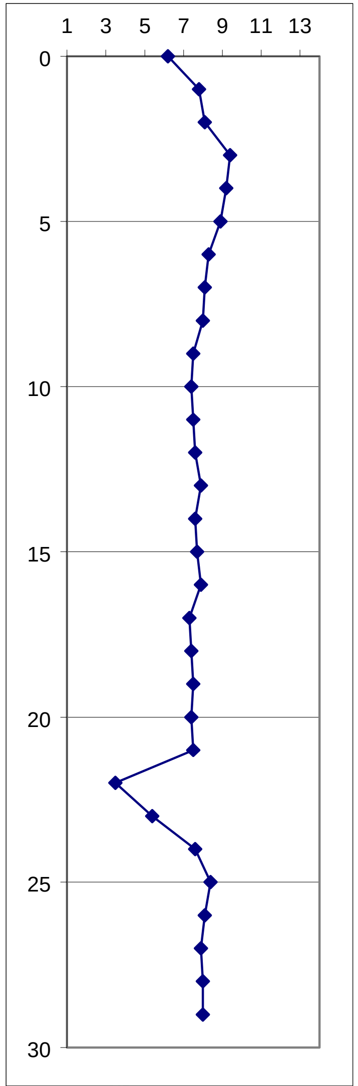


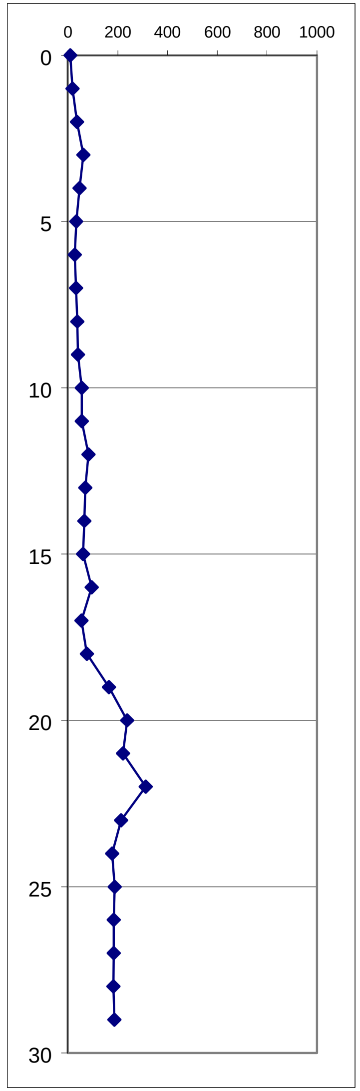
Bore ID	**AR06**	**Total Depth from Tube top (m)**	28.92
Date Drilled	05-02-99	**Tube Top agl (m)**	0.3
Driller	Kelly/Speed	**Length of slots (m)**	2
Property Location	J Illingworth	**Piezometer/Observation**	Piezo

Depth bgl (m)	Description
0	Yellow hardset clay loam
1	Orange sandy loam
2	Grey clay with grits to brown sandy clay
3	Grey clay with ironstone grits to gravel with qtz grit
4	Red/grey sandy clay
5	Orange/yellow sandy clay
6	Alternating grey & red sandy clays
7	
8	Yellow sandy clay
9	Grey sandy clay, wet
10	Orange sandy clay to grey/red sandy clay, dry
11	White sandy clay, dry
12	Yellow sandy clay to grey sandy clay
13	Dk grey clay
14	Grey gritty clay
15	Orrange/grey clay
16	
17	Black/green clay
18	Orange clay
19	Dk Brown 'pelleted' clay
20	Black/green clay
21	
22	Red/lt grey clay
23	Grey clay with ironstone grits
24	Red/grey clays with ironstone grits
25	
26	Grey/orange clays
27	Yellow/green clay
28	Grey clay
29	Green/grey clays
30	
31	
32	
33	

pH



EC1:5 (mS/m)



Bore ID	**AR07**	**Total Depth from Tube top (m)**	11.87
Date Drilled	09-02-99	**Tube Top agl (m)**	0.3
Driller	Speed/Kelly	**Length of slots (m)**	2
Property Location	M. Stokes	**Piezometer/Observation**	Piezo

Depth bgl (m)	**Description**
0	Grey sand
1	Bleached sand, moist
2	Orange mottled clayey sand, (clay with depth)
3	Grey/white silcrete, hard
4	Brown/white weakly cemented sands/sandstone
5	
6	Red earth to green/grey coarse gritty earth
7	Angular quartz grits
8	Dk grey micacous clays
9	
10	Hard quartz basement
11	Massive saprolite grits, quartz and mica
12	
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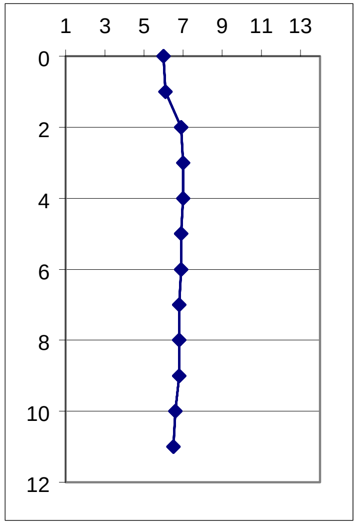
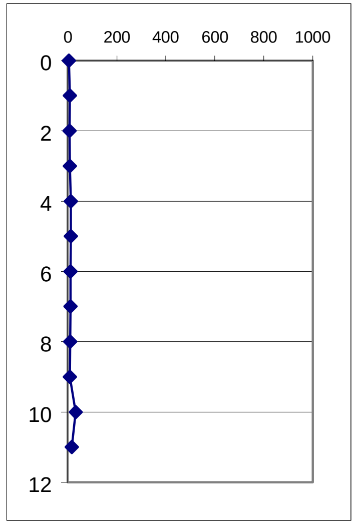
pH



EC1:5 (mS/m)



Bore ID	**AR08**	**Total Depth from Tube top (m)**	18.49
Date Drilled	09-02-99	**Tube Top agl (m)**	0.3
Driller	Kelly/Speed	**Length of slots (m)**	2.77
Property Location	N.Reed	**Piezometer/Observation**	Piezo

Depth bgl (m)	**Description**
0	Grey/yellow sandy clay
1	Red/grey clay
2	
3	Dk Red clay, moist
4	Grey clay, free water
5	
6	
7	
8	Grey clay with grits
9	
10	Harder layer with rounded qtz gravel
11	Well rounded gravels change to red clay
12	
13	Red Clays with gravels
14	Grey clay with gravels
15	Grey clay with gravels/pebbles
16	
17	Shale
18	
19	
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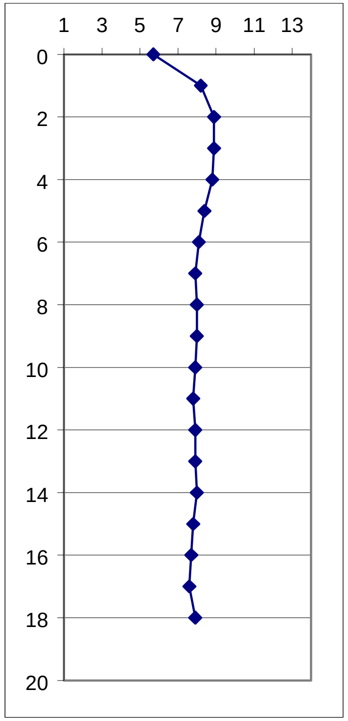
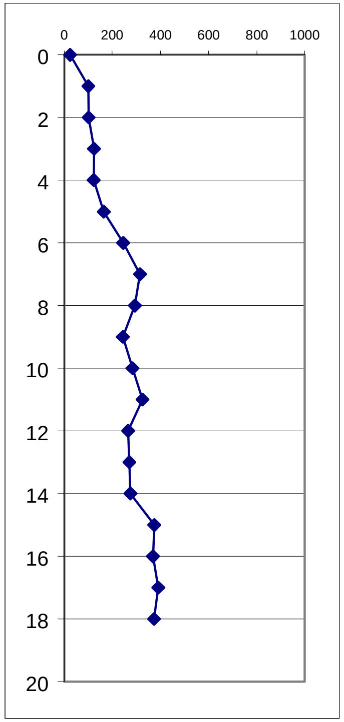
pH



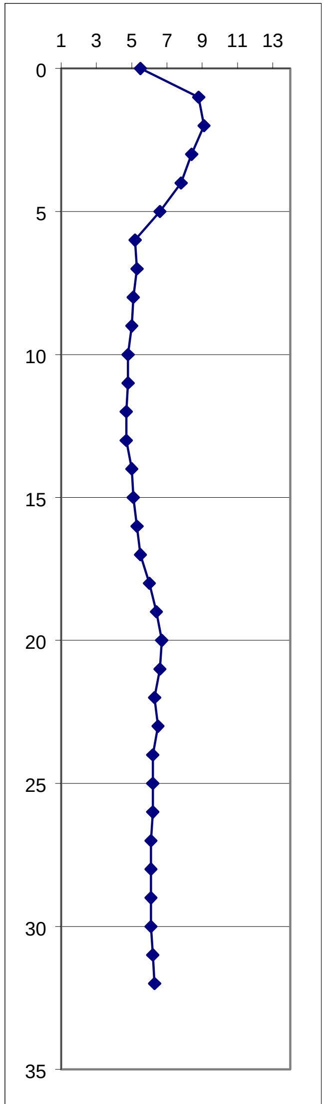
EC1:5 (mS/m)



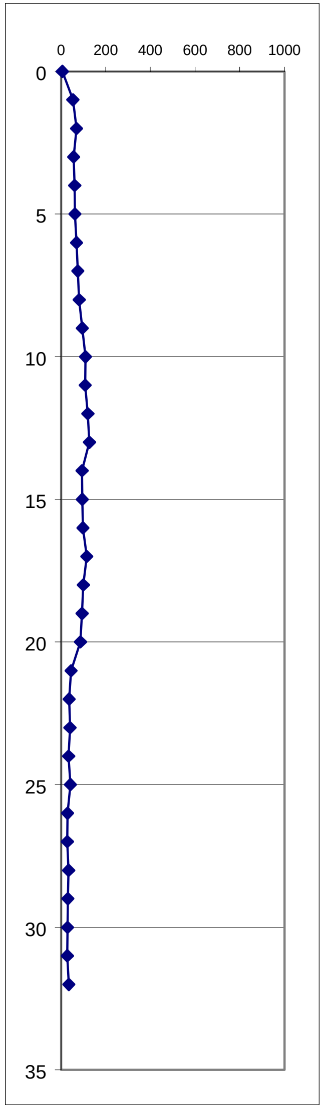
Bore ID	**AR09**	**Total Depth from Tube top (m)**	32.78
Date Drilled	10-02-99	**Tube Top agl (m)**	0.6
Driller	Speed/Kelly	**Length of slots (m)**	3
Property Location	N. Reed	**Piezometer/Observation**	Obs

Depth bgl (m)	**Description**
0	Grey sandy clay
1	Lt grey sandy clay
2	Yellow/brown loamy weak sandstone
3	Lt grey clay with bands of weak sandstone
4	Red mottled clay to light grey clay
5	Yellow/brown loamy weak sandstone
6	
7	
8	
9	
10	
11	
12	
13	Brown sandy earth with qtz gravel
14	
15	Bands rounded gravels
16	Brown/grey clay
17	White/brown fine sands, to red earth with gravels
18	
19	
20	White sandstone, hard with basal gravel
21	Qtz sand to qtz gravels
22	Creamy yellow clay/silt matrix with qtz sand and gravels
23	
24	
25	White silty clay
26	White sandstone
27	
28	
29	
30	
31	
32	White sandstone
33	
34	
35	

pH



EC1:5 (mS/m)



Bore ID	**AR10**	**Total Depth from Tube top (m)**	21.28
Date Drilled	10-02-99	**Tube Top agl (m)**	0.3
Driller	Kelly/Speed	**Length of slots (m)**	2
Property Location	N. Reed	**Piezometer/Observation**	Piezo

Depth bgl (m)	**Description**
0	Grey gilgai clays
1	Grey clay
2	Yellow/grey clay
3	Grey/brown clay
4	Red/brown clay
5	Grey clay with grits
6	
7	Hard gravel bed in grey clays
8	Grey sandy clay
9	Grey clay
10	Green/yellow clay
11	Grey/yellow clay, some moisture
12	Red clays, sticky
13	Grey clay
14	Yellow/grey clay
15	
16	
17	Brown/yellow clay
18	
19	
20	Shale
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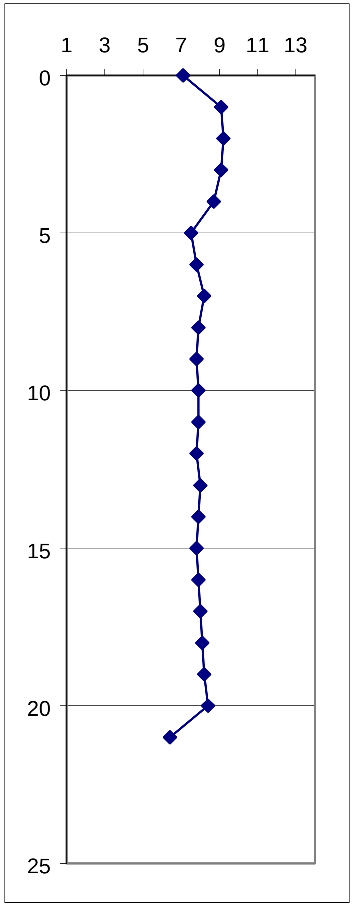
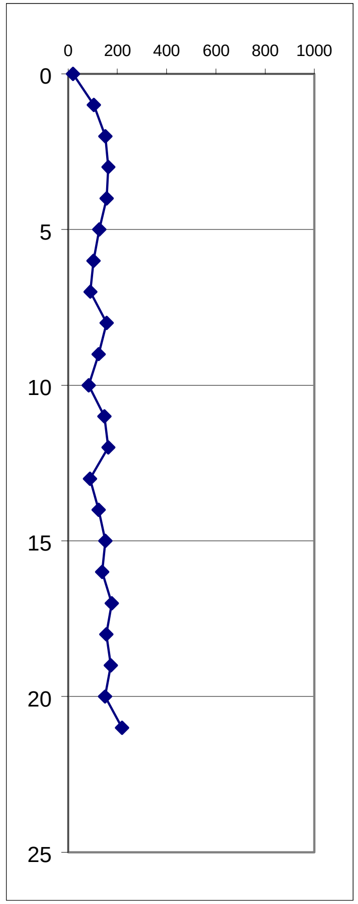
pH



EC1:5 (mS/m)



Bore ID	**AR11**	**Total Depth from Tube top (m)**	16.37
Date Drilled	11-02-99	**Tube Top agl (m)**	0.3
Driller	Speed/Kelly	**Length of slots (m)**	2
Property Location	N.Reed	**Piezometer/Observation**	Piezo

Depth bgl (m)	**Description**
0	Dk grey sandy loam
1	Yellow/grey sandy clay
2	Red earthy clay
3	Lt grey clay with red mottling
4	Red/brown earth clay
5	Grey clay, sticky/moist
6	
7	
8	
9	
10	
11	Thin band of gravels in clay
12	
13	
14	
15	Shale
16	Shale
17	
18	
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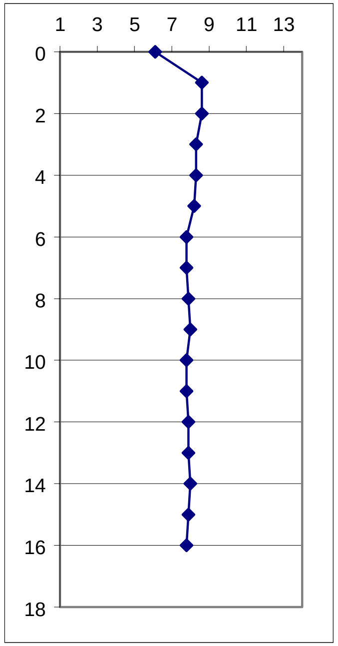
pH



EC1:5 (mS/m)