Hydrological behaviour of a Palæochannel system under irrigation

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Introduction

Small palæochannels located in irrigated cotton fields have been identified as areas of potential high deep drainage (Triantafilis *et al.* 2003). Palæochannels, being remnants of old streams and rivers, often contain a much coarser, sandier, sediment than the surrounding heavy clays. This difference is easy to see on aerial photos and there tends to be evidence of local waterlogging (T. Richards, pers. comm.). Such observations suggest differences in hydrological behaviour between the palæochannel sediments and the surrounding clays. Other research in NSW on the hydrology of palæochannels has either mainly looked at larger and deeper palæochannels, such as the Namoi palæochannel (Young *et al.* 2002), or looked at palæochannels in the southern irrigation districts, which have a distinctly different origin and geomorphology (Young *et al.* 2002). This paper reports on the hydrological field observations as part of the project: “Geophysical and hydrological characterisation of palæochannels in Northern NSW”.

Methods

This project investigates a small palæochannel in an irrigated cotton field north of Moree. The field is located close to Carroll Creek and part of the investigations was aimed at the connection between surface and groundwater. However that part of the project, involving groundwater modelling, will be reported later.

In 2004, 6 piezometers were installed in the field (Fig 1) and 4 were later installed between the field and the Creek by the Department of Natural Resources. Four piezometers were installed within and below the palæochannel sediments as a nested set at two locations. Two further piezometers were installed outside the palæochannel sediments (Fig. 2). These initial six piezometers were instrumented using high accuracy pressure transducers which measure water heights up to 5 meters. In addition to the piezometers, which measure “free” standing groundwater, drainage meters were installed to measure water which is held by the soil. The drainage meters were nested in groups of three between 1 and 1.5 m below the surface to measure the potential gradients to allow calculations of the water flux. The drainage meters are also equipped with pressure transducers. All data were logged on 15 minute cycles using a datalogger. Because of field operations, data can only be logged during growth or fallow periods and not during periods of field operation. Regrettably, the drainage meter data is still inconclusive due to difficulties with the equipment.

On four separate occasions over the course of two years soil samples were collected to characterise the topsoil and deeper sediments inside and outside the paddock. In July 2003, 100 m transects were surveyed on the paddock. The eight transects were separated by 50 m and were adjusted so that they bisected the palæochannel (as identified from the aerial photograph) (Fig. 1). On each transect, sampling locations were 20 m apart. A tractor-mounted pneumatic push probe was used to extract 56 cores from the topsoil extending to 1.5 meters below the soil surface. The samples were bulked in 0.5 m increments and placed in plastic bags for future analysis.

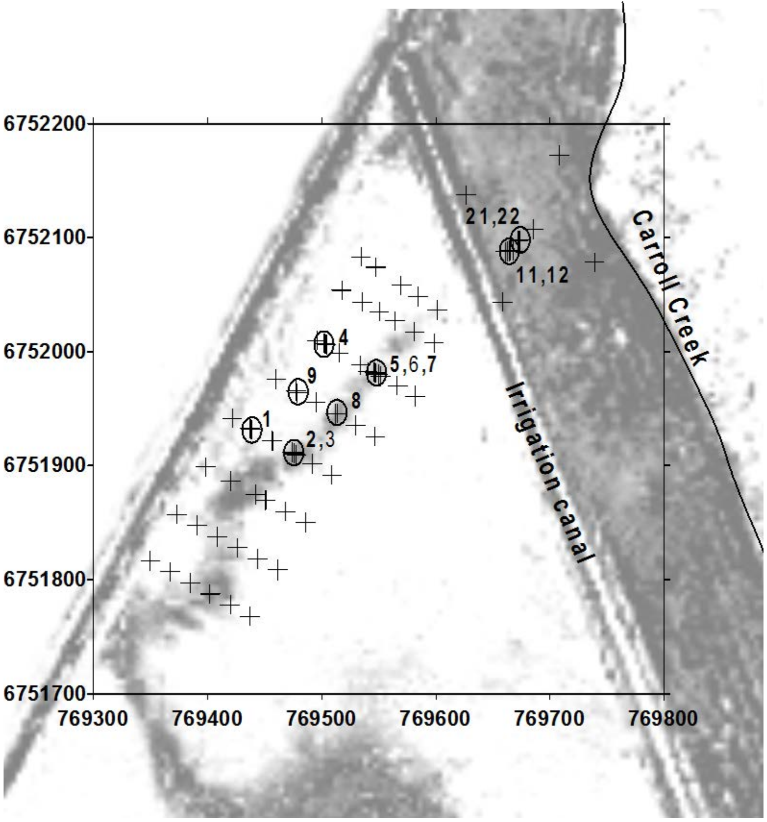

Figure 1 Sampling and well locations shown on red-band enhanced aerial photograph. Sampling locations are marked with crosses and deep cores with circles. Cores and wells are numbered, including the 6 m wells (3,6,12,22), 9 m wells (1,2,4,5) 20 m wells (11,21) and 9 m cores without wells (7,8,9). The north-east corner of the paddock is bordered by an irrigation canal. The tree-lined bank of Carroll Creek is shown in the north-east corner of the photograph.

In December 2003, transects were surveyed in a similar fashion, paralleling the irrigation canal and bisecting the palæochannel (Figure 1). Samples were taken at the beginning, end and midpoints of one transect and the beginning and ends of two transects using a hand auger. Samples were subsampled and bagged by horizon.

In May 2004, several samples were collected during the installation of the groundwater monitoring equipment. Inside the paddock, six holes were drilled to a depth of nine meters using this method with samples taken at one meter intervals. Samples were taken using a split-spoon auger. Cores were sub sampled every 15 cm and placed in sealed bags and tightly packed to maintain the core integrity. Four additional holes were drilled to approximately five to six meters below the surface to install the remaining piezometers in the palæochannel sediments.

The last sampling event took place outside the paddock in November 2004. A drill rig equipped with a 100 mm rotary drill was used to drill two holes to six meters and two holes to 20 m. Samples were taken from the ground surface in 0.5 m increments as they were brought to the surface, placed in burlap bags and transported to the laboratory for analysis.

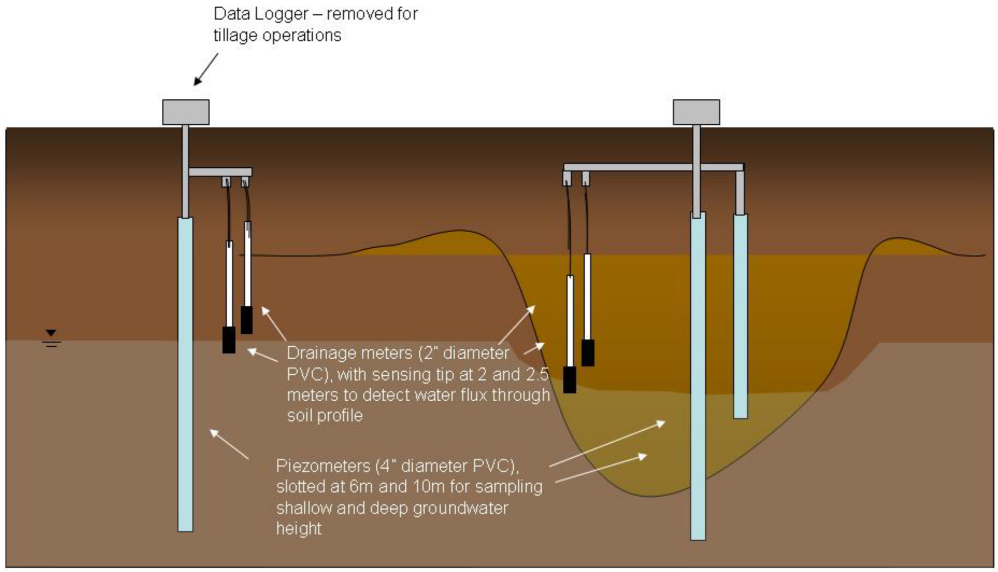

Figure 2 Detail of the instrument setup indicating the installation of the piezometers in and below the palæochannel in the field.

In the laboratory the dried samples were placed in a tumbling soil grinder and sieved to 2 mm. Particle size analysis was performed for each soil sample using the pipette method (Gee and Bauder, 1986) to determine the clay (< 2 µm), silt (2 - 20 µm), fine sand (20 - 200 µm) and coarse sand (200 - 2000 µm) fractions from a 50 g air-dried sample. The air-dried moisture content of the samples was determined by placing them in the oven at 105°C and recording the change in weight.

The electrical conductivity (EC) of each sample was determined using a 1:5 soil to water suspension. The soluble chloride was extracted using a different 1:5 soil to water suspension. After spinning the sample at 20000 rpm's for 20 minutes to settle the soil colloids (Diamond, 2001), the sample was decanted. The extract was then mixed with mercuric thiocyanate and analysed colourmetrically using a FOSS FIAstar 5000 flow injection analyser (ESS Method 140.4).

Results

Soil

Over the site, the average topsoil (<1.5 m) clay content ranged from 27 to 58%, with significantly lower clay contents above the palæochannel (Figure 3). Although it was assumed that the area nearest the stream would contain coarser-textured topsoil sediments (due to sediment transport during overbank conditions), there was no significant difference between the amount of clay inside and outside the paddock.

As expected, the clay content varied considerably with depth, particularly in cores lying in the palæochannel. Cores taken from inside the channel had significantly less clay than those outside the channel ($p < 0.001$). Although the clay content abruptly decreased in all wells located inside the palæochannel, there was a considerable amount of variability in clay content due to the stratigraphy of the channel (Figure 4).

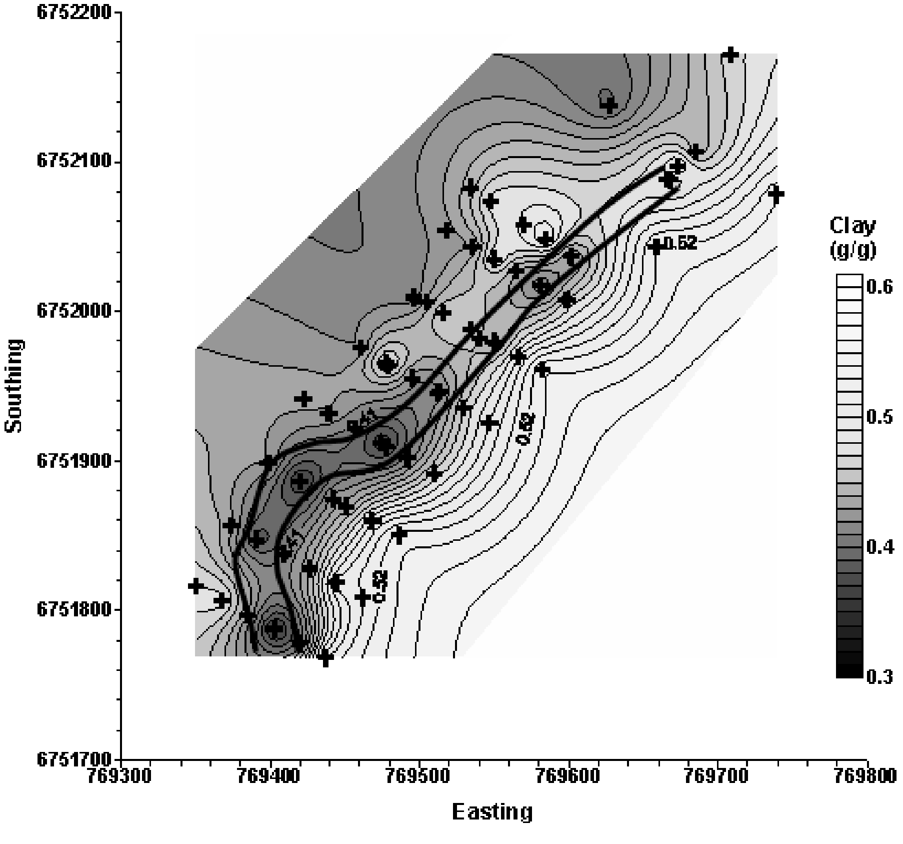

Figure 3 Interpolated average clay content for topsoil samples (<1.5 m) using ordinary kriging. Sampled locations are indicated with crosses. Clay contents within the channel (black lines indicating the channel as identified from the aerial photograph) were significantly less than outside the channel (p=0.0007)

A complex stratigraphy was observed based on the soil properties and profile descriptions from the cores taken at the site. Redoximorphic features, such as partially-indurated iron concretions and Mn nodules were observed in many of the soil profiles, but were particularly prevalent in the partially reduced clays beneath the palæochannel sediments.

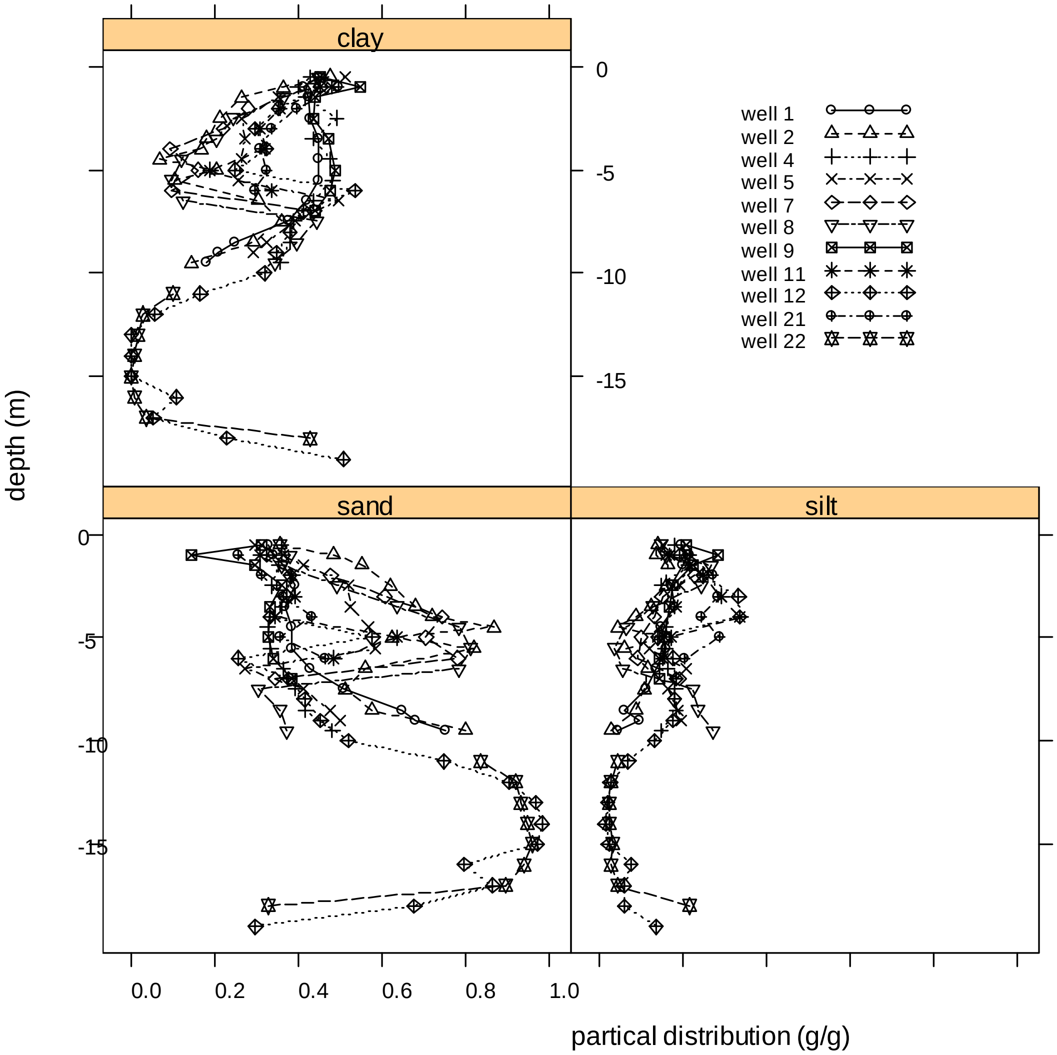

Figure 4 Clay silt and sand content (g g^{-1}) variation with depth z (m below the surface) is shown for each well in the study site. The plot clearly shows the dramatic reduction in clay content in wells 2, 5, 7, 8, 11, 12, 21, 22 located in the palæochannel from 2 to 6m below the surface, and a second from 10 to 18 m below the surface. These correspond to the palæochannel unit and the unconfined aquifer below believed to be the Narrabri Formation.

Geomorphic features such as pockets of gravel, sand stringers, and clay lenses were common in all of the cores within the channel (i.e. Stannard and Kelly 1968). In all cores, a large deposit of fine sand was deposited on the top of the channel, suggesting a significant amount of deposition coinciding with the termination of the stream flow (Butler 1950; Schumm 1968).

Although the clay content was similar in adjacent holes (Figure 4), the reduced nature of the sediment under the palæochannel suggests that the layer had been saturated for extended periods of time. Because soil hydraulic conductivity is strongly affected by the particle size distribution of the soil (Schaap *et al.* 1998), changes in these properties across the topsoil and with depth will affect infiltration rates, perched water tables, and lateral flow through the area.

A deposit of coarse gravel appeared around 9 m below the surface in most cores (Figure 4). This gravel is thought to form the top of the Narrabri formation, an unconfined aquifer which extends through much of the Gwydir and Namoi Valleys (Vervoort and Annen 2006). The 20 m cores outside of the paddock revealed that the deposit was 8 to 9 meters thick and rested on top of heavy clays (Figure 4). At the time of drilling the water in these wells rose to 14.9 m below the surface and has fluctuated several meters since. However a pressure transducer has only recently been installed in these bores.

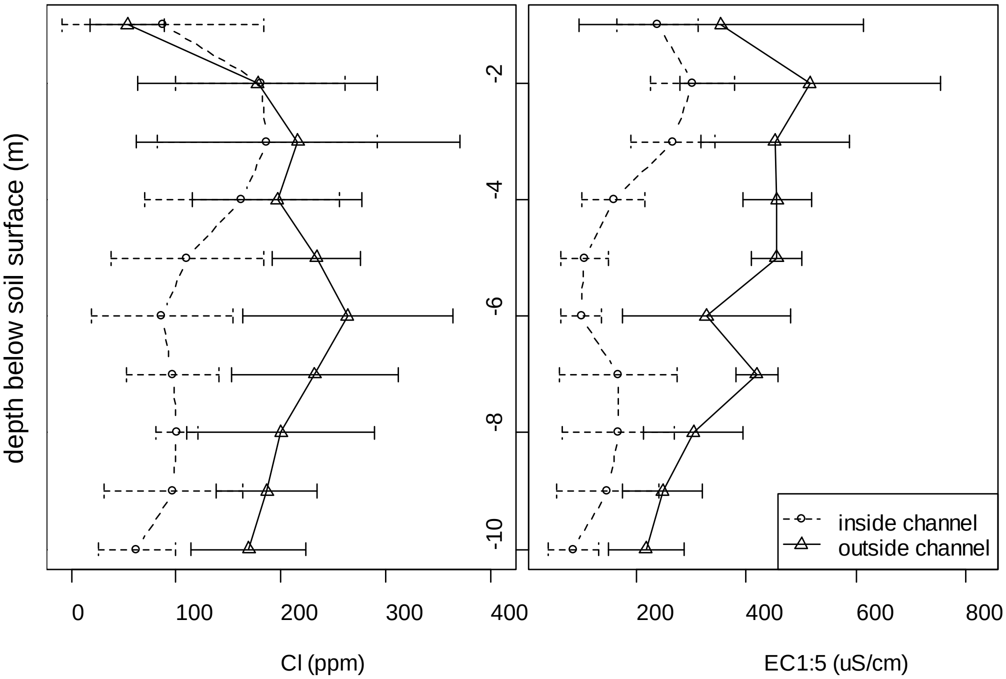

Figure 5 Profiles of Chloride and $EC_{1:5}$ compared for profiles within and outside of the palæochannel. Both profiles show significant reductions in the mobile ions, which may reflect preferential leaching due to the coarseness of the palæochannel sediments.

Overall, the soil property results indicate that there is a potential area of higher leaching and probably higher hydraulic conductivities above and in the palæochannel. For example there is a distinct decrease in Cl contents and EC values inside and below the palæochannel sediments compared to outside the palæochannel (Figure 5). A decrease in these mobile ions is related to higher leaching volumes, as predicted by mass balance models.

Groundwater

Groundwater behaviour was only observed for a short time period due to the difficulties with instrumentation. However, several months of data were collected earlier this year and this reveals some interesting groundwater responses. For example, the piezometer data (Figure 6) indicates a very rapid and distinct response to irrigation in and below the palæochannel. All piezometers have between 1 and 2 m of water, which means that there is a separate perched water table in the palæochannel (well 3) and another water table at a deeper level (well 2 & 4).

Some of the observed water level rises in the piezometers could be due to overburden pressures. This is the weight of the saturated soil and clays bearing down on the underlying clays and pushing the water into the piezometer. A “back of the envelope” calculation indicates that the weight of overburden of fully saturated and plastic clays with a bulkdensity of 1.4 to 9 m would translate to 16 m of water pressure. In practice, part of the weight of overburden would be born by sand grains in the profile, which are inelastic. Additionally, there is a dampened response to irrigation in the clay outside the palæochannel (well 4), which would be subjected to similar overburden pressures. This seems to indicate that palæochannels preferentially transport subsurface water. In addition, an observed slowly rising trend in water levels in the piezometers over the season indicates that there an increasing level of saturation at the site.

The general trend in the piezometer levels of well 2 and 3 can be used to estimate the amount of leakage occurring into the channel system. Using basic linear regression and multiplying the slope by the number of days, we find a rough estimate of 629 mm for well 2 and 390 mm for well 3. The lower deep drainage value based on well 3 is probably due to leakage from the perched water table to the lower lying water table. Such levels of deep drainage are clearly at the higher end of the scale. It needs to be pointed out that this water loss is local in and around the palaeochannel, and that the piezometer outside the channel gives no indication of a significant trend. Thus if the palaeochannel covers 5% of the paddock and the deep drainage under the rest of the paddock is possibly 50 mm, than the overall deep drainage on the paddock would be $0.05 \times 629 + 0.95 \times 50 = 79$ mm. Clearly, the palæochannel has a major influence on this overall deep drainage value (about 45%), despite its small area coverage. This data is also just a snapshot observation over about 105 days. Continued monitoring would allow developing detail in these numbers, and allow extension to annual values.

Conclusions

The limited field data presented in this paper confirm that palæochannels are areas of increased leaching and deep drainage. Although similar observations have been made based on ancillary data such as electromagnetic induction (Triantafilis *et al.* 2003;

Vervoort and Annen 2006) or soil surveys (Stannard and Kelly 1968), this is the first step in the quantification of the transported water. The simple calculations presented indicate that palæochannels may play an even more significant role than was previously thought. This means that management of irrigation in areas which include smaller palaeochannels should concentrate on excluding them from rotation, converting them to dryland crops, or using irrigation techniques which are not as highly dependent on the infiltration characteristics of the soil (such as overhead or drip irrigation).

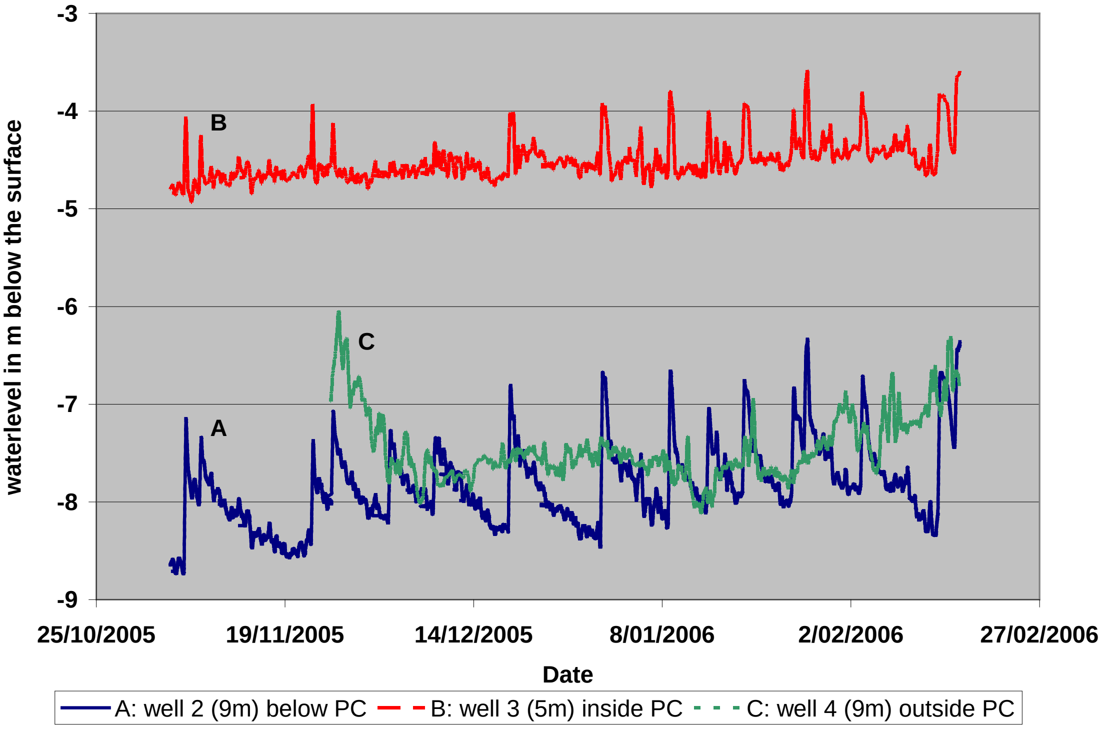

Figure 6 Water levels in piezometers at the Palæochannel project site. Note the rapid response to irrigation and rainfall events and the slowly rising trend over the irrigation season. Well 2 (A) is located below the inferred palæochannel at 9 m depth, while well 3 (B) is located within the palæochannel sediments at 5 m depth. Well 4 (C) is located at 9 m depth away from the palæochannel in the surrounding clays.

Acknowledgements

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