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LOWER RIVER MURRAY WEIR POOL RAISING 2005–06: GROUNDWATER COMPONENT

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EXECUTIVE SUMMARY

Starting in September 2005 and lasting for two months, the levels of Locks 5 and 6 were raised enabling a series of ecological and physical responses to be assessed. The physical and ecological monitoring of weir manipulation trials in the Lock 5 to 7 reach of the River Murray is a part of The Living Murray Implementation Program project 'Improving management of the Lower River Murray by weir manipulation'. The impact of this rise in weir pool level on the rivers littoral and floodplain vegetation, biofilms, within channel fish larvae and groundwater were monitored. This report details investigations surrounding the impact of weir pool raising on floodplain groundwater. The aims of this investigation were to examine the response of floodplain groundwater level and assess any changes in groundwater salinity resulting from raised weir pool levels. It is anticipated that the data collected in this monitoring program will be used to facilitate improvements in future weir management in a way that improves the health of the river channel, wetland and floodplain environments.

Statistical analysis using the Hodrick-Prescott filter and Cochrane-Orcutt estimation on logged time series data was used to investigate a relationship between river height and groundwater level. The smoothed Hodrick-Prescott filters indicated a strong positive relationship between the river and groundwater time series datasets. Cochrane-Orcutt estimation revealed that a rise in floodplain groundwater was related to a rise in river level on either the same or previous day, indicating a good hydraulic connection between the river and floodplain aquifer.

However, the sparse nature of the salinity data precluded sound conclusions being drawn on the impacts of weir manipulation on floodplain groundwater salinity. Generally little change in floodplain groundwater salinity was recorded during this weir pool raising, as the salinity monitoring was not sufficient to provide a clear indication of the effect of weir pool raising on floodplain groundwater salinity. Nonetheless, it was evident that salinity response is complex and varied between floodplains and over time. This varied response may make it difficult to devise general management guidelines that may be adopted across the Lower River Murray floodplain as a whole. The data collected could not determine whether or not the raised groundwater levels and changes in salinity caused any environmental benefits or harm, a relevant issue but beyond the scope of the investigation.

The project was hampered by the short lead-time in which to design and implement the investigation prior to weir pool raising. If the impact of weir pool raising on floodplain groundwater processes is to be comprehensively addressed in future, an event ready monitoring program needs to be designed and established prior to any future raisings.

WEIR POOL MANIPULATION PROGRAM

The ecological and physical monitoring of weir manipulation trials in the Lock 5 to 7 reach of the River Murray is a part of The Living Murray intervention monitoring project 'Monitoring weir pool manipulation of the River Murray in South Australia'. The data collected in this monitoring program will be used to inform future weir management in a way that improves the health of the river channel, wetland and floodplain environments.

Seasonal variation in the water level of the Lower Murray has dramatically reduced due to river regulation. Reduced variability has resulted in the disconnection of the river from its floodplain and has significantly altered the ecology of the region (Holland 2002). It is predicted that the introduction of a more variable water level regime in the lower River Murray through the manipulation of weir heights will, on a scale limited to the area inundated and the distance to which groundwater will be influenced, have significant influences on the health of the River Murray environment.

Existing weir structures can be used to raise and lower water levels in a weir pool to produce a more variable water level regime and to influence the extent of inundation of the adjacent floodplain and wetlands. It is predicted that a lowering or raising of 50 cm will be the range in which the 'regular' weir pool can be managed due to the physical structure of the existing weirs. It is predicted that manipulating weir pools will enable greater benefit to be derived from current flows by optimising the depth and duration of flow events.

Starting in September 2005, the levels of Locks 5 and 6 were raised enabling a series of ecological and physical factors to be assessed. The impact of this rise in weir pool level on the rivers littoral and floodplain vegetation (including river red gum and lignum), biofilms, within channel fish larvae and groundwater were monitored. Each of these components will be reported with this report detailing investigations surrounding the impact of weir pool raising on floodplain groundwater.

GROUNDWATER MONITORING

The aims of this investigation were to model the response of floodplain groundwater level and assess any changes in groundwater salinity resulting from raised weir pool levels. In the weir pool raising trial of 2000, Jolly (2001) found that floodplain groundwater levels rose in response to rising lock levels. In areas close to the river and its anabranches where there was good hydraulic connection, groundwater salinity was lowered in the short term by raising lock levels. This investigation of groundwater depth and salinity was designed similar to that conducted by Jolly (2001) but incorporating and broader range of investigation sites.

METHODS

With the intention to monitor groundwater response at a number of floodplain sites between Locks 5 and 6, initial water level data were measured in 32 piezometers at 7 different floodplain sites on September 15, 2005 (Fig. 1; Table 1). Bailed or pumped water samples were also collected for salinity measurement on this date for 20 of the 32 wells, however initial water samples were not collected at the Templeton observation wells until the subsequent monitoring on September 27, 2005. Groundwater samples were collected after 3 well volumes had been purged. For the low yielding observation wells, the water column was bailed dry, with samples taken from the subsequent refill. Salinities are presented as electrical conductivity (EC) with units of µS/cm.

A number of the piezometers became unsuitable for continued monitoring over the course of the weir pool manipulation, primarily due to floodplain inaccessibility as a result of inundation. Rainfall also hampered accessibility on occasions. As a result, irregular and opportune manual monitoring occurred only for those accessible sites, with manual readings occurring at approximately fortnightly intervals.

To enhance the data collection, 14 water level loggers were installed across a number of the sites (Table 1). Ten loggers were installed on October 19, 2005 and the remaining four were installed on November 16, 2005. The manual recording of water levels continued at a reduced frequency. Data loggers were removed for downloading and analysis on January 20, 2006 after river height had returned to normal operating level. Five of the installed loggers either malfunctioned or returned erroneous results. Consequently, nine loggers generated valid data, of which seven had a sufficient recording period for statistical analysis (October 20, 2005 – January 20, 2006). These seven groundwater time series datasets were used to investigate the impact of river height on groundwater level.

Manual and logger data are presented using Australian Height Datum (AHD) for wells where surveyed elevation data were available. To maintain consistency where possible, reduced standing groundwater levels (RSWL) and river levels are presented on the same scale. Where elevation data was not available, groundwater levels were presented as standing water levels on the same vertical scale extent as river level.

Daily River Murray flow data (upstream of Lock 5 and downstream and upstream of Lock 6) was downloaded from DWLBC surface water archive website (http://e-nrims.dwlbc.sa.gov.au/swa/) (Fig. 2).

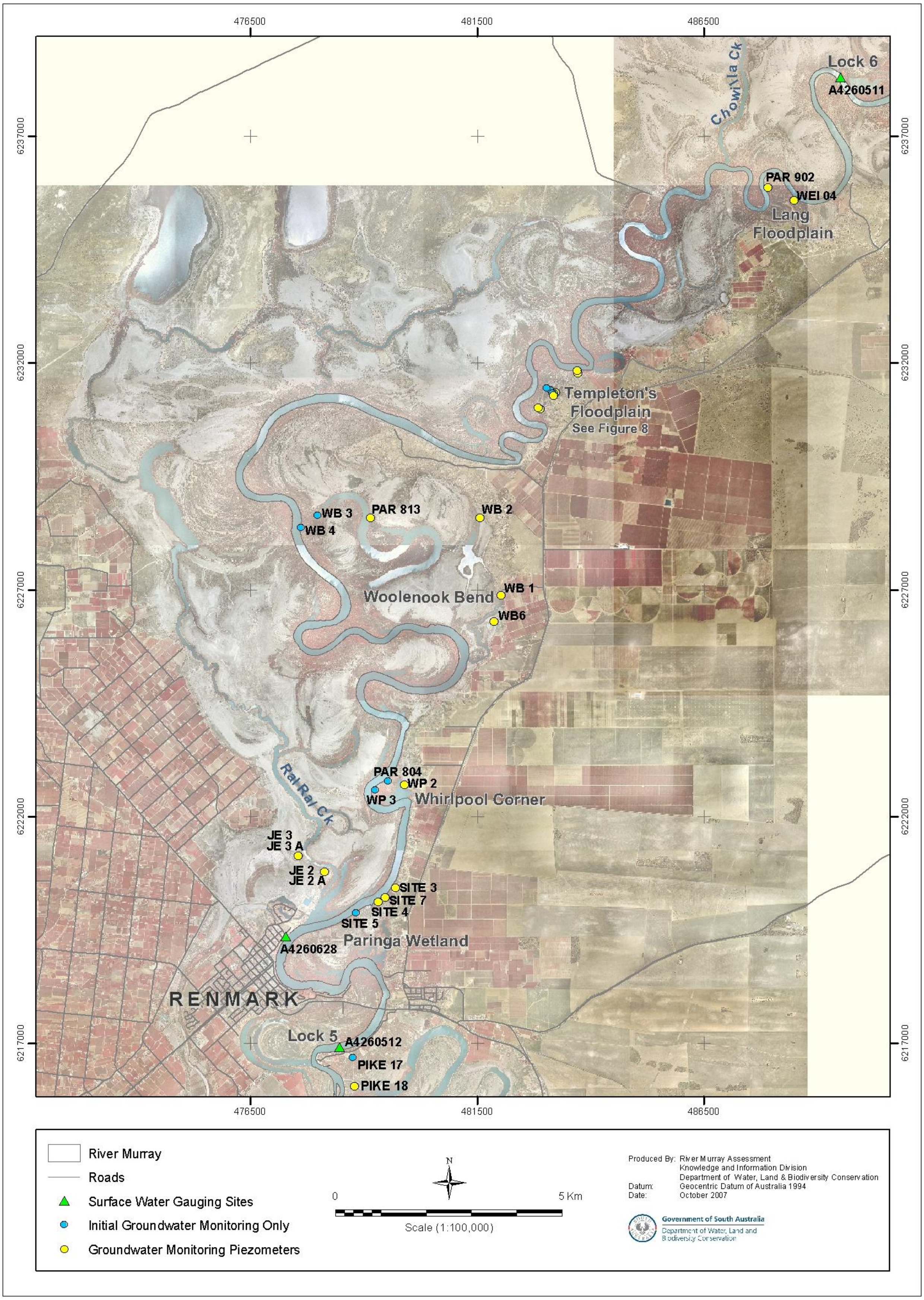

Figure 1. Location plan of observation piezometers

Table 1. Summary of groundwater monitoring program

Floodplain Site	Name	Unit No.	Accessible	Logger Data
Lang	WEI03	7029 2086	Yes	Yes
Lang	PAR 902	7029 1621	Yes	Yes
Templeton's	A2	7029 1453	Yes	Yes
Templeton's	A3	7029 1454	Yes	Yes
Templeton's	T1	7029 1815	Yes	~~Yes~~ *
Templeton's	T2	7029 1816	No	No
Templeton's	T3	7029 1817	No	No
Templeton's	T4	7029 1818	No	No
Templeton's	B1	7029 1457	Yes	Yes
Templeton's	B2	7029 1458	No	No
Templeton's	B3	7029 1459	No	No
Templeton's	C1	7029 1460	Yes	Yes
Templeton's	C2	7029 1461	Yes	Yes
Woolenook	PAR 813	7029 1620	Yes	~~Yes~~ #
Woolenook	WB1	7029 1823	Yes	~~Yes~~ #
Woolenook	WB2	7029 1824	Yes	No
Woolenook	WB3	7029 1825	No	No
Woolenook	WB4	7029 1826	No	No
Woolenook	WB6	7029 1828	Yes	~~Yes~~ #
Whirlpool Corner	PAR804	7029 1616	No	No
Whirlpool Corner	WP2	7029 1830	Yes	Yes
Whirlpool Corner	WP3	7029 1831	No	No
Paringa Wetland	SITE 3	7029 2064	Yes	No
Paringa Wetland	SITE 4	7029 2065	Yes	~~Yes~~ *
Paringa Wetland	SITE 5	7029 2066	No	No
Paringa Wetland	SITE 7	7029 2068	Yes	~~Yes~~ #
Ral Ral Creek	JE2	7029 1048	Yes	No
Ral Ral Creek	JE2A	7029 1049	Yes	No
Ral Ral Creek	JE3	7029 1050	Yes	No
Ral Ral Creek	JE3A	7029 1051	Yes	No
Lock 5	PIKE 17	7029 1200	Yes (blocked)	No
Lock 5	PIKE 18	7029 1201	Yes	No

* Logger malfunction, no data; # Insufficient or no data

DATA ANALYSIS

Statistical analysis of the relationship between river height and floodplain groundwater level was undertaken using logged data. As the manually recorded data was sampled with low and irregular frequency, it was excluded from detailed analysis but used to confirm the logged data. The impacts of weir pool raising on groundwater salinity are briefly discussed but detailed analysis was not possible due to the inopportune timing and low frequency at which salinity data was collected.

HODRICK-PRESCOTT FILTER (HP FILTER)

Logged river and groundwater level time series data were subjected to an HP filter to decompose trend (smoothed) and cycle (irregular) according to equation (1) (Hodrick and Prescott 1981)

$$X_t = m_t + c_t,\quad t=1,\ldots,T. \qquad (1)$$

Where: X_t is the time series of interest at time t, m_t is the long-term trend and c_t is the irregular cycle. The smoothed time series were analysed to identify if there was any impact of river height on groundwater tables at the observation sites.

COCHRANE-ORCUTT ESTIMATION

The Cochrane-Orcutt estimation technique (Cochrane and Orcutt, 1949) was used to establish the causal relationship between river level and floodplain groundwater level. Cochrane-Orcutt estimation is a statistical method for estimating a time series linear regression in the presence of autocorrelated errors. This method corrects for statistical problems caused due to correlated error terms or serial correlations. The Cochrane-Orcutt method is well known in the econometrics literature, but has not been widely appreciated outside this field (Thejill and Schmith, 2005). A brief description of the procedure is presented below.

Consider the model

$$y_t = \beta + X_t\gamma + \varepsilon_t \qquad (2)$$

where y_t is the time series of interest at time t, β is the intercept, X_t is a matrix of explanatory variables, γ is a vector of coefficients, and ε_t is the error term. The error term can be serially correlated over time:

$$\varepsilon_t = \rho\varepsilon_{t-1} + e_t.\ |\rho| < 1 \qquad (3)$$

The Cochrane-Orcutt procedure transforms the model:

$$y_t - \rho y_{t-1} = \beta(1 - \rho) + \gamma\,(X_t - \rho X_{t-1}) + e_t \qquad (4)$$

Then the sum of squared residuals is minimised with respect to (β, γ), conditional on ρ (until estimates of ρ have converged satisfactorily).

Using the final estimate of ρ, an estimate of the covariance matrix of the errors can be constructed, and by applying Generalised Least Squares an efficient estimate of β can be made. Transformed residuals, R^2 and the covariance matrix of the estimate of β can also be calculated.

Explanatory variables were tested against river level time series immediately upstream and downstream of Lock 6 and upstream of Lock 5. These time series data were also assessed with a one day lag.

RESULTS AND DISCUSSION

Rainfall in the Victorian and New South Wales catchments of the River Murray between August and November 2005 led to South Australia receiving above entitlement flows through September to December in 2005, with a peak flow of 15 100 ML/d occurring on November 12, 2005. This compared to the 2000 peak event of 42 300 ML/d. The weir pool raising trial was conducted at Lock 5 starting on September 18, 2005. By October 5, 2005, the water level at Lock 5 had reached a height of 16.8 m (AHD). The increased water level (0.46 m) was maintained for over two months until December 16, 2005 when the normal operational level was resumed. On January 8, 2006, water level at Lock 5 returned to the original height of 16.36 m. The trial took a total of 110 days including 17 days of water level raising, 72 days of high water level, and 21 days of water level recession (Fig. 2).

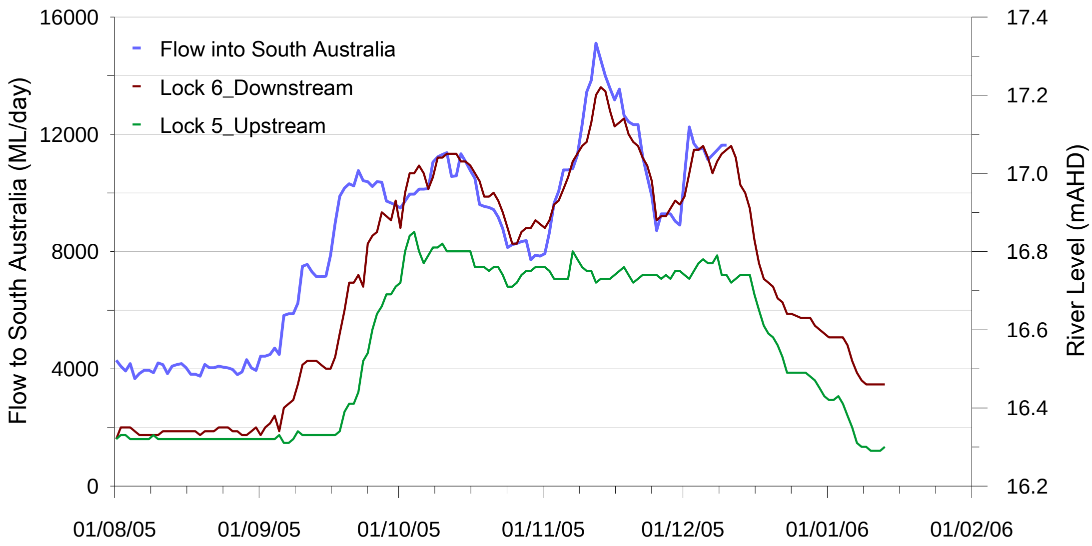

Figure 2. Flow into South Australia and levels recorded at Lock 5 and Lock 6

IMPACTS OF RIVER HEIGHT ON GROUNDWATER LEVEL

The smoothed filters of river height and groundwater level (trends) using the Hodrick-Prescott filter were comparable, indicating a strong relationship between the two sets of time series data (Figs 3, 4).

As the loggers were installed on October 19, 2005, one month after weir raising began and when river height was at its peak, the raising phase of the operation could not be depicted. However, the manually monitored data confirmed that the groundwater levels were initially lower in all wells, indicating that groundwater tables rose in response to heightened river levels.

Despite the short-term nature of the data, the smoothing procedure produced clear graphs showing the concurrent fluctuations of river height and groundwater level, although some lags were noticeable. As all test wells were with relatively close proximity (30 m to 400 m) to the main channel or connected backwater, the relationship between surface water and groundwater can be explained by the dynamic equilibrium between the river and aquifer, which is controlled by the pressure head between the groundwater and the surface water.

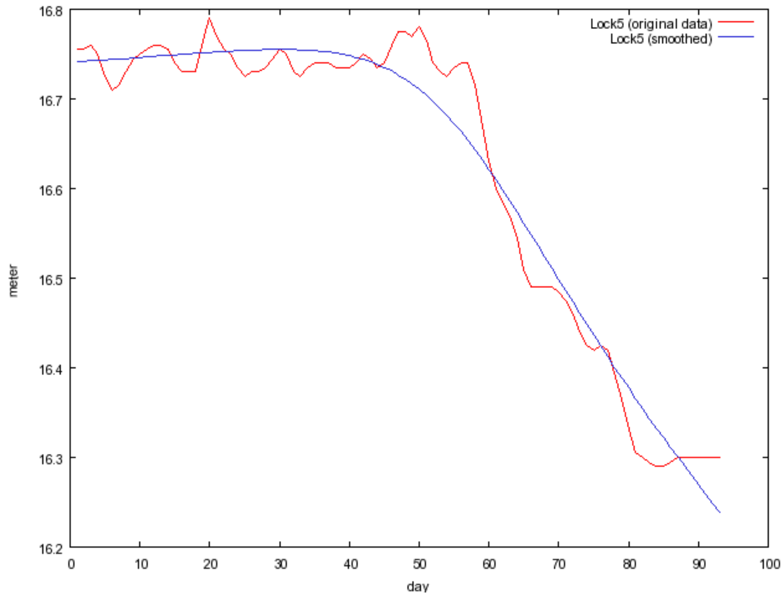

Figure 3a. **Raw and smooth trend HP filtered river level data (m AHD) upstream of Lock 5**

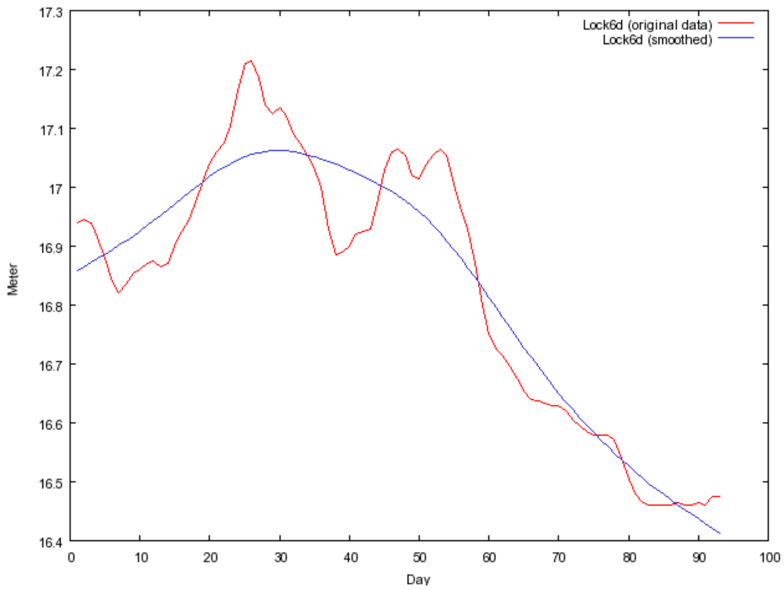

Figure 3b. **Raw and smooth trend HP filtered river level data (m AHD) downstream of Lock 6**

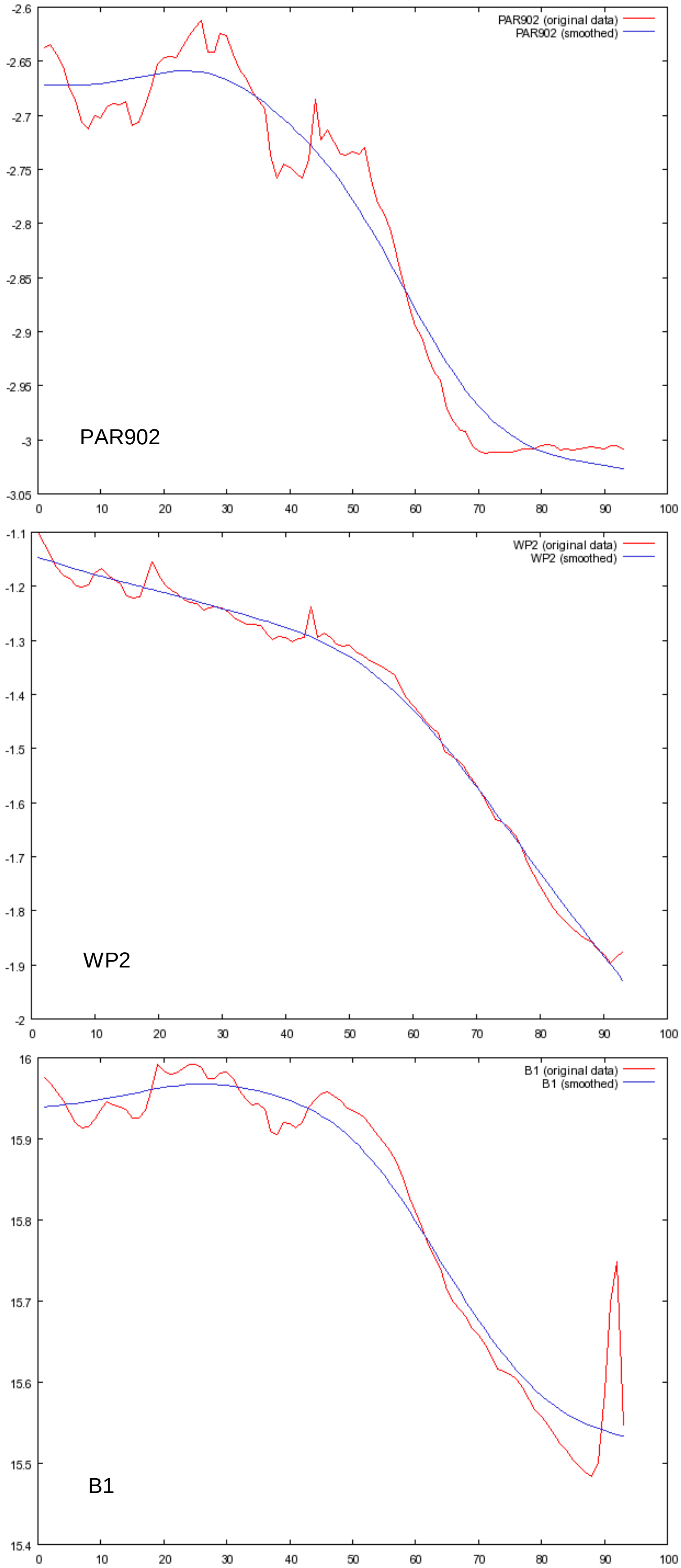

Figure 4a. Daily groundwater observation levels (SWL) for raw and smooth trend HP filtered data. B1 presented in m AHD. x-axis, water level; y-axis, day

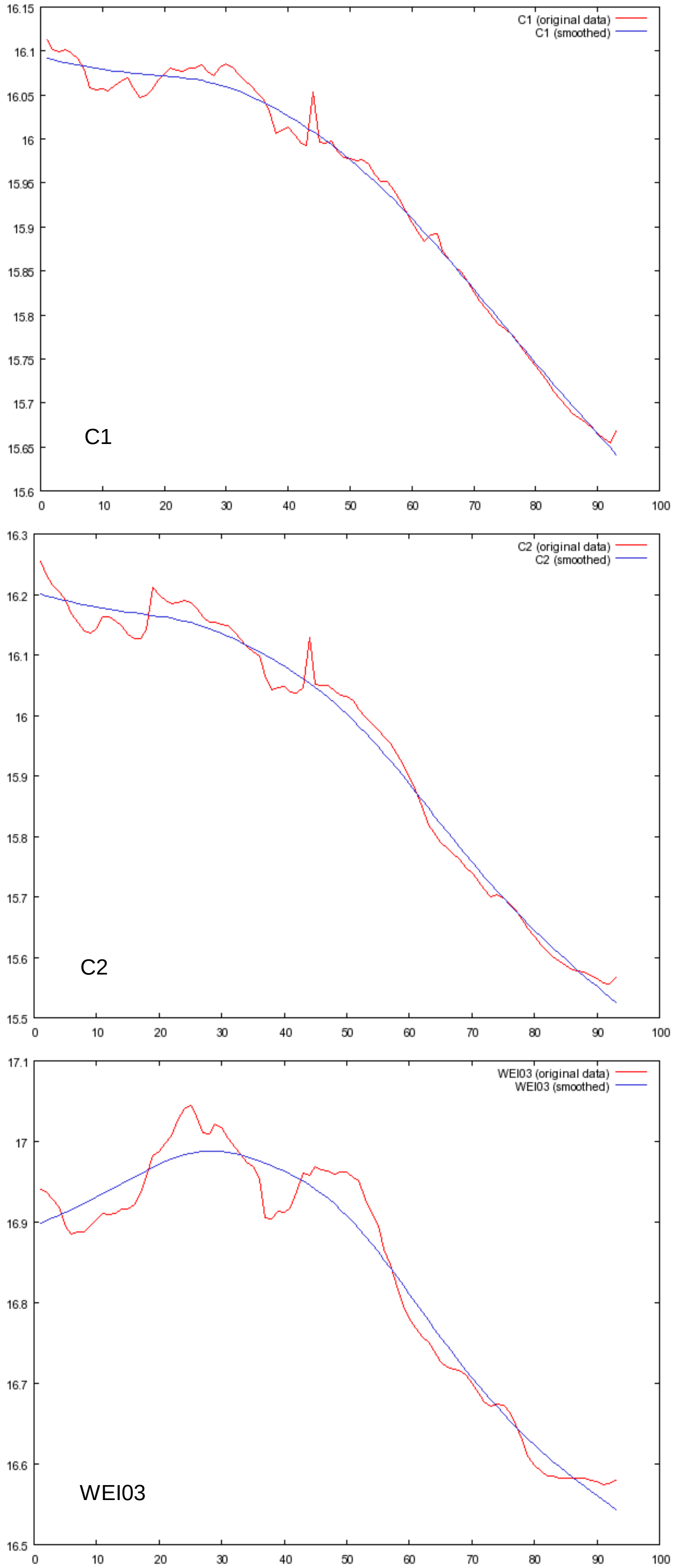

Figure 4b. Daily groundwater observation levels (m AHD) for raw and smooth trend HP filtered data. x-axis, water level; y-axis, day

Lang Floodplain

Two observation wells, PAR902 and WEI03, were monitored on the Lang Floodplain, which is located ~5 km downstream of Lock 6. Test well PAR 902 was dry at the beginning and end of the raising trial but meaningful data was captured during the periods of elevated river levels. Logger data for PAR 902 displayed a flattening out in level prior to the full recession of river level, indicating the level at which the test well ran dry (Fig. 5). The flattening out of groundwater level in test well WEI03 at the end of the data period was in response to a flat (steady) period observed in the river level data downstream of Lock 6 (Fig. 5).

The best-fit Cochrane-Orcutt model for the data from well WEI03 used 91 records, with independent variables of river level downstream of Lock 6 at day t (X_t) and day t-1 (X_{t-1}), was very accurate explaining 99.7% of the variation in groundwater level (Fig. 6; Table 2). Groundwater level was dependent on the river height downstream of Lock 6 on the same and previous days. The best model Cochrane-Orcutt model for well PAR 902 used 92 records, with independent variables of river level downstream of Lock 6 at day t (X_t), explaining 99.4% of the variation in groundwater level (Fig. 7; Table 3). Groundwater level was significantly associated with the river height downstream of Lock 6 on the same day. In contrast to WEI03, the one-day time lag was insignificant ($p = 0.38$, for variable X_{t-1}).

For the Lang floodplain, the river level downstream of Lock 6 provided the best model of groundwater level as it produced better results than river level upstream of Lock 5 and the river level upstream of Lock 6. This was not unexpected given the floodplain was located only 5 km downstream of Lock 6.

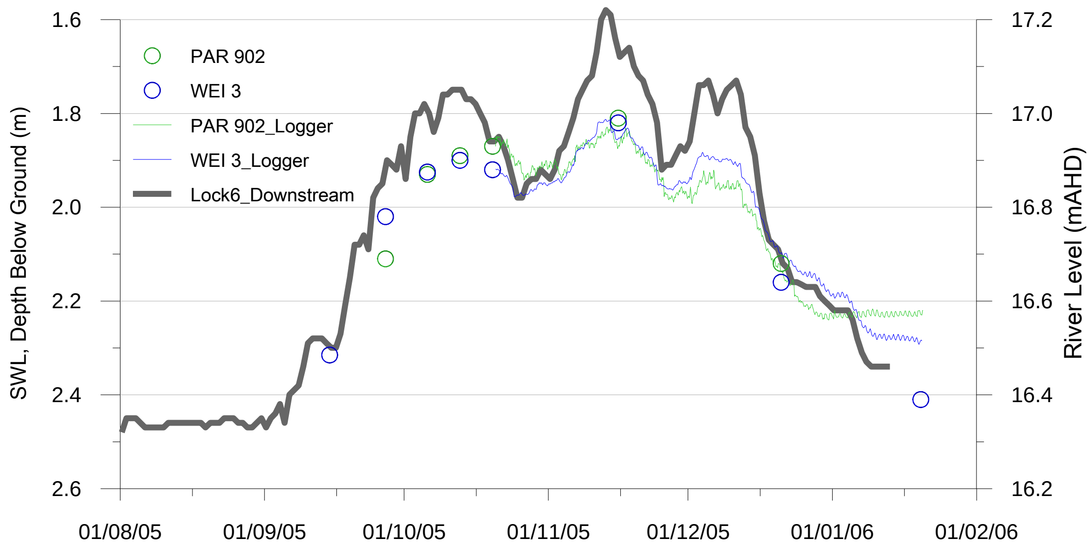

Figure 5. River level downstream of Lock 6 and groundwater level data from observation wells PAR902 and WEI03

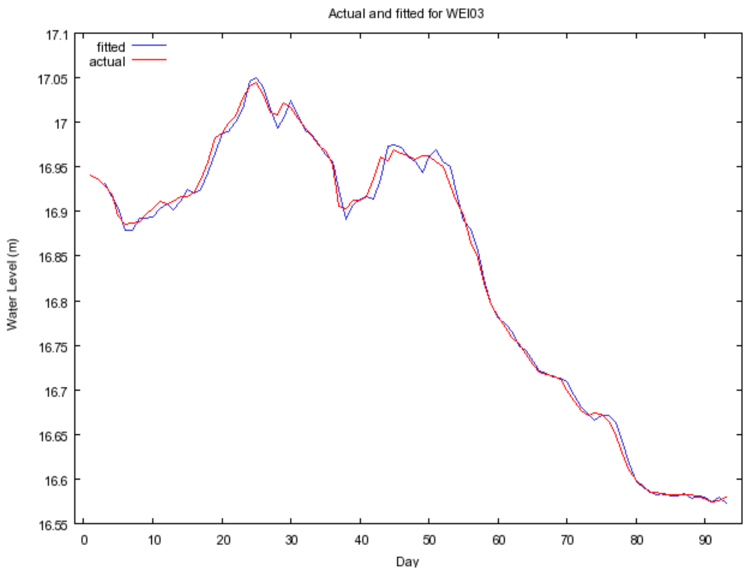

Figure 6. **Cochrane-Orcutt modelled (blue) and actual (red) groundwater level data for observation well WEI03**

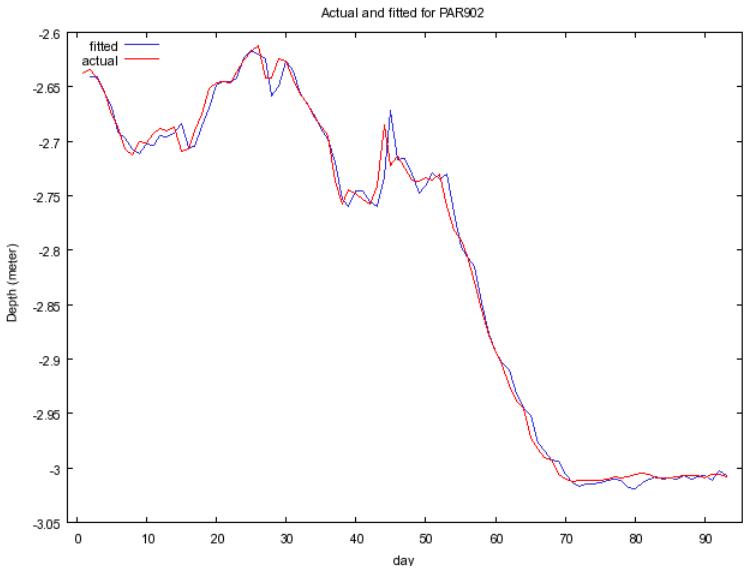

Figure 7. **Cochrane-Orcutt modelled (blue) and actual (red) groundwater level data for observation well PAR902**

Table 2. **Cochrane-Orcutt estimates for well WEI03**

Variable	Coefficient	SE	T	p
Constant (β)	11.285	0.628	17.962	<0.001 ***
X_t (γ_0)	0.401	0.055	7.254	<0.001 ***
X_{t-1} ($\gamma 1$)	-0.094	0.055	-1.708	0.091 *
R-squared	0.997			

Table 3. Cochrane-Orcutt estimates for well PAR 902

Variable	Coefficient	SE	t	p
Constant (β)	-7.835	0.785	-9.987	<0.001***
X_t (γ_0)	0.290	0.047	6.135	<0.001***
R-squared	0.994			

Templeton's Floodplain

Templeton's Floodplain (Fig. 8) is located midway between Lock 5 and Lock 6. The southern end of this floodplain has connected, regulator controlled backwaters that fill during elevated river levels. Initially, 11 test wells were monitored. Floodplain inundation resulted in only 6 of these wells remaining easily accessible, into which loggers were installed (T1, B1, C1, C2, A2 and A3). The logger in well T1 malfunctioned during the course of the trial, which precluded analysis of this data.

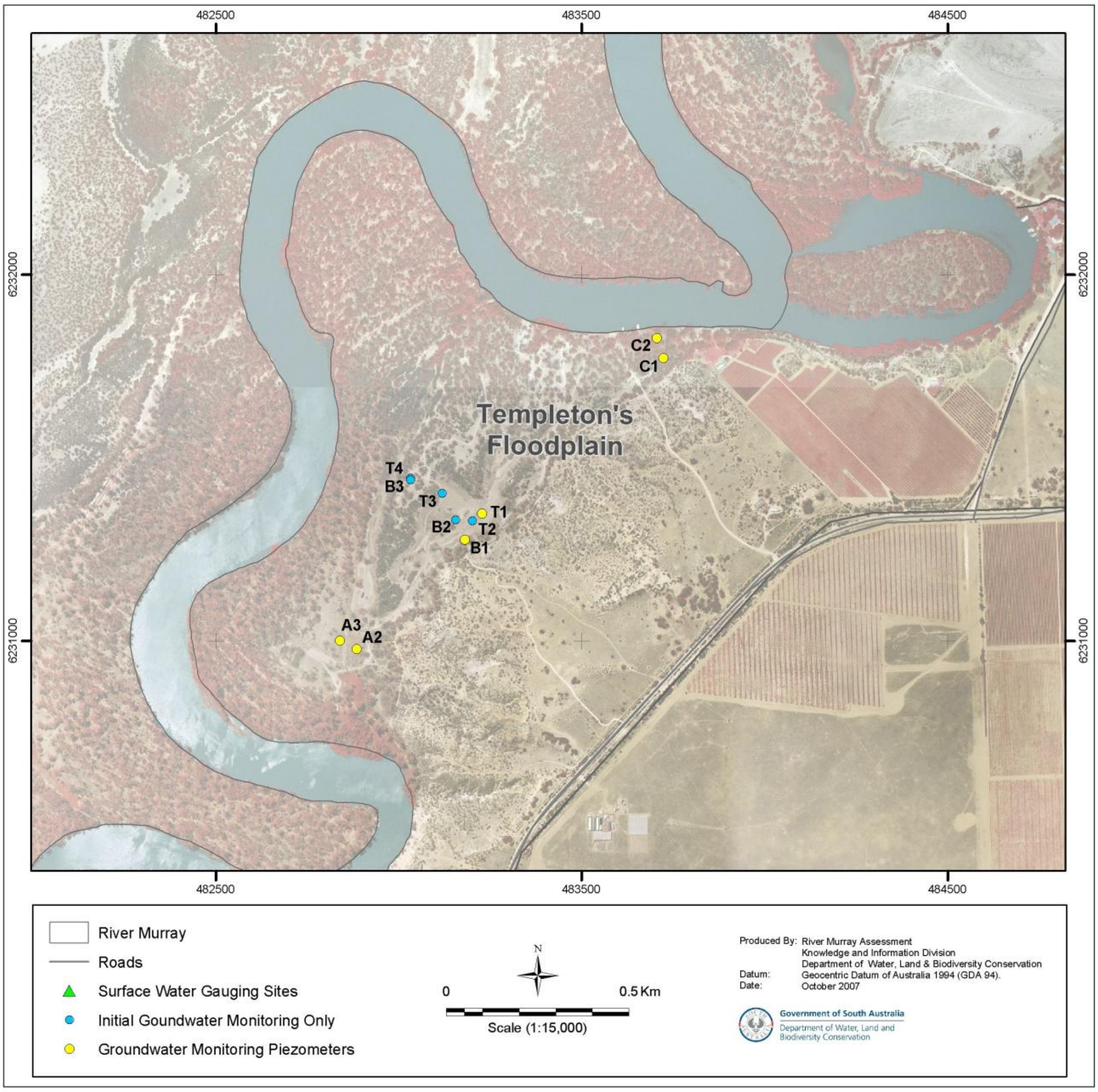

Figure 8. Groundwater observation network on Templeton's Floodplain

Wells C1 and C2 were located at the northern end of the floodplain, along a line running perpendicular to the river that rises in topography, with C1 ~2 m higher than C2. With a higher groundwater level, the hydraulic head difference between C1 and the river is larger, thus inhibiting the groundwater response to river level variations. The response amplitude of C1, which is further from the river, was less than that displayed by C2 (Fig. 9) despite the two wells being in close proximity to one another. Jolly (2001) also observed this and suggests that higher elevated regional groundwater from eastern highlands can strongly influence floodplain groundwater and may force to counteract the influence of river fluctuations.

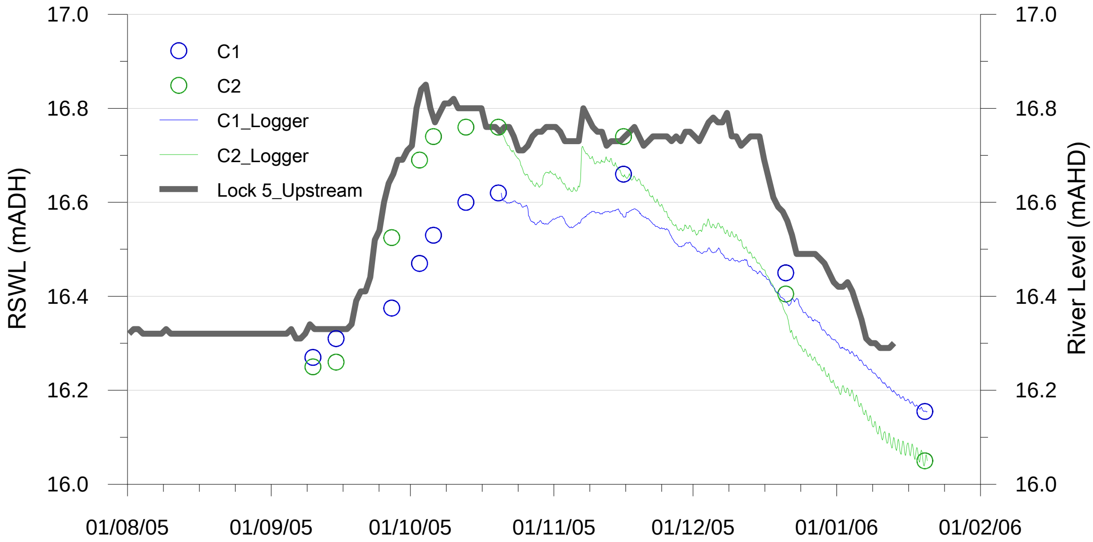

Figure 9. River level upstream of Lock 5 and groundwater level data from observation wells C1 and C2.

The best-fit Cochran-Orcutt models for C1 using 91 records, with independent variables of river level upstream of Lock 5 at day t (X_t) and day t-1 (X_{t-1}), accounted for 99.4% of the observed variations in groundwater level. For C2, 92 records with independent variable of river level upstream of Lock 5 at day t (X_t) accounted 99.5% of the observed variation in groundwater level (Figs 10, 11; Tables 4, 5). For well C1, the groundwater level was not significantly associated with river height on the same day (t) but significantly related with river height the day before (t-1), indicating a one day time lag in groundwater response. Well C2, which was closer to the main channel than C1, did not display a time lag between river height and the response of the groundwater table.

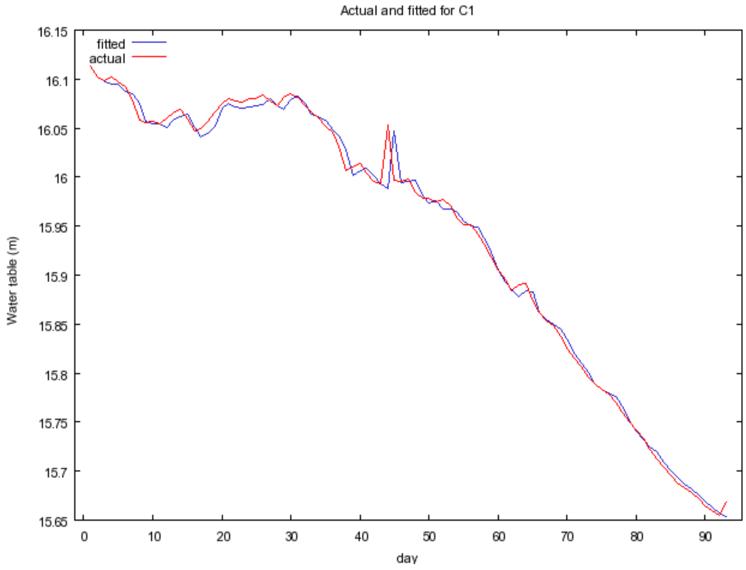

Figure 10. **Cochrane-Orcutt modelled (blue) and actual (red) groundwater level data for observation well C1**

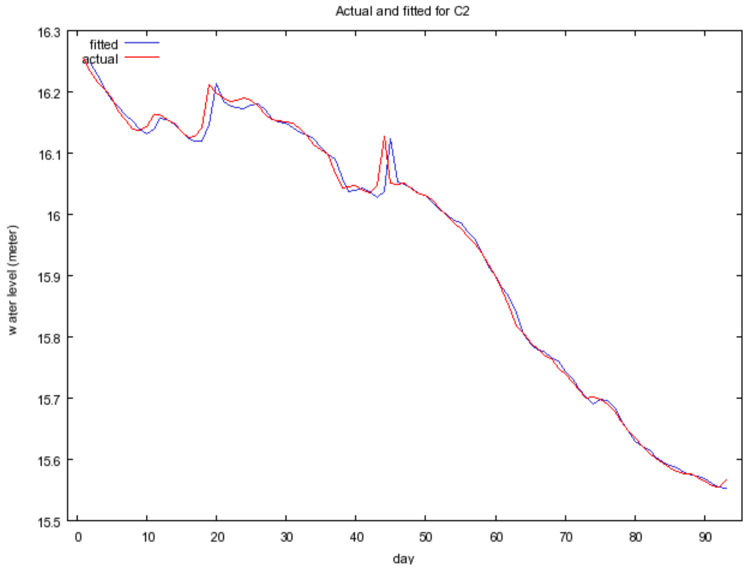

Figure 11. **Cochrane-Orcutt modelled (blue) and actual (red) groundwater level data for observation well C2**

Table 4. **Cochrane-Orcutt estimates for well C1**

Variable	Coefficient	SE	t	p
Const (β)	11.836	1.448	8.175	<0.001 ***
X_t (γ_0)	0.014	0.110	0.129	0.897
X_{t-1} (γ1)	0.206	0.110	1.875	0.064*
R-squared	0.994			

Table 5. Cochrane-Orcutt estimates for well C2

Variable	Coefficient	SE	t	p
Constant (β)	8.985	1.922	4.674	<0.001 ***
X_t (γ_0)	0.391	0.118	3.300	0.001 ***
R-squared	0.995			

At the southern end of the floodplain, logger data from wells A2, A3 and B1 display markedly similar groundwater responses and accurately mimicked changes in river level (Fig. 12). Each of these wells was located along the edge of the backwaters within close proximity to the raised weir pool high water mark. It was likely that both lateral and vertical recharge contributed to the responsiveness of the groundwater level.

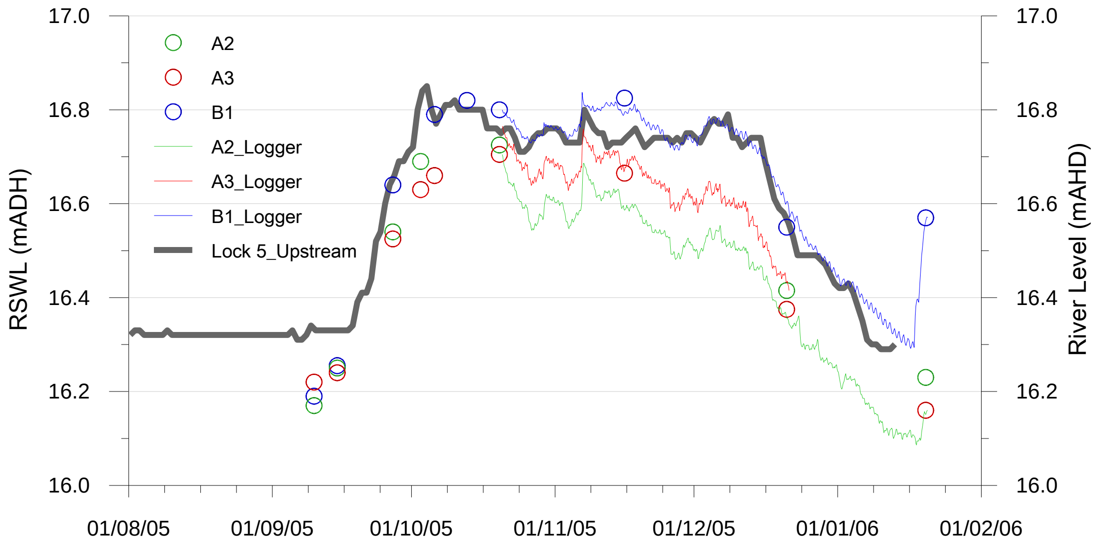

Figure 12. River level upstream of Lock 5 and groundwater level data from observation wells A2, A3, and B1

The best-fit Cochrane-Orcutt models for A3 and B1 accounted for 98.9 and 97.4% of the observed variation in groundwater level respectively (Figs 13, 14; Tables 6, 7). Both incorporated 92 records, with independent variable of river level upstream of Lock 5 at day t (X_t). For both wells, the groundwater level was dependent on river water level upstream of Lock 5 on the same day.

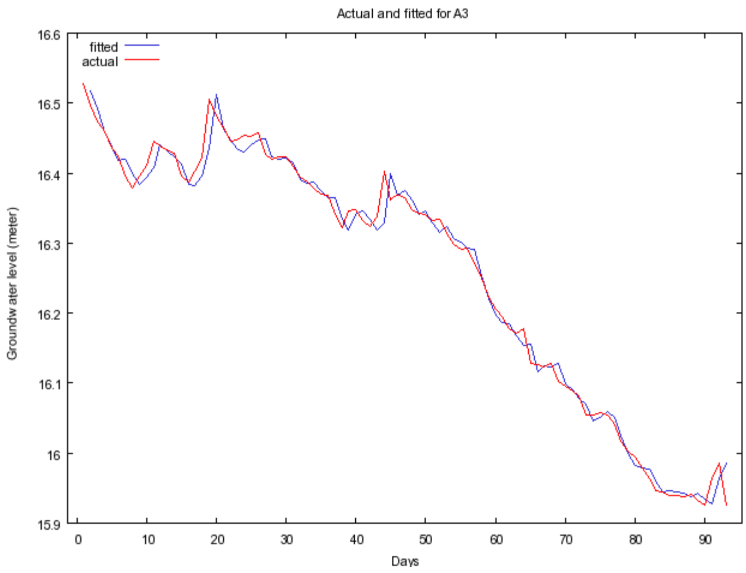

Figure 13. Cochrane-Orcutt modelled (blue) and actual (red) groundwater level data for observation well A3

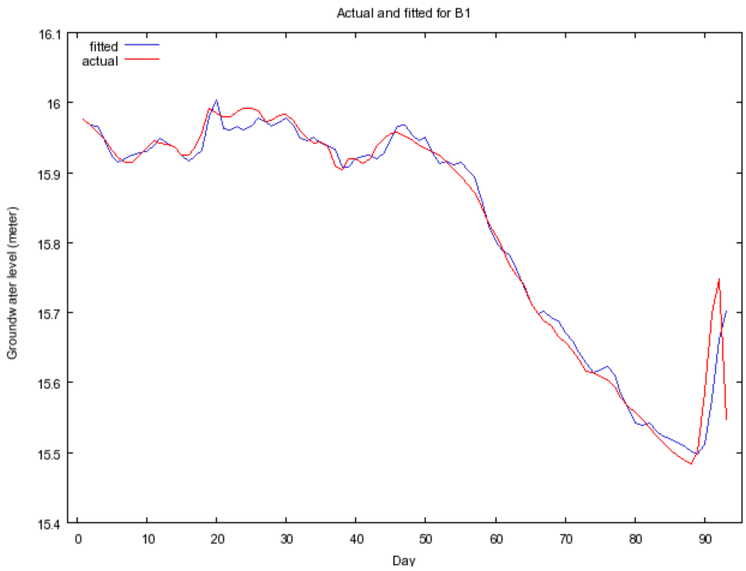

Figure 14. Cochrane-Orcutt modelled (blue) and actual (red) groundwater level data for observation well B1

Table 6. Cochrane-Orcutt estimates for well A3

Variable	Coefficient	SE	t	p
Constant (β)	6.061	2.007	3.020	0.003 **
X_t (γ_0)	0.608	0.122	4.998	<0.001 ***
R-squared	0.989			

Table 7. **Cochrane-Orcutt estimates for well B1**

Variable	Coefficient	SE	t	p
Constant (β)	1.342	1.070	1.255	0.213
X_t (γ_0)	0.871	0.064	13.523	<0.001 ***
R-squared	0.973			

Whirlpool Corner

Three wells were initially monitored at this site, but only WP2 remained accessible after the filling of floodplain backwaters. Although the distance between the River and WP2 was around 280 m, the well was within 15 m of a wetland openly connected with the main channel. Groundwater levels in well WP2 closely followed the changes in river level (Fig. 15).

The best-fit Cochran-Orcutt model for well WP2 using 92 records, with independent variables of river level upstream of Lock 5 at day t (X_t), accounted for 99.7% of the observed variation in groundwater level (Fig. 16; Table 8). The groundwater level was dependent on river level upstream of Lock 5 on the same day.

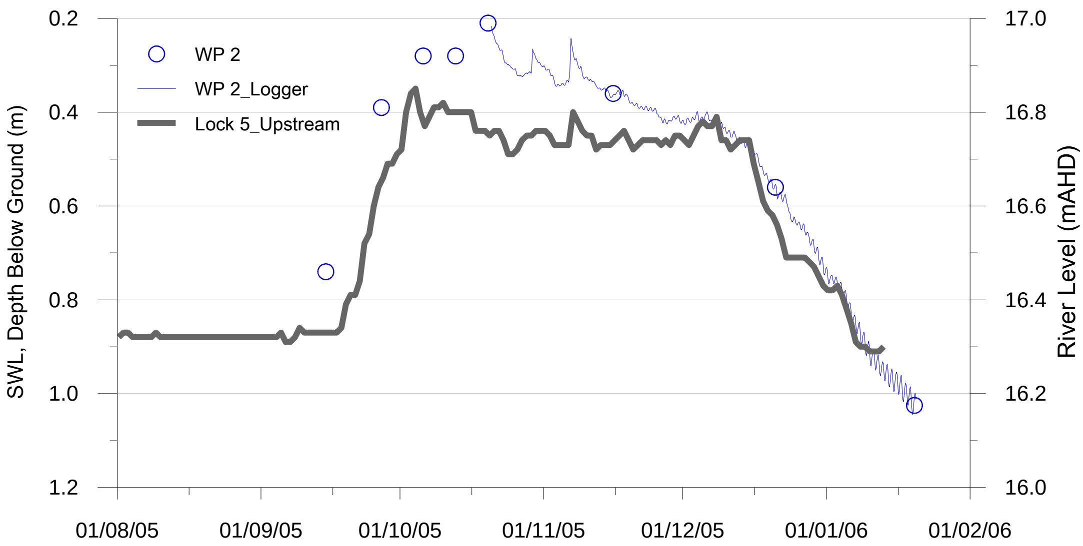

Figure 15. River level upstream of Lock 5 and groundwater level data from observation well WP2

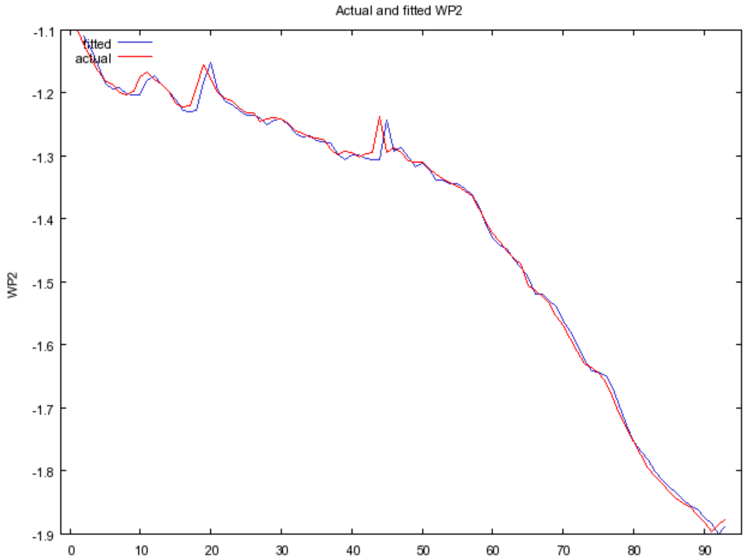

Figure 16. Cochrane-Orcutt modelled (blue) and actual (red) groundwater level data for observation well WP2

Table 8. Cochrane-Orcutt estimates for well WP2

Variable	Coefficient	SE	t	p
Constant (β)	-9.436	1.575	-5.990	<0.001 ***
X_t (γ_0)	0.440	0.098	4.505	<0.001 ***
R-squared	0.997			

Woolenook Bend

Woolenook Bend is a large floodplain located downstream of Templeton's Floodplain and is bounded by 17 km of river (Fig. 1). Woolenook Bend has a number of permanently filled backwaters, which are connected to the main channel at the southern downstream end of the floodplain. Groundwater level at Woolenook Bend responded to rises and falls in the river level, but the rapid response to smaller river level fluctuations observed at Templeton's was not observed at Woolenook Bend. This is intuitively understandable as the Woolenook observation wells were a considerable distance from the main channel. The logged water level data from well WB1 showed that the groundwater level was more responsive than either wells WB6 and PAR813 (Figs 17, 18). This can be explained by well WB1 being in closer proximity to a connected backwater than either wells WB6 or PAR813. In all test wells, the groundwater level rose by at least 20 cm indicating that even over substantial distances from the river (up to 1.5 km), a raised groundwater response occurred due to the elevated river level. Cochrane-Orcutt estimation for wells WB1, WB6 and PAR813 was not undertaken due to an insufficient period of logged data.

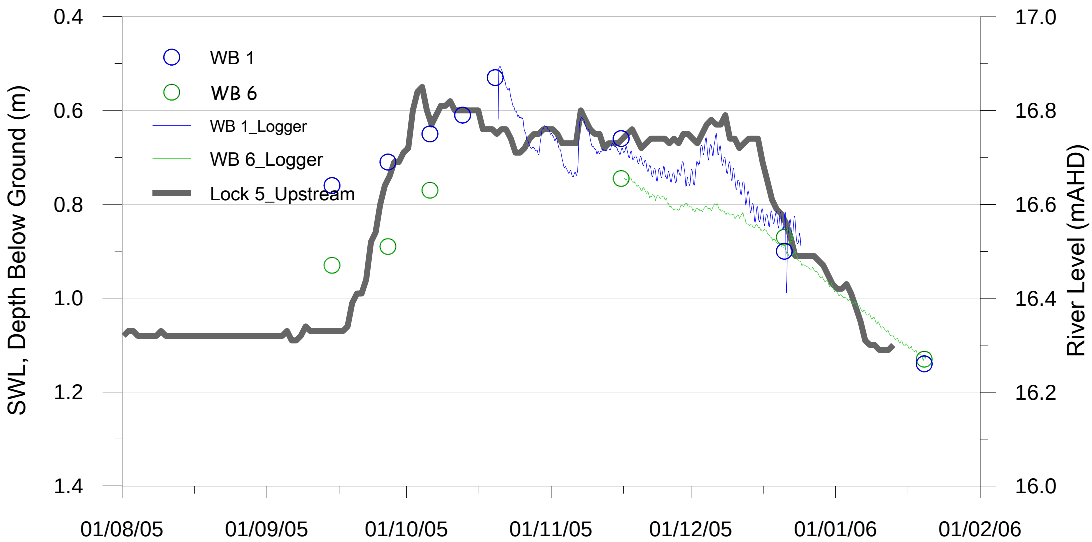

Figure 17. River level upstream of Lock 5 and groundwater level data from observation wells WB1 and WB6

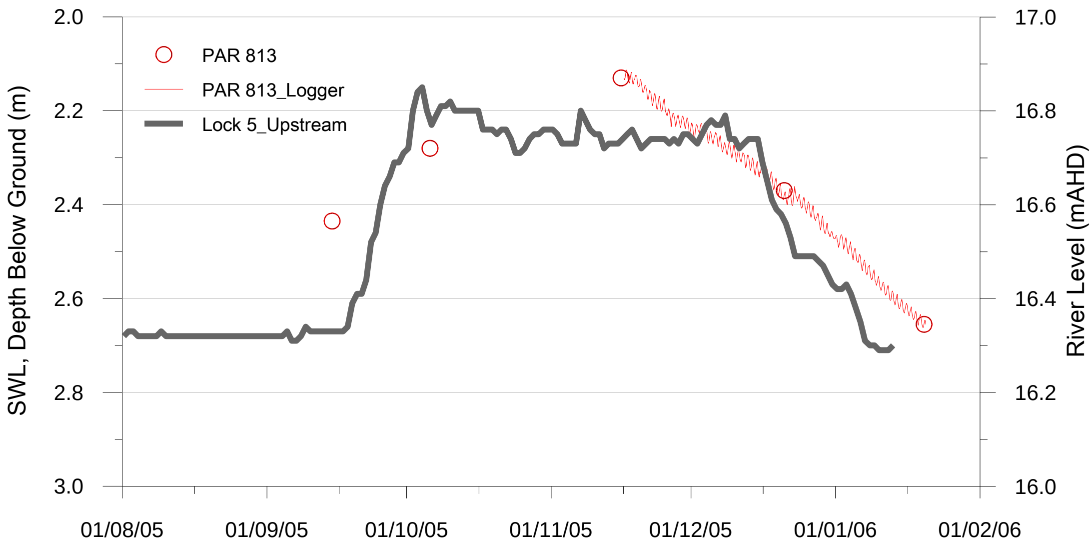

Figure 18. River level upstream of Lock 5 and groundwater level data from observation well PAR813

Ral Ral Creek

The observation wells for this floodplain are at the discharge end of Ral Ral Creek, a short distance upstream of Renmark and Lock 5. Monitoring at this site consisted of two dual completion wells (four wells in total) with one of each pair completed in the Coonambidgal Formation and one of each pair in the Monoman Formation. The wells were within ~130 m of Ral Ral Creek.

Limited manual monitoring of these bores suggested that groundwater level rose as a result of raised pool levels above Lock 5, which in turn would have raised the level of Ral Ral Creek. The data indicated that levels in both the Coonambidgal and Monoman Formations rose by nearly 0.4 m in response to the 0.5 m pool level rise (Fig. 19). This suggests that at this site the groundwater was hydraulically well connected to Ral Ral Creek (as per Jolly, 2001). Early data for JE3 and JE3A suggest a considerable drop in groundwater levels between the first and the second readings before rising in concert with river level. It is suspected that these initial readings were an error.

There appeared to be a delay between the peak river level (monitored upstream of Lock 5) and the peak groundwater level. This is only a cautious interpretation due to the frequency of manual readings. However, it is reasonable to consider that there would have been a degree of lag as heightened river levels translated to heightened creek and then groundwater levels.

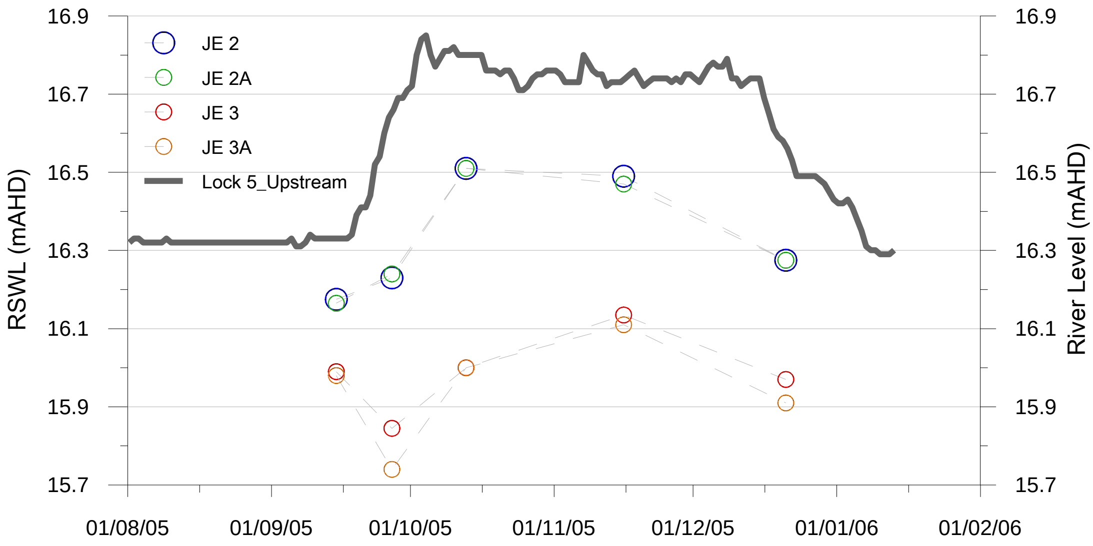

Figure 19. River level upstream of Lock 5 and groundwater level data from observation wells JE2, JE2A, JE3 and JE3A

Paringa wetland

The Paringa Wetland forms part of a RAMSAR wetland between Lock 5 to the tri-state border. Initial water levels were collected from four observation wells, one of which (Site 5) became inaccessible due to floodplain inundation. Loggers were installed into Site 4 and Site 7 wells with manual monitoring only for Site 3 well (Fig. 20). Unfortunately the logger in Site 4 failed to operate correctly and no data was obtained. Logger data for observation well Site 7 indicated a subdued groundwater response to fluctuating river levels and suggested that although the surface water and groundwater were connected, there was a degree of hydraulic resistance. It is apparent that the groundwater response at Site 3 was of a lesser magnitude than at Sites 4 and 7. This can be explained by the additional distance from the main channel.

IMPACTS OF WEIR POOL RAISING ON GROUNDWATER SALINTIY

The salinity of the observation wells ranged from fresh (<400 µS/cm) to hyper saline (>90 000 µS/cm). Unfortunately the timing of sampling before (15 September 2005), and during (21 December 2005) weir pool raising was not ideal. The early data was collected at the time when flows into South Australia had reached their first peak, and levels at Lock 6 were already at a quarter of the maximum level whilst the Lock 5 level had not yet started to rise. The latter data was collected when Lock 5 and 6 levels had already receded to approximately half their peak height. Given the limitations of the data, detailed analysis was neither possible nor attempted. However the data were used to draw broad, but tentative conclusions regarding the effect of weir pool raising on floodplain groundwater salinity.

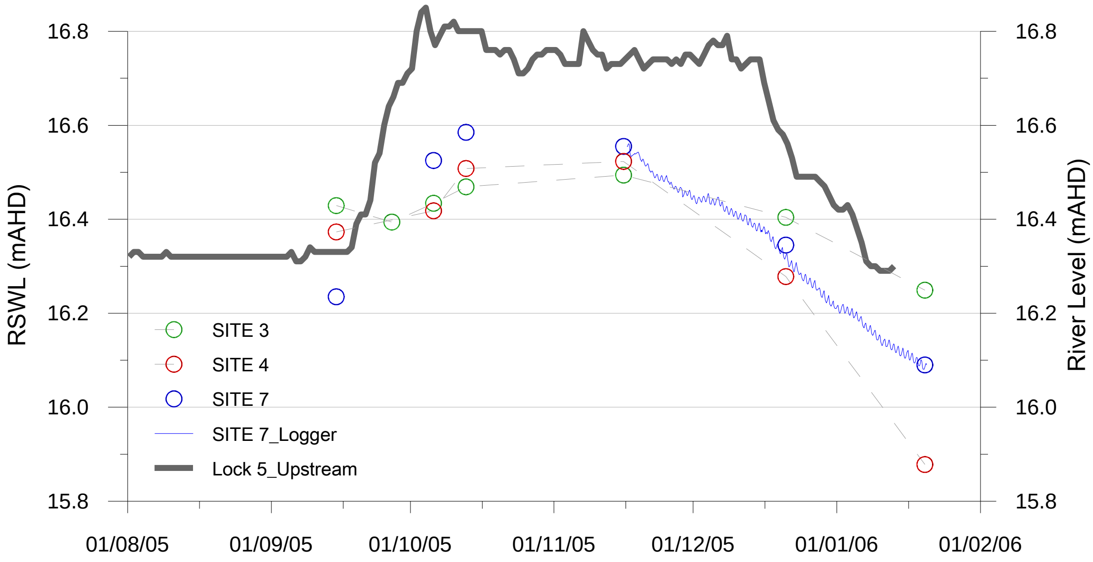

Figure 20. River level upstream of Lock 5 and groundwater level data from observation wells Site 3, Site 4 and Site 7

Templeton's floodplain

Templeton's floodplain had the most extensive data set due largely to the additional data collected by the Renmark to Border LAP (Table 9). For the majority of wells, no significant change was observed. A number of wells (A3, A4, A5, B3 and C1) indicated a slight initial reduction in salinity. This was possibly a result of vertical leakage from backwaters into the groundwater system. However the majority of variations were so slight that they are within the range of potential measurement error, such as EC probe or calibration inconsistencies.

Wells T1, B1 and C2 displayed notable salinity change over the period of raised weir pool levels. Observation well T1 remained relatively constant until a significant jump from 18 000 to over 40 000 µS/cm occurred in late December after levels had already started to recede. It was unclear what the transport mechanisms were, but it was apparent from the historical data of nearby wells (T2, T3, B2, B1) that significant spatial and temporal variability exists across the floodplain, suggesting a complex interaction between surface water, groundwater and salinity.

Well B1 displayed a decrease from 9000 µS/cm to 6000 µS/cm during the monitoring period. Considering it's distance from the main channel, this freshening was most likely due to vertical leakage from the backwaters. Historical data suggested considerable temporal variability in B1 salinity. The data from observation well C2 was curious, with salinity levels steadily increasing over the course of the monitoring period from 6,150 µS/cm up to nearly 18,610 µS/cm. It was anticipated that raising pool levels would have caused lateral freshening at C2, reducing the groundwater salinity. It is difficult to explain this unexpected increase, but proximity to a sharp main channel meander and a very narrow floodplain may have played some role in spatial and temporal salinity variations. Historical data supports these observations with elevated salinities occurring in October 2000 (Jolly, 2001) and January 2002 (Table 9) at times of elevated Lock 5 levels. The data from the 2000 monitoring program (Jolly, 2001) revealed notable salinity reductions in A2, A3, A4, whereas similar changes were not observed in the current data set.

Whirlpool Corner

At Whirlpool Corner, initial salinity observations of three wells indicated a salinity gradient from the river's edge towards the highlands. The two wells adjacent the river had initial salinity readings of around 400 μS/cm, compared with 11,990 μS/cm in well WP2 (Table 10). Although this test well was adjacent to a connected wetland, it was much closer to the highlands and the regional saline groundwater, perhaps explaining the higher salinity level. It was likely that this open backwater/wetland was a source of saline groundwater accession to the River Murray. Groundwater salinity in WP2 decreased slightly to 10,870 μS/cm towards the end the raising trial.

Woolenook Bend and Lang Floodplain

There was little change in groundwater salinity at either Woolenook Bend on Lang Floodplain over the period of weir pool raising (Table 10).

Ral Ral Creek

On the Ral Ral Creek floodplain, groundwater salinity rose in all observation wells during weir pool manipulation (Table 11). As these test wells were are at a considerable distance from Ral Ral creek, freshwater inflows from the creek were unlikely to have influenced samples taken from these wells. Jolly (2001) reported an increase in salinity for a test well within 40 m of the creek and suggested that density effects may influence salinity change. Although the salinity throughout this floodplain is consistently high, there may be discrete zones of localised hyper salinity, which could mobilise under the increased hydrostatic pressure.

Paringa Wetland

Salinity at the Paringa Wetland was quite variable across the floodplain (Table 11). There was a distinct difference in groundwater salinity between Site 4 well (>25 000 μS/cm) and Site 7 well (<3000 μS/cm) despite both being a similar distance from the main channel (~60 m). The groundwater levels (Fig. 20) show that the head difference between the surface and groundwater was also similar for both wells, and it was unclear why there was such a marked variation. Furthermore, State archives for well PAR02, further inland from Site 4 had a salinity of around 10 000 μS/cm where it would typically be expected that salinity increases with increasing distance from the main channel. Without a more detailed temporal data set, it is difficult to explain these differences in salinity distribution across the Paringa Wetland floodplain. There are a number of creeks connected with the main channel that dissect the floodplain, which may influence the distribution of fresher groundwater. Whilst these spatial differences made interpretation difficult, slight increases in salinity were observed in wells Site 3 and Site 4 whilst the salinity in well Site 7 decreased by more than a factor of two.

Table 9. Groundwater salinity from Templeton's Floodplain including additional historical data prior to weir pool raising

	Groundwater Salinity (µS/cm)													
Date	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**C1**	**C2**	**T1**	**T2**	**T3**	**T4**
28/01/2002	26 000	31 300	17 810	15 530	1493	4330	22 000	47 900	45 900	11 040				
12/02/2002	25 700	31 200	19 510	14 880	1203	4210	21 800	46 000	44 900	9860				
24/02/2002	25 900	31 000	23 200	14 880	1042	4170	22 300	46 700	44 800	9310				
09/03/2002	25 100	30 300	24 500	15 220	991	4290	22 100	46 900	45 400	9350				
13/04/2002	25 100	29 300	26 400	16 010	898	4220	21 900	45 900	44 500	9020				
12/05/2002	24 200	27 900	26 300		829	5350	21 300	44 000	41 900	8680				
16/06/2002	23 600	27 200	25 900	15 790	753	5820	18 620	42 400	39 800	7940				
30/09/2002	22 200	26 500	26 000	16 050	733	9410	18 940	41 300	40 400	7860				
02/03/2002	19 050	23 900	24 000	15 400	635	9390	19 200	40 000	38 400	7650				
08/08/2003	19 450	24 800	25 800	16 530	619	10 430	21 500	43 500	41 500	7320				
04/10/2003	*21 300*	*26 100*	*26 900*	*18 340*	*623*	*11 500*	*22 200*	*46 700*	*45 000*	*7400*				
21/01/2004											*18 793*	*42 961*	*49 857*	*15 732*
10/04/2004	*16 520*	*23 300*	*24 300*	*16 190*	*584*	*10 600*	*19 050*	*37 800*	*39 300*	*6910*	*16 720*	*14 360*	*31 300*	*32 300*
22/04/2005	*17 220*	*23 900*	*26 200*	*16 240*	*593*	*9330*	*19 600*	*41 000*	*39 400*	*6270*	*16 200*	*14 000*	*32 500*	*34 400*
12/05/2005				*16 430*									*37 700*	*46 900*
10/09/2005	*18 430*	*27 500*	*29 900*	*18 270*	*533*	*9180*	*23 700*	*49 400*	*46 800*	*6150*	*18 500*	*14 530*	*37 700*	*46 900*
15/09/2005									45 700	12 380				
27/09/2005		30 200				6210					17 480			
03/10/2005	*18 240*	*28 700*	*29 100*	*18 150*	*494*	*6050*		*47 200*	*45 300*	*15 410*	*18 780*		*36 000*	*39 700*
21/12/2005		35 000	30 800			6330			48 500	18 610	41 300			
15/01/2006	*18 870*			*19 020*	*560*		*24 500*	*50 700*				*16 280*	*38 500*	*44 400*
02/04/2006	*18 130*	*36 000*	*29 800*	*19 130*	*588*	*7140*	*23 500*	*48 200*	*45 800*	*19 690*	*21 400*	*16 470*	*641*	*42 200*
21/07/2006	*17 830*	*36 100*	*29 800*	*21 400*	*657*	*8740*	*23 500*	*49 300*	*46 900*	*17 760*	*20 600*	*15 430*	*1003*	*42 100*

Italics denote data collected by the Renmark to Border LAP.

Table 10. Groundwater salinity from Whirlpool corner, Woolenook Bend and Lang Floodplains during weir pool raising

	Groundwater Salinity (μS/cm)								
	Whirlpool corner			Woolenook Bend			Lang		
Date	**WP 2**	**WP 3**	**PAR 804**	**WB 1**	**WB 2**	**WB 3**	**PAR 813**	**WB 6**	**WEI03**
15/09/2005	11 990	395	485	4010	62 300	33 200	12 580	49 500	609
21/12/2005	10 870			3920	67 700		11 570	51 700	415

Table 11. Groundwater salinity from Ral Ral Creek and Paringa Wetland Floodplains during weir pool raising

	Groundwater Salinity (μS/cm)							
	Ral Ral				Paringa			
Date	**JE 2**	**JE 2A**	**JE 3**	**JE 3A**	**Site 3**	**Site 4**	**Site 5**	**Site 7**
15/09/2005	44 200	39 100	62 000	85 300	36 800	27 600	24 500	2770
21/12/2005	50 100	42 800	70 500	98 300	38 700	32 200		1024

CONCLUSIONS

FLOODPLAIN GROUNDWATER LEVEL

This study observed that floodplain groundwater levels rose in response to rising weir pool levels. This was the case for all sites studied including the two floodplain sites of Templeton's and Ral Ral Creek, which were examined by Jolly (2001) with supporting conclusions. In a separate study, a rise in floodplain groundwater level during the 2005 high river levels was also reported at Bookpurnong between Locks 3 and 4 (White et al. 2006).

The statistical modelling undertaken in the analysis of this data was able to determine the accuracy of correlation between the surface water and groundwater time series data sets, as well as assess if a time lag in the groundwater's responsiveness played a role. For wells with suitable periods of logged data, the analysis confirmed that groundwater level was significantly associated with river level on the same day for all wells excluding C1 and WEI03. Using river level on the same day, the best-fit Cochrane-Orcutt models accounting for between 97.4% and 99.5% of the observed variation in groundwater level. Whereas, observed variation in wells C1 & WEI03 were closely associated with river level changes recorded on the previous day indicating a one day time lag. The modelling and statistical verification of this study built on the visual observations by Jolly (2001) for the 2000 weir pool raising event.

Weir pool raising caused rapid increases in groundwater level indicating a good hydraulic connection between the river and aquifer beneath the floodplains that were monitored as part of this trial. The phase of water table rising was not effectively monitored with the data loggers, but manual measurements confirmed that the floodplain watertable increased in accord with river water level during the raising phase of the weir pool trial. Any wells that observed delayed response may have been a result of poor hydraulic connection to the river or high resisting hydraulic heads.

Increased distance from the river would also play a role in delaying response but there was only limited observation available to quantify this groundwater response at the surveyed sites with most wells responding accordingly with rises in the river level. Some of the distant well at Woolenook Bend floodplain displayed decreased accuracy and magnitude in response, in comparison to others nearer the main channel, which mimicked small variation in river level. The models developed for wells closer to the river produced better statistical estimates than those at a greater distance. The concept of distance was not thoroughly examined as the furthest distance from a well to the waters edge was less than 500 m in this investigation, and the conclusion cannot be expanded to a large floodplain, which may extend for kilometres. Understanding of the aquifer type, as either confined or unconfined, is important in determining groundwater level response. The groundwater level response for a confined aquifer is very much quicker due to pressure transfer, than that of an unconfined aquifer that requires the physical movement of water.

FLOODPLAIN GROUNDWATER SALINITY

From the available data, there were limited sites that recorded notable change in floodplain groundwater salinity during the 2005 weir pool raising (15 September to the 21 December 2005). The sparse nature of the collected data precludes sound conclusions being drawn on the impacts of weir manipulation on groundwater salinity. Across the Floodplain sites there was no consistent pattern of salinity response to the heightened river levels. At most sites, there were minor changes in salinity to either the positive or negative, but for the large percentage of sites this change was not regular or of a magnitude great enough to warrant firm interpretation.

For the two floodplain sites, Ral Ral Creek and Templeton's, that were monitored in both the 2000 (Jolly, 2001) and 2005 weir pool raising events, the results were not consistently in agreement with one another. At Ral Ral Creek both the 2000 and 2005 event observed increases in the groundwater salinity. However, at the Templeton's Floodplain, agreement in the salinity response of the two events was limited. Of the wells with acceptable records for both raising events, A2, A3 and A4 decreased in salinity by around an order in magnitude in 2000, whereas the salinity was largely unaltered in 2005. One significant difference was that the 2000 event had a peak flow almost twice the magnitude (42 300 ML/d) compared to the 2005 event (15 100 ML/d). This dissimilarity accounts for different areas of backwater inundation, which in the case of the Templeton's floodplain has been a considerable factor. In 2000 observation wells A2, A3 and A4 were inundated, whilst in 2005 these wells remained above the backwaters high level mark, indicating that vertical recharge or leakage at the well casing played an important role at these observation wells.

In both studies the frequency of sampling was limited, with in many cases only two salinity samples collected. Thus, there was insufficient data from either study to be able to determine the cause of these differences in salinity. At the other floodplain sites sampled, there was little meaningful salinity change at Whirlpool Corner, Woolenook Bend, Lang Floodplain or the Paringa wetland in response to weir pool raising, and any small changes observed were difficult to qualify due to the limited salinity samples. This strongly highlights a need for in-situ salinity loggers, which would allow for continuous collection of salinity, with frequency and time periods similar to that of river and groundwater level. Regrettably, dual level EC loggers were not available for use during the monitoring phase of the 2005 weir pool raising.

Whilst the level of salinity monitoring was not sufficient to provide a clear indication of the effect of weir pool raising on floodplain groundwater salinity. It is clear that the response was complicated and varied between floodplains and over time. This suggests that response will be highly specific to each floodplain and the magnitude of each raising event, which may make it difficult to devise general management guidelines that may be adopted across the Lower River Murray Floodplain as a whole.

ENVIRONMENTAL EFFECTS

The data collected could not answer whether or not the raised groundwater levels and changes in salinity caused any environmental benefits or harm. It would be anticipated that floodplain vegetation health benefits may be achieved from lowering groundwater salinities by providing an additional supply of lower salinity water for terrestrial floodplain vegetation. However the results collected in the 2005 study and the 2000 study (Jolly, 2001) showed it difficult to predict where any improvements will take place due to the spatially and temporally complex nature of the hydraulic connection between the river, it's anabranches and the floodplain groundwater aquifer, which in some cases exhibited potentially detrimental increases in groundwater salinity.

During the period of monitoring, and along the edges of the backwaters there was minor evidence of salt precipitation at surface. A similar expression of concern was noted by Jolly (2001), the temporary rise in floodplain groundwater may lead to increased salt accumulation in soils due to greater rates of capillary rise of groundwater and salt concentration via increased evapotranspiration. It's suggested that if water levels are raised for months or longer, then this issue might be of concern. Whilst the 2005 raising took place for a period of two months no data were collected on either salt accumulation (soil samples) or tree condition response, presenting a significant knowledge gap.

RECOMMENDATIONS

This study observed two main points. Floodplain groundwater levels will rise in response to the raising of lock pool levels, and the response of floodplain groundwater salinity to weir pool raising is both spatially and temporally complex with more detailed monitoring required to understand these effects. The project was hampered by the short lead-time in which to design and implement the investigation prior to weir pool raising. If the impact of weir pool raising on floodplain groundwater processes and vegetation condition is to be adequately addressed, an event ready monitoring program needs to be designed and established prior to any future raisings. This requires site selection, monitoring program design, infrastructure establishment (i.e. piezometers) and sourcing of monitoring equipment. A number of recommendations can be made from the outcomes of this study:

Dual level salinity and depth loggers should be installed at least one month prior to weir pool raising. Groundwater level loggers were not installed until after the river had already substantially risen. Thus the river and groundwater raising phase was only monitored manually and could not be adequately modelled and assessed. The installation of loggers would also allow data collection from observation wells that would otherwise be inaccessible due to floodplain inundation.

Future trials should employ soil salinity profiling prior to and post weir manipulation. The impact of weir pool raising on groundwater level was short-term as groundwater returned to their initial levels once river levels reverting to pool level. However, the effect on floodplain soil salinity could be a detriment to floodplain condition. Rising groundwater mobilises saline water through the vadose and unsaturated zones. As groundwater levels returned to pre trial conditions, salts may have concentrated within the soil profile due to evaporative concentration. The length of the trial would influence this magnitude of soil salinity increase. The alternate argument is that raising of groundwater may mobilise salts out of the soil profile, thus increasing the salinity of the groundwater but reducing soil salinity. Soil salinity observations would allow these concept to be investigated.

Groundwater salinity should be continuously monitored before, during, and several months after weir pool manipulation. The groundwater salinity response should be the focus of future investigations as it is most likely to have the greatest environmental implications. The impact of raising the pool level on salinity was difficult to quantify given the available data. Some sites recorded a decrease in salinity whilst others increased. This 2005 and the 2000 study highlighted the difficulty in predicting where salinity improvements will occur, resulting from the spatially complex nature of the hydraulic connection between the river and alluvial aquifer. Also, it is difficult to predict the distribution of vertical recharge from floodplain surface waters. It is reasonable to infer changes in groundwater level in response to heightened river level, but the distribution of groundwater salinity change is yet to be well characterised.

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