Long-term Salinity Changes in an Inland Aquifer, NSW, Australia

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Low salinity groundwater must be maintained for the environment, drinking water supplies, stock water and irrigation in the Namoi Catchment of NSW, Australia to support an industry worth at least $380 million each year. In this study, variability of groundwater quality across the catchment and over time was analysed with a multi-decadal historical dataset and new data. Standard protocols were used to test ~60 samples at 45 bores on three occasions during 2009 with a total of 189 field parameter records and 121 major ion analyses. Groundwater salinity was relatively stable at most sites where sufficient historic data was available (116 monitoring pipes), however significant increases had occurred at about 25% of sites over the past two decades. Salinity increases were most concentrated on the Breeza Plain, where soil salt stores are high. The worst case was a bore screened at 80 m depth where the average EC from monitoring in 2000-2011 was 156% higher than the average from 1980-1999. Salinity changes were highly variable throughout the catchment and even in neighbouring bores, however increases were greatest in areas of long-term decline, high drawdowns during pumping seasons and reversal of head gradients. Comparison with hydrographs showed salinity increases appeared to be associated with periods of intense extraction during droughts. Further away from the Namoi River where there is no strong pumping influence, salinity increases appeared to be associated with rising water levels. In contrast, groundwater in other bores in the area was found to be fresh. Freshening had occurred at about 25% of sites, mostly those near to connected and losing areas of the river. These variations show the complexity of salinity changes in inland alluvial aquifers and the need to incorporate a range of processes when considering the risk of aquifer salinisation.

1. INTRODUCTION

The Namoi region of north-eastern NSW is based around the Namoi, Manilla and Peel Rivers and features the major regional centres of Tamworth, Gunnedah, Narrabri, Boggabri and Wee Waa. Groundwater in the Namoi catchment supports an irrigation industry worth in excess of $380 million and is the water supply for many towns and intensive industries such as feedlots.

Groundwater resources in the Namoi region are the most intensively developed in NSW (CSIRO, 2007). They are mostly sourced from deeper alluvial deposits associated with the main rivers and prior streams; and are often overlain with relatively saline or brackish waters. These major areas of alluvium are divided into the Upper Namoi to the east and the Lower Namoi to the west, two of the 12 Groundwater Management Units (GMU's) in the Namoi Catchment. The Upper Namoi Alluvium is further divided into 12 zones. Water use in the Upper Namoi Alluvium and Lower Namoi Alluvium peaked at 325 GL in 1994-1995 (NSW Office of Water, 2011). The Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources commenced in 2006 under the Water Management Act 2000 and limited extraction to 122.1 GL/yr in the Upper Namoi Alluvium and 86 GL/yr in the Lower Namoi Alluvium. With supplementary water provision, this entitlement totaled 245 GL in 2009-2010.

Changes in groundwater salinity may threaten the beneficial use of the groundwater. Even slight increases in salinity may be significant, leading to reductions in cotton crop yield if used within the first 10 weeks of growth. Understanding the cause of salinity change is vital to groundwater management in the region and must be underpinned by long-term groundwater quality monitoring.

2. STUDY AREA

2.1. Hydrogeology

The most productive aquifers are found in the Upper and Lower Namoi Alluvium, however there are also fractured rock aquifers, including the Great Artesian Basin that both outcrop and underlie the alluvial aquifers.

The main source of groundwater in the Upper and Lower Namoi Alluvium GMU's is the Gunnedah subsystem (up to 110 m thick) with yields in excess of 120 L/s (Sinclair and Barret, 2004). The Gunnedah subsystem consists of coarser grained sands and less clay content than the overlaying Narrabri subsystem (up to 40 m thick). However, there are significant clays in the lower sand unit (Gunnedah subsystem) and significant sands in the upper clay rich unit (Narrabri subsystem). In the lower Namoi, the Cubbaroo Formation (palaeochannel) (up to 60 m thick) underlies the Gunnedah Subsystem and is also highly productive (McLean, 2003).

2.2. Groundwater Salinity

The chemistry of the groundwater varies from the east (recharge zone) to the west of the catchment (discharge zone). Generally water quality varies with the aquifer laterally and vertically, deteriorating with distance from the coarser sediments of the main alluvial fan and palaeochannel (Sinclair and Barret 2004). The vast majority of the catchment contains water of marginal salinity which can be used for tolerant crops and most stock. However, the large area of alluvium between Cryon and Walgett contains mostly brackish and saline groundwater (Sinclair and Barret, 2004). Areas alongside the Namoi River have fresh water sources suitable for drinking. Initial observations of groundwater salinity after drilling are given in Figure 1. This is based on a single measurement taken at the time of drilling, which may have been 30 years ago or more.

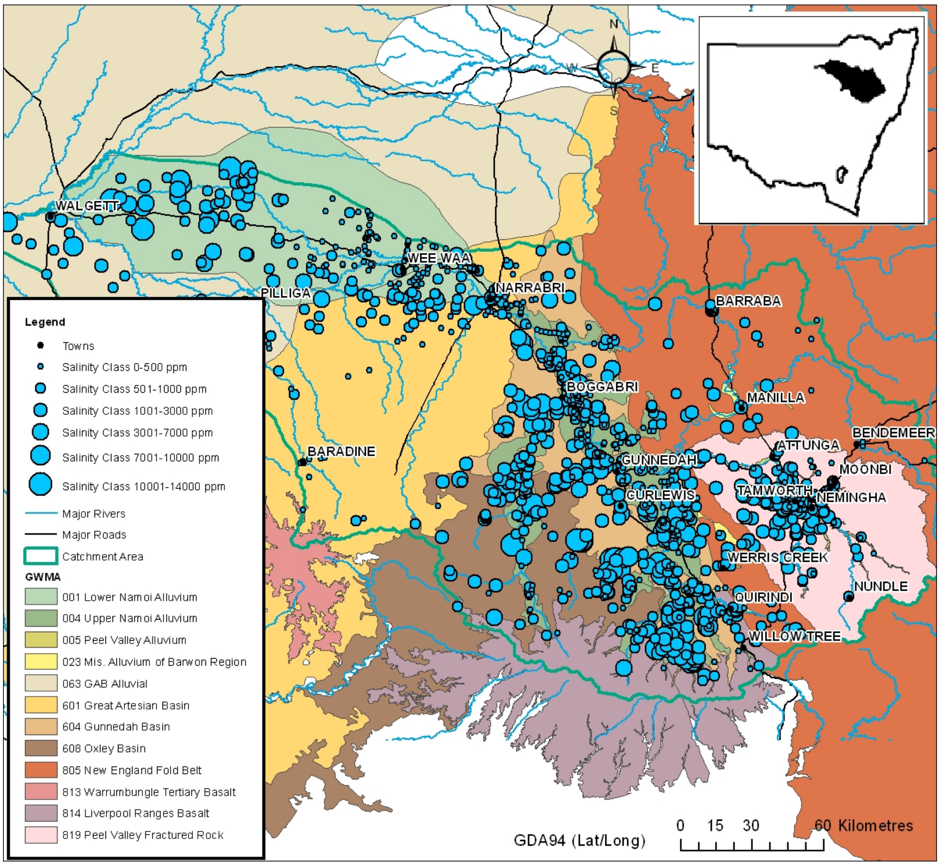

Figure 1: Groundwater Salinity Class – Initial Observation after Drilling

Higher salinity groundwater is generally found in the shallower alluvial aquifer with highly saline water found at Pine Ridge, and north of Breeza towards Pialloway and Curlewis. Groundwater measured from shallow piezometers in this catchment ranged from 600-20 000 µS/cm with no spatial trends apparent (Broughton, 1994b). Water from deeper than 30 m in this area is generally fresh with the exception of water between Pialloway and Carroll. As groundwater head is declining in this area, possible drawdown of overlying saline water into the deeper aquifer needs to be investigated.

In the Lower Namoi, bores sampled north of the Namoi River between Narrabri and Wee Waa had medium levels of salinity (280 – 800 µS/cm), whilst south of the river, the electrical conductivity of the groundwater was as high as 1463 µS/cm in some of the bores tested. Variations in salinity across the Lower Namoi were most significant laterally, rather than vertically (The & Kelly, 2009). Salinity in the shallow and deeper areas of the aquifer were comparable, however, the deeper groundwater found in the palaeochannel was significantly fresher, with the extent of the fresh water extending much further to the west than in the overlying formations.

2.3. Influences on Groundwater Salinity

Groundwater salinity is influenced by factors such as the salt store of the stratigraphy, recharge sources, groundwater extraction and mixing with saline water sources.

The potential for mixing of fresh and saline groundwaters induced by groundwater pumping is a major concern for the region. According to Kelly, et al., (2007), "only limited research has been undertaken to examine the rate at which fresh and saline waters are mixing due to pumping. Further studies are required…." During their 2003-2006 field study in the Cryon area Barret *et al.* (2006) similarly expressed concerns about mixing of saline and fresher waters jeopardising the water quality of fresh aquifers. Studies by McLean (2003) in Kelly, et al., (2007) indicate that salinity is increasing across the catchment, with increases of 100 µS/cm in the recharge zone and up to several thousand µS/cm in the western part of the catchment as a result of changes in flow paths due to pumping.

Many locations that were once gaining streams are now losing streams due to development of the groundwater resources (Kelly, et al., 2007; CSIRO, 2007; Ivkovic, et al., 2009). Prior to intensive development of the Lower Namoi Alluvium, recharge from stream losses would have been about 9 GL/yr, whilst from 1980-1998 stream loss accounted for an average of 41 GL/yr. Conversely, groundwater discharge to streams decreased from an average of 8 GL/yr to 2 GL/yr (Kelly, et al., 2007; Merrick, 2000; Merrick, 2001). The impacts of current levels of extraction on stream loss are yet to be fully realised (CSIRO, 2007). This enhanced stream loss could lead to freshening of groundwater or enhance the mobilisation of salt stores.

In the Upper Namoi Alluvium, rainfall was found to be the most significant recharge source and occasional flood events also important. Irrigation deep drainage was the second most important recharge source in several areas, whilst in others it was found to be river losses. Deep drainage is poorly quantified in most of the catchment. Stream loss may be significant on a local level. In the Lower Namoi Alluvium, there is debate as to whether occasional flood events or stream loss are the most important source of recharge (Kelly, et al., 2007). Irrigation deep drainage may also be very important. The source, quantity and flowpath of recharge will impact on the salinity of groundwater.

High soil salinity increases the risk of groundwater salinisation, as salts can be mobilised through irrigation deep drainage and recharge events. The salt store in the top 2-3 m of soil in the Namoi catchment as a relative value is given in Figure 2. This map shows that the salt store throughout most of the Upper Namoi and Lower Namoi Alluvium is either moderate or high. Most of the Lower Namoi west of Pilliga and north of Wee Waa has high salt stores, which is reflected in the groundwater salinity in these areas. There are also high salt stores in Zone 3 near Curlewis, an irrigation area. High salt stores are also found along Cox's Creek, which currently has drinking water standard groundwater, and should be regularly monitored to allow early detection and management of groundwater quality changes.

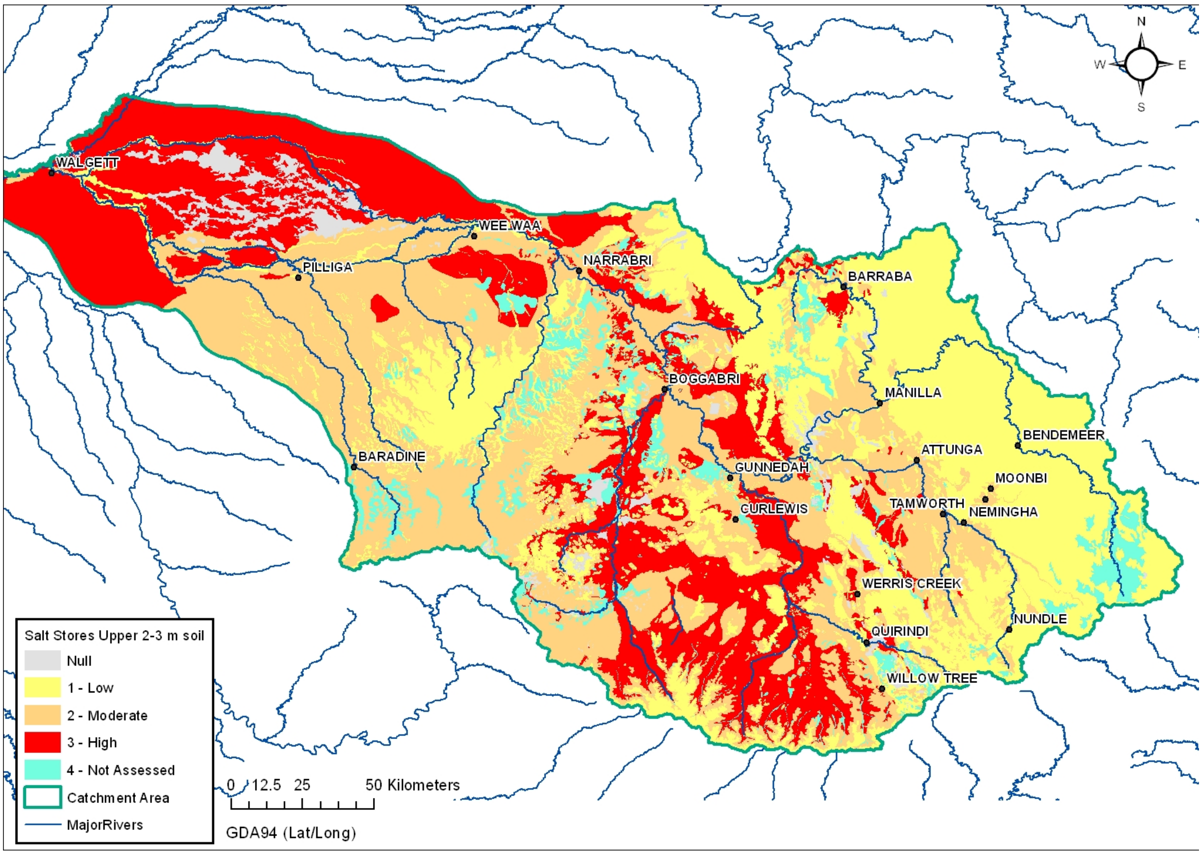

Figure 2: Salt Store in Upper 2-3 m of Soil

3. METHODOLOGY

3.1. Historical Data

All available historical groundwater level and groundwater quality data was obtained from NSW Office of Water. The NSW Office of Water maintains a network of 305 groundwater bores in the Upper Namoi and 258 in the Lower Namoi, with additional bores located in the Peel River catchment sediments. Each groundwater bore location may have a number of pipes screened at different depths. Water levels are manually measured and recorded every six weeks at the majority of sites, with a smaller number of bores further from irrigation areas monitored every 12 weeks. There is no regular monitoring of groundwater quality. Unfortunately, much of the data is incomplete – in many cases the screen depths of bores (and therefore aquifer penetrated) is unknown.

Historical data was combined with data from WRL sampling rounds for analysis of long term trends. Due to the paucity of data, a simple analysis was completed comparing the average groundwater electrical conductivity (EC) from 1980-1999 with the average groundwater electrical conductivity from 2000 – 2011 at each pipe. From this analysis, bores with EC increases greater or less than 10% were selected for more detailed study of groundwater quality and EC trends compared to groundwater levels.

3.2. Sampling

WRL completed three sampling rounds in 2009 during January, March and July with a total of 189 measurements from 50 sites. A semi-quantitative methodology was adopted to target monitoring bores. Representative bores for sampling were chosen based on coverage of groundwater management zones, data availability from previous monitoring, proximity to major groundwater extraction, proximity to river recharge sources, groundwater quality changes identified and proximity to significant salt sources.

Sampling was conducted according to standard protocols. All deep bores were purged prior to sampling and water level measurements were recorded prior to and during purging. Shallow bores were sampled using a low flow method while continuous measurements ensured no change in the standing water level (SWL) values. Field measurements of electrical conductivity (EC), dissolved oxygen (DO), acidity (pH), temperature (T), and redox (Eh) were made using calibrated water quality meters and a flow cell. Readings of field parameters were recorded after stabilising. 121 samples were analysed by Australian Laboratory Services, which are NATA accredited for major ion analysis. Standard QA/QC procedures were adopted including blind field duplicates, chilling of samples and compliance with maximum holding times. Charge balance errors of <5% indicated acceptable standard of analysis.

3.3. Streamflow Correlation

Connectivity between groundwater and surface water was investigated by correlating the cumulative streamflow departure with groundwater levels (after Blakers *et. al,* 2011). This was used to determine if surface water recharge is likely to be affecting groundwater EC.

4. RESULTS

4.1. Salinity Across the Namoi Catchment

The range of salinity of the 2009 samples across the GWMA's is shown in Table 1. The electrical conductivity of groundwater in the Upper and Lower Namoi is very varied. From the minimum EC measured in each Zone, it can be seen that high quality water exists in every zone, yet maximum EC shows there is also marginal water in most of the zones. The highest electrical conductivity measured (26 500 µS/cm) was in the Lower Namoi Alluvium, whilst in the Upper Namoi Alluvium, the highest EC measured (19 000 µS/cm) was in Zone 3 near Curlewis. Poorer quality water is found to the far west of the Lower Namoi Alluvium, but also in hotspots throughout the catchment around Curlewis (Zone 3), Zone 6, Boggabri (Zone 4) and Narrabri (Zone 5).

Table 1: WRL Monitoring EC Results Summary

GWMA	Zone	No of Samples	EC(µS/cm) Min	Max	Average
(001) Lower Namoi Alluvium		63	272	26500	2432
(004) Upper Namoi Alluvium	Zone 2	17	879	5895	3129
	Zone 3	27	736	19000	3604
	Zone 4	27	283	1850	731
	Zone 5	18	442	769	593
	Zone 6	11	818	9694	3419
	Zone 8	8	946	1117	1056
	Zone 9	7	690	1380	1012
	Zone 12	4	737	1512	1117

4.2. Groundwater Salinity Changes

Historical groundwater quality data spanning 1980 to 1999 and 2000 to 2011 was only available for

115 pipes across the catchment. The location of bores and their corresponding EC increase is displayed in Figure 3.

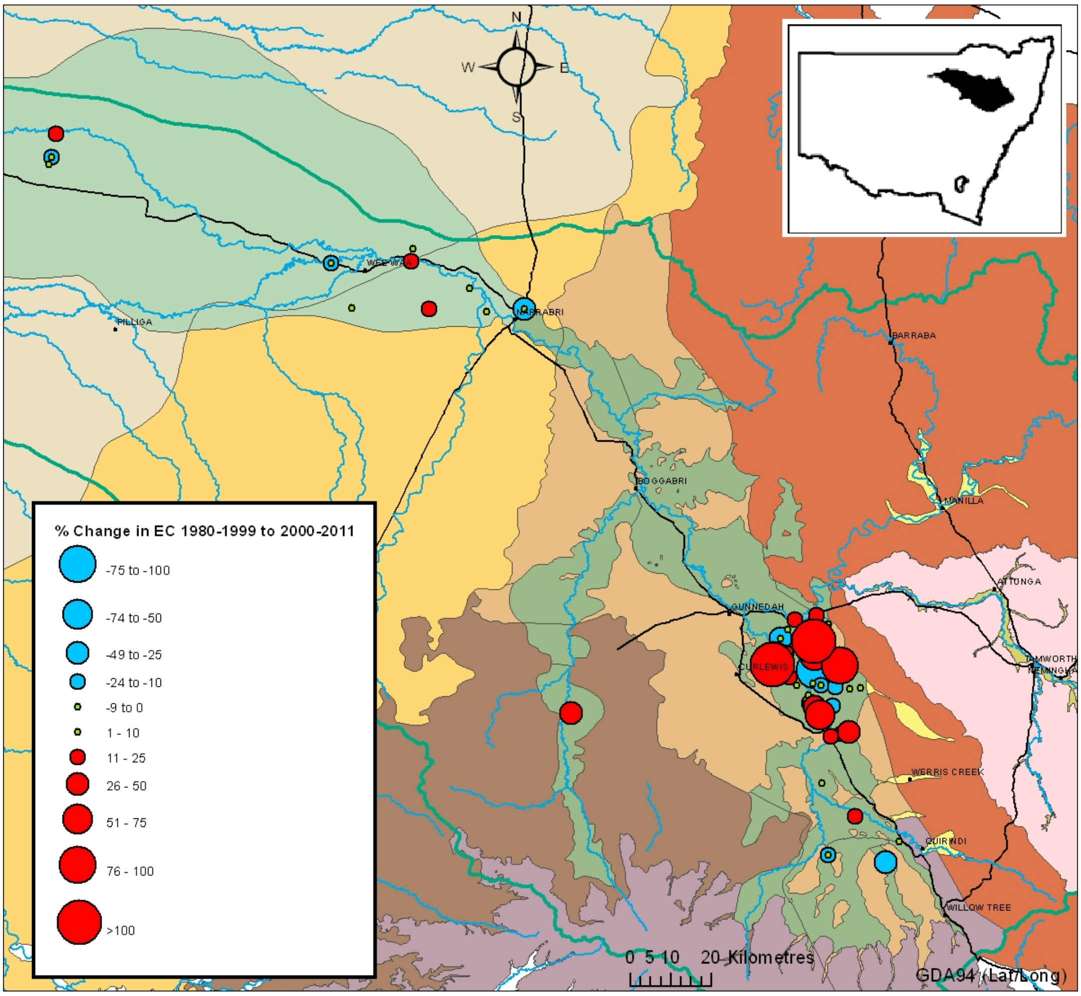

Figure 3: Change in average EC 1980-1999 to 2000-2011

Most of the available data is centred around Zone 3 (Curlewis) of the Upper Namoi. Figure 3 presents salinity increases in the Cox's Creek catchment (1 data point only) and near Curlewis (Zone 3 of the Upper Namoi). Both these areas have high salt stores (Figure 2). The largest increases occur east of the Namoi River in Zone 3 eg. average EC from 2000-2011 is 156% greater in Pipe 2 of GW036166 than the average from 1980-1999. However, bores with large salinity increases are intermingled with bores showing no real increase. In between Curlewis and the Namoi River, all bores showed some increase over this period (11-25%). This area is at major risk of salinisation.

Groundwater salinity in Lower Namoi appears to be fairly stable (where data is available). There are a few points showing some increase in salinity to the south-east of Wee Waa towards the edge of the alluvium, and to the west of Burren Junction, towards Pian Creek.

4.3. Risk of Salinisation

The influences on salinisation were investigated in more detail in Zone 3 of the Upper Namoi Alluvium near Curlewis. Figure 4 presents Zone 3 in higher resolution with salt stores overlain by salinity increase data points and streamflow correlations. No clear relationship can be seen between salt stores and salinity increases. Salinity decreases are mostly associated with positive streamflow correlations, however this is not always true (GW36266_1, GW036097_1), nor are salinity increases always associated with negative streamflow correlations (GW036130_1).

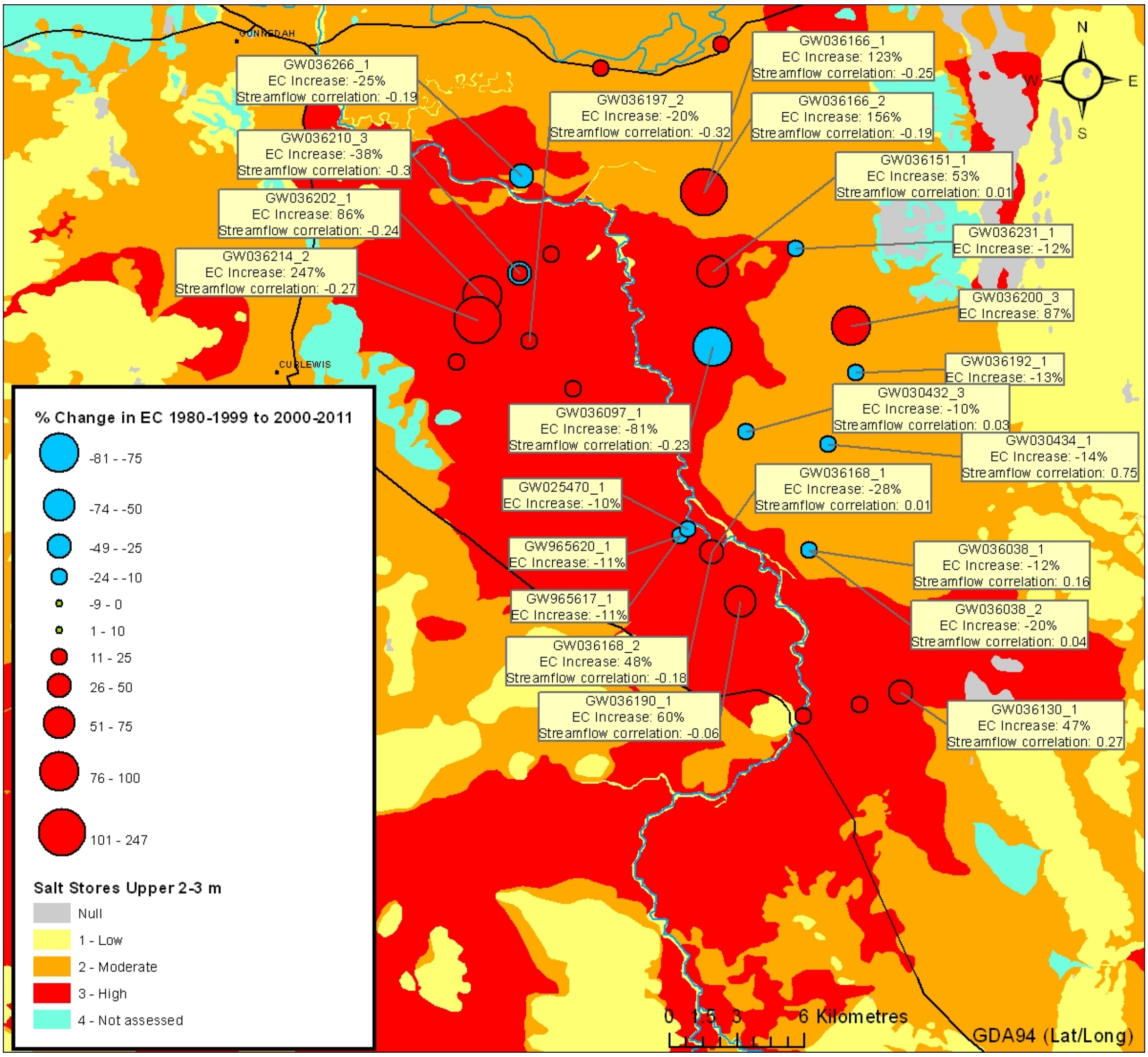

Figure 4: Salinity Increases and Influences, Zone 3 Upper Namoi Alluvium

Historical water level was compared with salinity for several bores within Zone 3 and is presented in Figure 5. At site GW036166 (Figure 5a), GW036151 (Figure 5b) GW036190 (Figure 5d) sharp increases in salinity occurred in Pipe 1 occurring from 2002, corresponding to a distinct decline in water level in the lower pipes during the drought at that time. After this time, water levels appear to stabilise at this new level and salinity starts to decline or stabilise. This pattern seems to indicate that salinity increases in this area may be associated particularly with periods of large extraction during drought periods, although there is not enough salinity data to confirm this. More frequent data has been collected from GW036166 since 2008, which demonstrates the high temporal variability of salinity at that site, and the importance of regular data gathering.

GW036200 (Figure 5c) is located further away from the river on the edge of the alluvium and is showing significantly different trends. Water levels have an overall rising trend in all pipes (~87 m and above), although water levels have been in decline since 2000. Salinity has been increasing at depth, however, while salinity increased prior to 2002 in Pipe 2 (~44 m depth) it has since decreased. The period of increasing salinity appears to be associated with increasing water levels and may be due to salts mobilising during groundwater level rise. Water levels in this bore do not show any strong pumping influence.

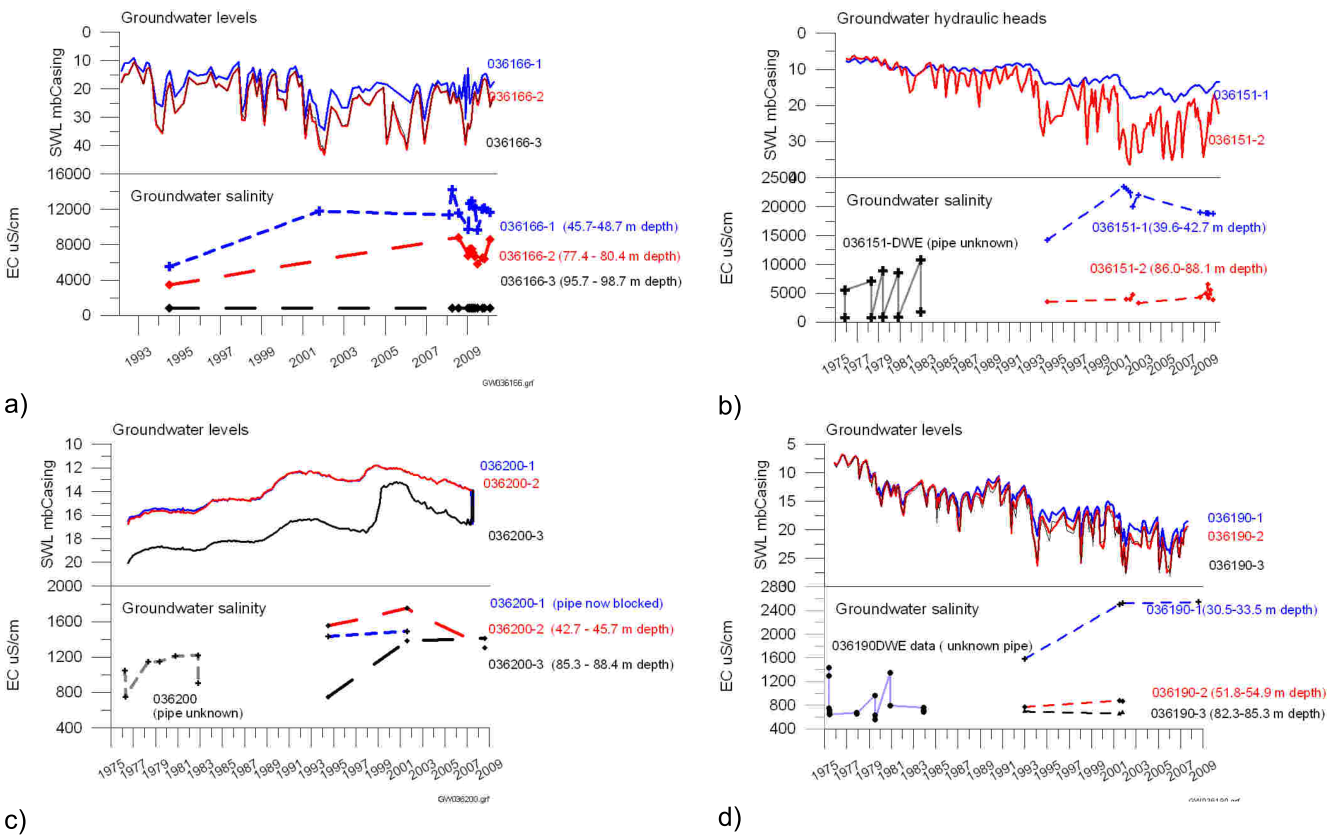

Figure 5: Groundwater Salinity compared with Groundwater levels for a) GW036166, b) GW036151, c) GW36200, and d) GW036190

5. DISCUSSION

Risk factors for groundwater in the Namoi catchment include high background salinity, proximity to salt sources, rate of groundwater extraction, irrigation intensity, soil type and distance from recharge sources. Study of salinity increase throughout the catchment is limited by lack of historical data. Salinity is highly spatially and temporally variable throughout the catchment and no single parameter can be used to determine salinisation processes. Comparing areas of salinity increase to streamflow correlation and salt stores could not clearly explain salinity increases, however limited data indicated that in some bores salinity increases are linked to periods of intense extraction when groundwater is drawn through saline aquitards. In other bores, it is likely that rising groundwater tables are mobilising salt stores. Ongoing groundwater quality monitoring with a higher frequency is required to assess the key influences on groundwater salinity. At a minimum this monitoring should include water level, EC, pH and temperature, however including major ion analysis would give a greater insight into the sources of groundwater quality change.

6. ACKNOWLEDGMENTS

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