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## The initial hydrological effect of deep drains at Wallatin Creek : (2006-2008)

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# The initial hydrological effect of deep drains at Wallatin Creek (2006–2008)

Richard George and Grant Stainer



September 2009

## RESOURCE MANAGEMENT TECHNICAL REPORT 348

Cover photo: **Wallatin Creek Drain** (photo taken by Richard George)

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This project was one of seventeen demonstrations collaboratively managed by the Wallatin-O'Brien CDI Management Committee along with a technical panel.

Results of collaborative work funded by the Grains Research and Development Corporation (GRDC) on the response of soil salinity and crops to drainage at this site (DAW00138: Project Manager, Dr Richard George and partner Professor Richard Bell, Murdoch University) are reported in GRDC 00138, an extract of which forms Appendix 2).

## **Summary**

A 9.7 km length, 2.5 m deep drain was installed in the Wallatin Creek catchment in June 2006. It was positioned within a broad valley floor and designed to drain several large yet discrete saline scalds and return the area to productive farmland.

Groundwater monitoring wells were installed prior to construction of the drain on a transect that crossed the eastern and western arms of the drain. Bores were drilled at close spacings to enable the impact of the drain on water levels to be observed. Data loggers (capacitance probes) were placed in bores west of the main drain. Other bores in the valley floor were also monitored to provide comparison with the responses observed near the drain.

A weir was constructed at the drain outlet to record flow volume, salinity and pH. Data from the weir was available for a period of eighteen months. During the monitoring period, the drain had an estimated baseflow (groundwater only) of 26 868 kL. This flow had an average salinity of 4790 mS/m, a low pH (~3.50) and a salt load of 1740 tonnes for the combined drain flow of 51 888 kL over the period.

Bore monitoring conducted between May 2006 and September 2008 revealed that the groundwater level fell from about 1 m to about 2 m below ground level. While the logger data indicates that the drain had an initial effect—within 7 days of construction—on water levels, it was minor (< 0.2 m) and only occurred in observation wells ~25 m from the drain. No unambiguous response in water levels due to the drain could be observed in wells at a greater distance. Moreover, any short-lived initial impact was overshadowed by the effect of low rainfall between 2006 and 2008. Low rainfall had a greater impact than drainage on water levels in the area.

A simple water balance based on the likely zone of impact of the drain revealed that the average baseflow of 48 kL/d could be derived by the loss of water from storage (as watertables fell) and/or from annual recharge close to the drain.

Several uncertainties remain regarding the effect of the drain. In particular how the drain will respond in wetter periods and if the climate related reductions in watertables will be reversed. Whether the current low watertables will be sustained for long enough to enable leaching and whether this may lead to subsequent crop improvement is being monitored. Results to date show no clear impact of lowered watertables on soil salinity and crop yield.

We recommend loggers be maintained in key drain and comparison bores and that this analysis be updated in two years.



## **Introduction**

From the 1970s, landholders in the Western Australian wheatbelt have installed deep drains to minimise waterlogging and lower watertables (Chandler & Coles 2004). Implemented mainly at farm scale until the 1990s, regional or catchment scale drainage is now common, with most drains installed as single structures to depths of 2 to 3 m adjacent to natural waterways.

International research indicates that effective drains are constructed in soils that have a high permeability or are installed in parallel or herringbone patterns to maximise the area of groundwater interception (Skaggs & van Schilfgaarde 1999). In Western Australia, published data confirms that single deep drains constructed in permeable calcareous or sandplain soils (e.g. Watheroo and Baandee) have lowered the watertable by ~1 m up to 100 m from the edge of some drains (George & Nulsen 1985, George 1991). By contrast, drains constructed in the low hydraulic conductivity soils characteristic of many valley floors may affect watertables by as little as 0.5 m within 10–30 m of the drain (Speed & Simons 1992).

Of the 6678 farmers in the wheatbelt, 1370 have installed deep drains (ABS 2002), and since the 1970s more than 11 000 km of mostly deep drainage has been undertaken (ABS 2002). A resurgence in drainage since the 1990s is partly due to the lack of success of plant-based options in managing groundwater levels (Barrett-Lennard et al. 2005) and the acclimation around local and interstate drainage schemes, for example in South Australia (Coles et al. 1999).

Results of a number of local drainage studies were summarised by Coles and Chandler (2004) and Coles et al. (1999). The Belka Valley and Narembreen drainage were among these projects. Both of these drainage systems were of the order of 70 to 100 km in length, with the Belka Valley drain being a shallower (~2 m) and discontinuous system, and Narembreen a deep (2–3 m) continuous drain. While results from studies of the Belka Valley drain were variable (Chandler & Coles 2004), Ali et al. (2001) considered the Narembreen drain effective, being associated with lower watertables at a greater distance (up to 200 m) than any previously studied drains. They cited both initial and longer term responses from distant bores as evidence. However, these and several other drainage results have been questioned owing to their divergence from previous published analysis and to their debated methodology (monitoring regime, short period of record and effects of climate).

Widespread uncertainty around the effectiveness of deep drainage (Kingwell & Cook 2007) encouraged farmers in the Wallatin Creek catchment to initiate this assessment of the hydrologic impact of a deep drain. The 9.7 km, 2.5 m deep valley floor drain was evaluated along with 16 other salinity management options, as part of the Wallatin-O'Brien Catchment Demonstration Initiative (CDI). The CDI project also analysed plant-based (lucerne, saltbush, revegetation) and other engineering (siphons, pumps) options (Robertson et al. 2008).

Similar evaluations of deep drainage are being conducted at Morawa, Pithara, Beacon and Dumbleyung as part of the Department of Water's Engineering Evaluation Initiative.

## **Study area**

The Wallatin Creek catchment is an area of approximately 24 000 ha (McFarlane & George 1992), located 241 km by road from Perth. The relative relief of the catchment is 140 m (topography ranges from 380 m to 240 m AHD). The Wallatin Creek drains towards the Woolundra Lakes and is a tributary of the Yilgarn River.



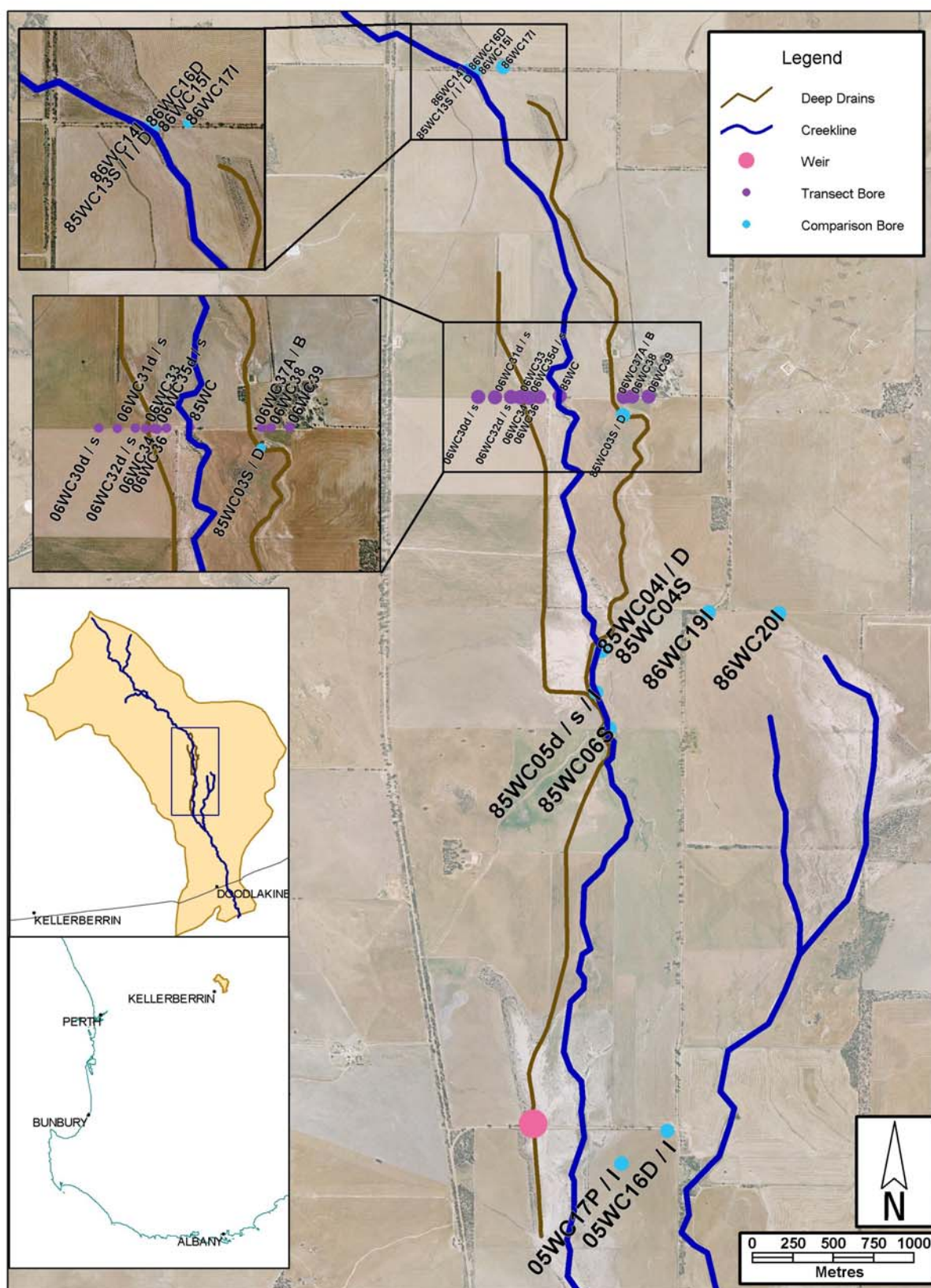


Figure 1 Wallatin drain, monitoring bores cited in this report, weir and natural waterways in the Wallatin Creek catchment. See Figure 2 for bore details on the main transect.

A 9.7 km length, 2.5 m deep drain was installed in the Wallatin Creek catchment in June–July 2006. The deep drain is located 12 km north of Doodlakine and 28 km north-east of Kellerberrin (see Figure 1). The project design, specifications and pre-drainage evaluation were undertaken by Cox (2005).

The drain is located in a broad valley floor and designed to dewater several large scalds on the floor and flanks of the valley. The design incorporates parallel levees along the drain length to exclude surface runoff, although at specific sections, locally derived surface water is able to enter the drain. The design also enables floodwaters to be kept separate and confined to the existing creek system. In the upper section, the drain consists of two segments, one that drains a saline scald to the west and another that drains one to the east (Figure 1). The drains converge near a large scald that formed above a bedrock ridge (McFarlane & George 1992) before continuing to a discharge point in the Wallatin Creek.

## **Soils and geomorphology**

The Wallatin Creek catchment occurs in a transition zone between the landforms of the central and eastern wheatbelt. It falls within the Zone of Ancient Drainage, with landforms described by McFarlane & George (1992) using a soil and topologic classification as defined by CSIRO (Bettenay et al. 1964). The landscape catena consists of uplands dominated by the Ulva unit (gravels and deep sandplain). Adjacent to these soils, often at a high elevation, is the Danberrin unit, comprising extensive areas of rock outcrop, arkosic and skeletal soils. Lower in the hill-slope sequence, erosional surfaces (Booraan), shallow colluvium and alluvium (Collgar unit) infill minor valleys. The broad valley soils are comprised of alluvium of various textures, from sandy (Belka) to saline clay (Stirling). These units are the most affected by salinity. The area mapped as saline in the Wallatin Creek catchment in 1998 was 2.2 per cent. However, the area of salinity on individual farms in the valley is significantly greater (Robertson et al. 2008).

Regolith thickness in the Wallatin Creek catchment (~15 m) is less than that in adjacent North Baandee and other comparable wheatbelt catchments (20–30 m) due to the abundance of Danberrin and Booraan soil systems (McFarlane & George 1992). Much deeper regolith (40–50 m) occurs in the lower Wallatin catchment due to the prevalence of deep alluvial sediments. Hill-slope and upper catchment valley aquifers are local, with all recharge becoming discharge within the same sub-catchment. While intermediate flow systems have the potential to occur in wheatbelt valley sediments, the complexity of the regolith and geological systems means that most groundwater flow occurs at a local scale. As a result, salinity is generally expressed where there is a reduction in flow capacity, such as areas with shallow bedrock, convergent valleys, changes in surface slope or the presence of dykes (McFarlane & George 1992). Recharge to groundwater is estimated to have increased from 0–1 mm/year to 10–30 mm/year after clearing (George 1992).

## **Climate**

Long-term (1900–2006) average rainfall is 330 mm/year (Kellerberrin) and pan evaporation exceeds 2472 mm/year (Merredin). Potential evaporation exceeds rainfall in all months. Approximately 75 per cent of the rain falls between May and September. While summer rainfalls can be large (100 mm/rainstorm), they are infrequent. Rainfall totals during the last 30 years (1975 to 2006) were reported to be 10 per cent lower than the 1900 to 2006 average, with rainfall in June and July having dropped by more than 25 per cent (Robertson et al. 2008).

## Vegetation

Most (70 per cent) of the original vegetation had been cleared for agriculture by the 1940s and only 11 per cent remains in isolated remnants, mainly in two large A-Class nature reserves within the Wallatin Creek catchment. The Durokoppin (1030 ha) and Kodj Kodjin (204 ha) reserves are large enough to have delayed the onset of salinity (McFarlane & George 1992). Significant revegetation has occurred in the catchment in the last 15 years (~5 per cent).

## Farming systems

Agriculture supports 15 to 20 farm-based enterprises within the catchment. Dryland farming systems are based on coarse grains (wheat and barley) with some lupins, peas and canola. Sheep are the main livestock system, but their numbers have been falling in recent years primarily due to low economic returns and the labour intensive nature of the sheep industry.

## Method

### Groundwater monitoring

Fifteen monitoring bores were installed along a transect perpendicular to the drain (see Figures 1 and 2). Shallow wells were approximately 3 m deep. Deeper piezometers at five sites (to 6 m) recorded the response of the sedimentary aquifer at depth. All bores were cased with 50 mm PVC. The slotted section of the observation wells was brought to within 1 m of the soil surface, while the piezometers were only screened over the lower metre of casing. The section adjacent to the screen in both bore types was surrounded by commercial graded sand and the annulus backfilled with bentonite and drill cuttings.

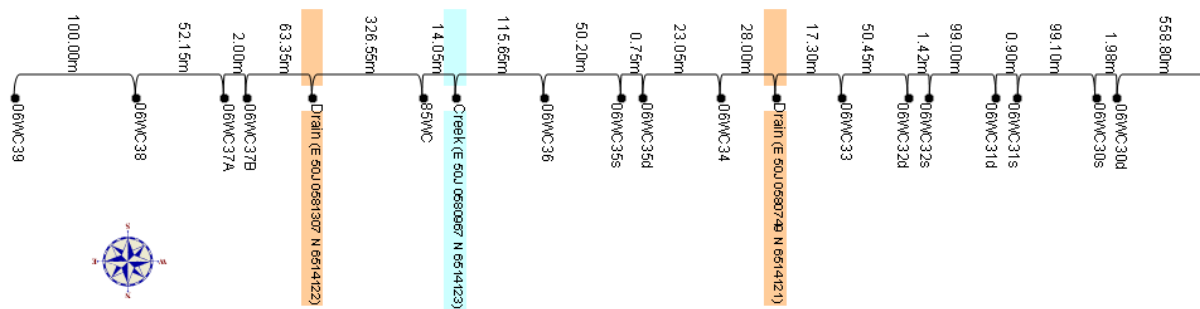


Figure 2 Location of bores along the transect across the deep drain on Bonser's property. (For details in cross-section see Figure 3).

The horizontal distance between wells varied according to proximity to the drain and the location of the creek line and infrastructure (fences, laneways). An arbitrary vertical datum was established at ground level at bore 06WC36 and all bores were measured from that point. The horizontal datum was the centre of the western arm of the drain, and all horizontal distances were measured from that point (negative east, positive west). Distances to the drain and elevations of all bores were established after the drain was constructed (Table 1).

The monitoring bores traverse the valley in an area of extensive salinity. All bores except the two end bores (06WC30 and 06WC39) are located in areas where the watertable was less than 2 m from the surface and the land was moderately to severely affected by salinity. The furthestmost bores had initial water levels of about 3 m (Table 1).

The western section of the transect consists of bores at seven sites (06WC30 to 06WC36s). These bores were also located at variable distances to the drain, ranging from east (–28 m, –51 m, –102 m) to west (17 m, 69 m, 170 m, 270 m). The Wallatin Creek, located between bores 85WC and 06WC36, is dissected into the valley (0.5 m) and has a bed width of about 5–10 m. The location of the bores is diagrammatically presented in Figure 2.

The smaller eastern section of the transect consists of four bore sites located adjacent to the eastern arm of the drain. An additional bore drilled in 1985 comprising two piezometers (85WC03: depth s = 3.3 m and d = 8.81 m) is located adjacent to the monitored transect. This bore is approximately 3 m from the edge of the drain. Prior to 2006, only records from 1985 to 1989 were available.

Table 1 **Location of monitoring bores adjacent to the transect**

<b>Easting</b>	<b>Northing</b>	<b>Bore (06)</b>	<b>AGL (m)</b>	<b>Total depth (TOC m)</b>	<b>Datum survey (m)</b>	<b>Datum (m)</b>
0580478	6514124	WC30d	0.29	6.30	10.2	270 (W)
0580478	6514124	WC30s	0.25	3.35	10.2	268
0580580	6514123	WC31d	0.19	6.23	9.4	170
0580580	6514123	WC31s	0.24	3.50	9.4	170
0580679	6514124	WC32s	0.25	3.47	8.68	69
0580679	6514124	WC32d	0.22	6.72	8.68	68
0580735	6514122	WC33s	0.33	3.43	8.39	17
0580781	6514123	WC34s	0.27	2.63	8.09	-28
0580798	6514117	WC35d	0.31	5.61	7.95	-51
0580798	6514117	WC35s	0.31	3.43	7.95	-51
0580851	6514125	WC36s	0.26	3.55	7.9	-102
0581366	6514010	85WC	0.19	8.81	8.6	-232
0581373	6514126	WC37d	0.32	5.84	8.72	-624
0581373	6514126	WC37s	0.35	3.32	8.72	-622
0581425	6514127	WC38s	0.16	3.30	8.92	-676
0581527	6514128	WC39s	0.57	3.30	9.94	-776 (E)

In addition to these wells, several sites containing other new (2006) and older bores (1985–1986) were also monitored (see Figure 1). Most of these bores were located in the valley floor, well away from the drain, and were used as comparison bores<sup>1</sup> to those on the transect, or adjacent to the drain.

Monitoring of most comparison bores commenced after February 2006, and had approximately the same frequency as those on the drain site (e.g. 85WC03), while the other older bores were drilled twenty years prior to the commencement of this project, their monitoring records only extended to 1989 (4 years). Details of these bores and results can be found in McFarlane & George (1992). This deficiency in the record highlights the need for consistent long-term monitoring wherever possible.

The deep drainage system was constructed between 21 June and 26 July 2006. Construction passed the western section of the observation bore transect on or about 10 July 2006 and is understood to have passed the eastern section of the transect about 5–7 days later.

<sup>1</sup> *The term comparison bore is used in preference to control bore. It is not feasible to drill control bores owing to the natural variability in the landscape.*

Bores were monitored manually from 11 April 2006, prior to the construction of the drain. Data loggers, installed at six sites in eight bores in the western transect, began logging on 21 June 2006. Loggers were set to record water levels at 30 minute intervals. Occasional manual records (8) were collected from then until the loggers were removed in June 2007. Manual records continued to be collected until frequent monitoring ceased in September 2008.

Of the logged sites, only logger records from seven bores next to the drains (bores 06WC31–36) were considered usable. Logger records in other bores such as 06WC35 and 06WC36 either showed high frequency changes in water levels during periods of little actual water level change, or they failed to respond to rainfall response peaks (determined by comparison with rainfall and manual data). Therefore in most bores, only the logger record around the period of drainage construction (10 July 2006) was assessed. This was done to determine the immediate pressure response. Logger records in the remainder of bores were only used if they were able to be verified by manual records.

One additional shallow comparison bore (86WC17), located 500 m north of the drain, was equipped with a data logger. However the logger record showed a monotonic trend—increasing 0.5 m throughout the installation period of July 2006 and stabilising in August—consistent with either a very low permeability or a data logger fault. The data for this bore (Appendix 1) was not analysed further.

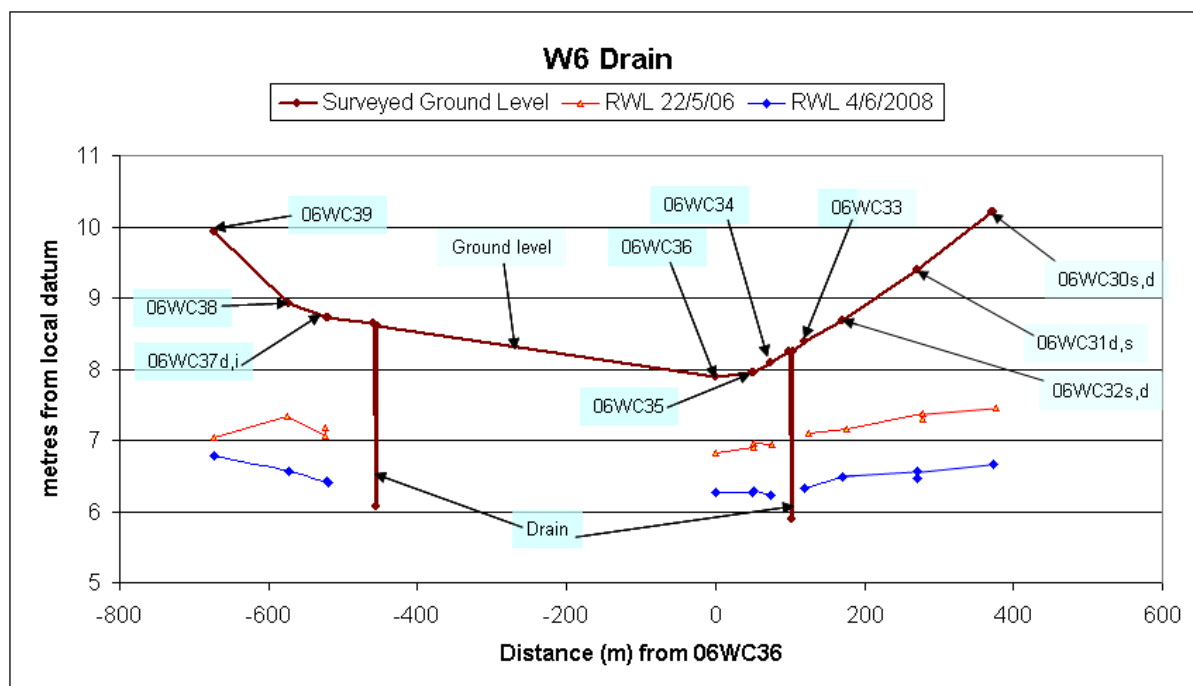


Figure 3 Cross-section of the transect across the W6 drain, showing the locations of the bores as well as pre-drain and post-drain water levels. Water levels for both deep and shallow bores are shown on the cross-section.

## **Drain flow and water balance**

A stream-flow gauging station (6151449) was established by the Department of Water at the outlet of the drain. The station began collecting data on 29 May 2007, almost twelve months after the drain had been completed. However not all data was being reliably logged until 20 July 2007, when the station began to collect flow, electrical conductivity and temperature information (Brad Degens, pers. comm.). At the time of publication of this report, flow data was only available until 3 February 2009 (564 days total). Electrical conductivity (EC) and pH was measured manually to 27 June 2008. Logged data was verified according to Department of Water standards.

In order to undertake a drain water balance and determine how much of the flow may have been sourced from groundwater, the inputs and outputs to the drain were assessed. Only total drain flow, measured at the weir, was known. Other variables were estimated and the water balance calculated using the equation:

$$\text{Groundwater flow} = \text{total drain flow} - \text{direct rainfall} + \text{direct evaporation} - \text{surface run-off}$$

As an approximation, direct rainfall/run-off was estimated to be equivalent to 100 per cent of the daily rainfall on the drain floor and part of the embankment (to a width of 4 m). This represented up to 32 per cent of total drain flow.

The drain flow and electrical conductivity (EC) data was also used to estimate the amount of water evaporated within the drain. By measuring the change in EC during extended periods without rainfall (for instance, 1 September 2007 to 13 December 2007) and relating this to the surface area of water within the drain and daily evaporation (estimated from Merredin data), an evaporation factor was established. Daily stream-flows were increased by this amount to account for water lost in the drain. Evaporation was estimated to be about 5000 kL or 10 per cent of the observed flow.

Estimates of the amount of surface run-off that entered the controlled inlet structures were derived from hydrograph analysis and the electrical conductivity record. Large volumes of surface water entered the drain on several occasions, in particular on 28 July 2007, 17 December 2007 and 1 April 2008. On these dates, daily rainfall around the drain was approximately 13.5, 29 and 26 mm respectively, and estimated daily flows were recorded as 1484, 2265 and 1829 kL. To determine the drain water balance, daily flows above 200 kL/day (considered the maximum potential baseflow from hydrograph analysis) were deleted and replaced with a value of 200 kL. This occurred on 38 of the 564 days of record. Taking all these elements into consideration, total surface flow was estimated to be a maximum of 60 per cent of the measured total drain flow.

## **Rainfall trends (AMRR)**

Daily and monthly rainfall records were obtained from Bureau of Meteorology climate stations at Kellerberrin and Doodlakine (see Figure 4a). The Doodlakine data had several missing records in 2007, so the main long-term dataset cited in this report is from Kellerberrin. This was supplemented by data from local farmers (Bonser, Thomas and Dixon 2006–2008) and a corrected Kellerberrin accumulated monthly residual rainfall (AMRR) graph based on the 1975–2008 averages.

Actual monthly rainfalls in the composite station were subtracted from the average monthly rainfall (1975–2008) to enable the AMRR to be determined. This period was chosen as a benchmark for this hydrologic analysis as it represents the period after which rainfalls are believed to have declined markedly across the South-West Land Division (Bert et al. 2004).



A composite plot of AMRR was determined using local farmer data supplemented with Kellerberrin data. This AMRR was based on the 1975–2008 averages. Figure 4b shows the composite AMRR plot. The variability (steps) in the raw Doodlakine and Kellerberrin data is due to missing values in early 2007 and June 2008. Only the composite AMRR plot is used in the following analysis.

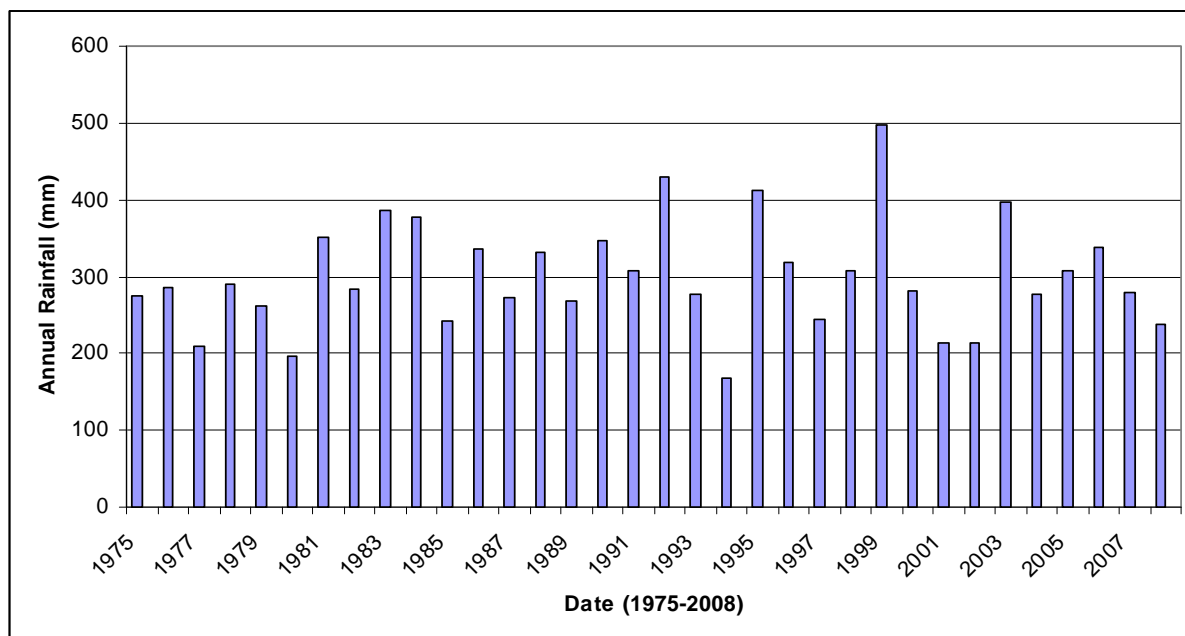


Figure 4a Annual rainfall (mean 328 mm)

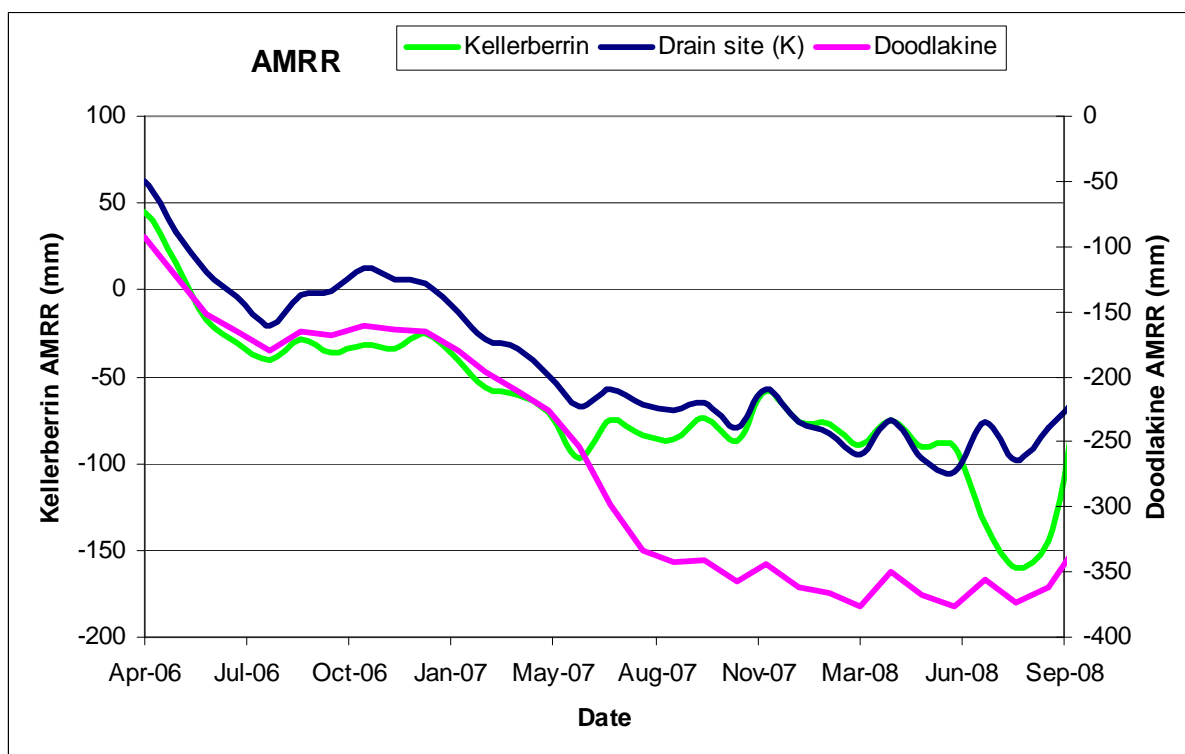


Figure 4b Data for Kellerberrin, drain composite AMRR (includes farmers' data 2006–2008, drain site (K), supplemented by Kellerberrin data), and Doodlakine.

## Results

### Groundwater response

The water levels in 16 observation wells drilled at 11 sites on one transect straddling two parallel drains were measured before and after the installation of the 2.5 m deep drain. Water levels in all bores were manually observed from April 2006 to September 2008 and six drain sites were equipped with eight data loggers from 21 June 2006 to 5 June 2007. Only seven of the loggers functioned adequately through the twelve month period of record. As noted in the methods, some of the loggers did not match the manual data for the full period and therefore were used only used to look at the initial response (dewatering and/or pressure release) after construction.

#### *Initial response*

Logger responses used to assess the magnitude of water level change before (21 June 2006) and immediately after (31 July 2006) construction of the 2.5 m deep drain are presented for six bores in Figure 5 and summarised in Table 2. The logger data reveals the greatest response occurred close to the drain (17 m west, 28 m east) and *no significant response* was apparent at distances greater than 17 m west and 28 m east. If there was a response at 69 m west, it was small (< 0.05 m) and within the likely errors of detection.

Table 2 Initial water level response in bores adjacent to the drain

Bore	Distance from drain	Initial response (m)
06WC31	178	Nil
06WC32	69	Uncertain (nil or 0.05 m)
06WC33	17	0.1 to a maximum of 0.2 m
06WC34	-28	About 0.1m
06WC35	-51	Nil
06WC36	-102	Nil



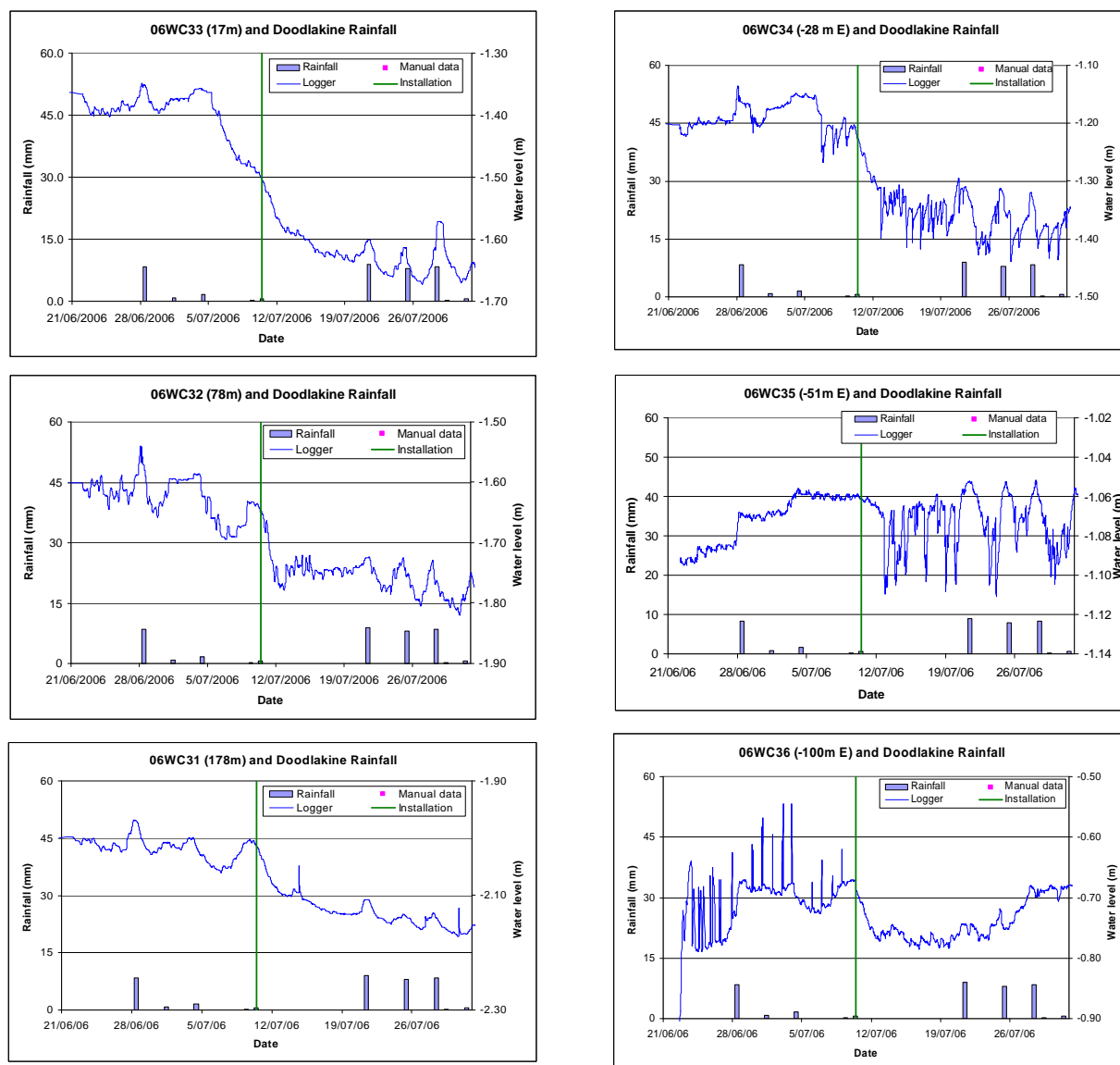


Figure 5 Logger data showing initial water level response in bores west (left column) and east (right column) of the western drain. Note the sporadic high frequency logger response (particularly in eastern bores). This is logger 'noise'.

### **Longer term response**

Figure 6 shows the data record (both manual and logger data) for two representative bores adjacent to the drain. Bore 06WC33 is 17 m west of the drain and showed the greatest initial response after construction (Figure 6a), while bore 06WC31 (located 178 m west) showed no initial response (see Figure 5, Figure 6b, Table 2).

Both the manual and logger data collected from all bores on the transect show a gradual water level decline that began prior to construction and continued throughout the monitoring period. By 2007, water levels had dropped by about 1 m, to between 2 and 2.5 m below ground.

A second cluster of bores located near the convergence of the east and west tributary drains (1 km south of the transect) was also assessed. These bores are located to the east of the Wallatin Creek, between 20 and 30 m from the deep drain. The bores are in an area that is extremely saline and monitor groundwater as it discharges vertically from a relatively deep (25 m) basement trough. A granitic ridge to the south of bore 85WC05 impedes southward groundwater flow (McFarlane & George 1992, Figure 6). The basement ridge was intersected by the drain, causing the drain to become shallower (to 1–2 m) in this area.

In contrast to the main transect bores, those adjacent to the drain in the saline seep above the basement ridge showed consistently high water levels and only seasonal responses to rainfall. No effect attributable to the deep drain was able to be observed (see Figure 7 and Figure 17) in any of these bores.

Three other bores near the drain have records that precede drain construction. One (85WC03) is located close (3 m) to the drain on the western transect and the others (85WC05, 05WC10) are further south and 20 m to 30 m from the same drain (see Figure 1). Despite being close to the drain, they show little obvious impact of the drain. Further analysis of the response of bore 85WC03 and 05 is considered in the discussion section of this report.

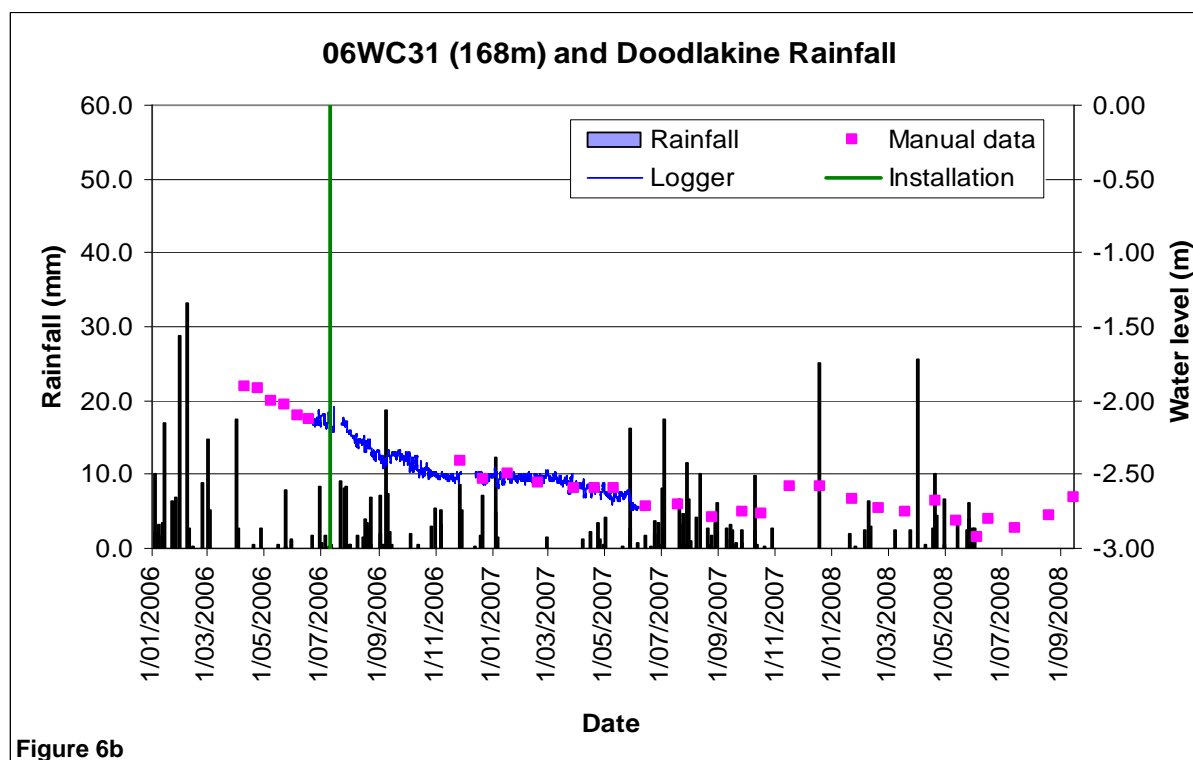
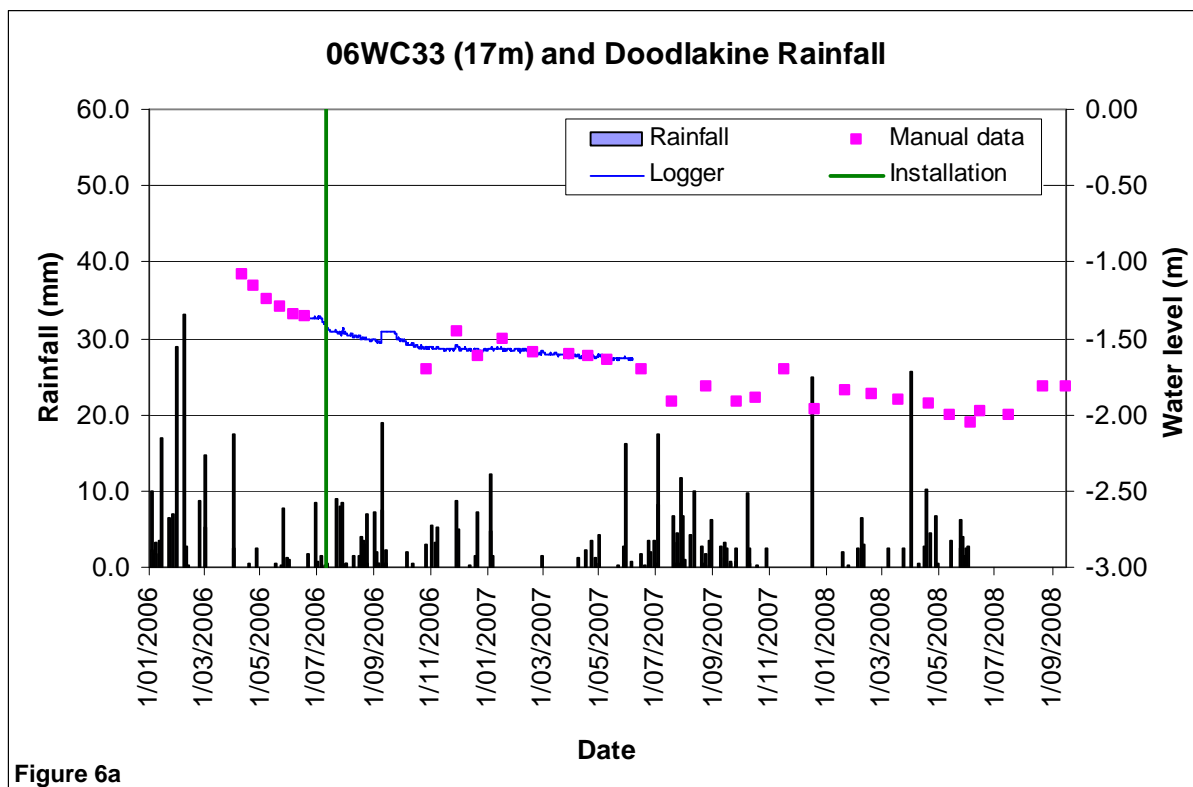


Figure 6a & 6b Logger data showing water level response to rainfall in (Figure 6a) bore 06WC33 located 17 m west of the drain and (Figure 6b) bore 06WC31 located 168 m west of the drain.

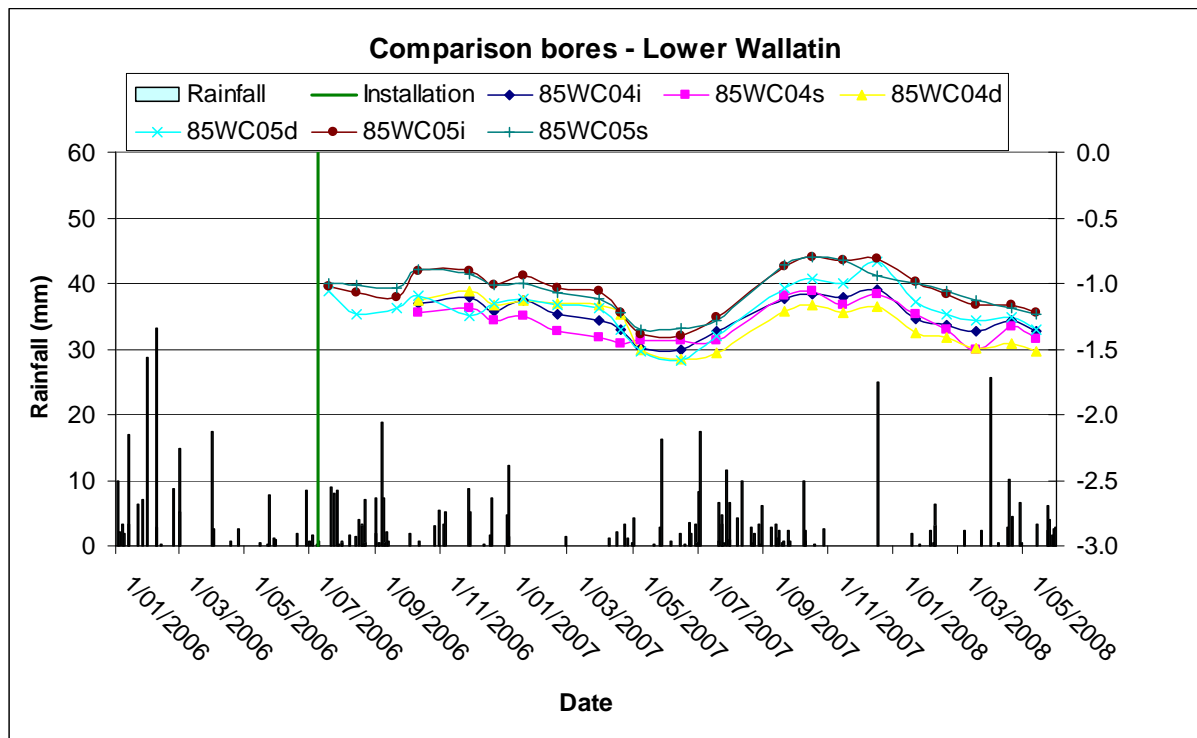


Figure 7 Manual data showing little response in water level to rainfall in two bore nests adjacent to the Wallatin Creek and drain on the Thomas property at a highly saline and scalded area. The bores show upward heads.

## Comparison bores

Water level responses in observation wells drilled at distances greater than 500 m from the drain were studied as a means of comparing the responses in bores adjacent to the drain.

Three clusters of bores are located to the north (Wallatin Road North: 85WC13–17, Figure 8), east (near Walsh Road: 85WC19 and 20, Figure 9) and south (Wallatin Road South: 05WC16 and 17, Figure 10) of the drainage area. Water levels observations were made at a frequency similar to that of the bores on the transect across the drain, although pre-construction data only exists for bores 05WC16 and 17 (Wallatin Road South).

The bores located near Wallatin Road North are in an area where the valley narrows and there is a deep sequence of permeable valley sediments (George 1992, McFarlane & George 1992). Water levels in this area show a gradual decline (~0.5 m) that is not as great as the decline on the drainage transect (Figure 8).

Bores to the south-east of the drainage transect, near Walsh Road, are located on a broad expanse of fine-grained valley sediments, midway between the saline area being drained and a large area of salinity to the south-east. These bores show a similar or slightly greater decrease in water level (Figure 9) over time compared to those near the drain and those on Wallatin Road North (Figure 8).

Further south, where the drain terminates near the weir, a series of bores was established about 500 m east of the gauging station to serve as comparison bores for the W6 drain and for future use in monitoring the effect of a proposed groundwater pump. The bores are in a cropping paddock (barley) that has shallow watertables and a continuum from moderate salinity (near the creek line) to non-saline soils (to the east). Water levels in these bores

showed a significant and monotonic downward trend throughout the monitoring period, with levels falling by 1.0 to 1.5 m (Figure 10), depending on geomorphology and distance to saline areas.

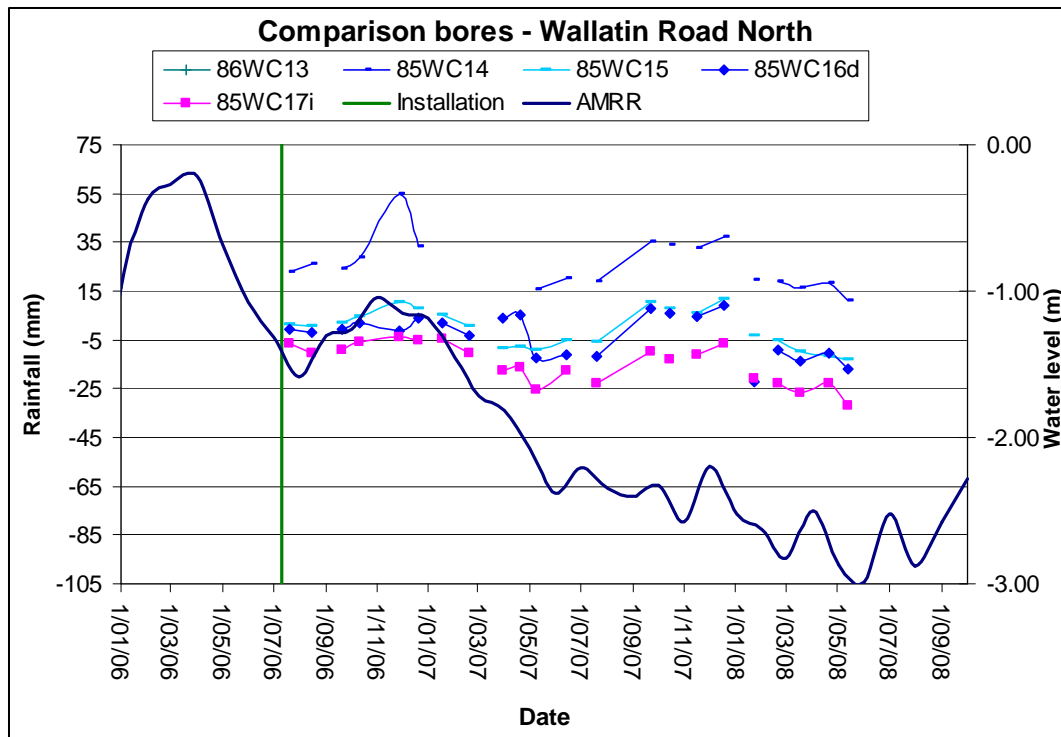


Figure 8 Comparison bores on Wallatin Road North.

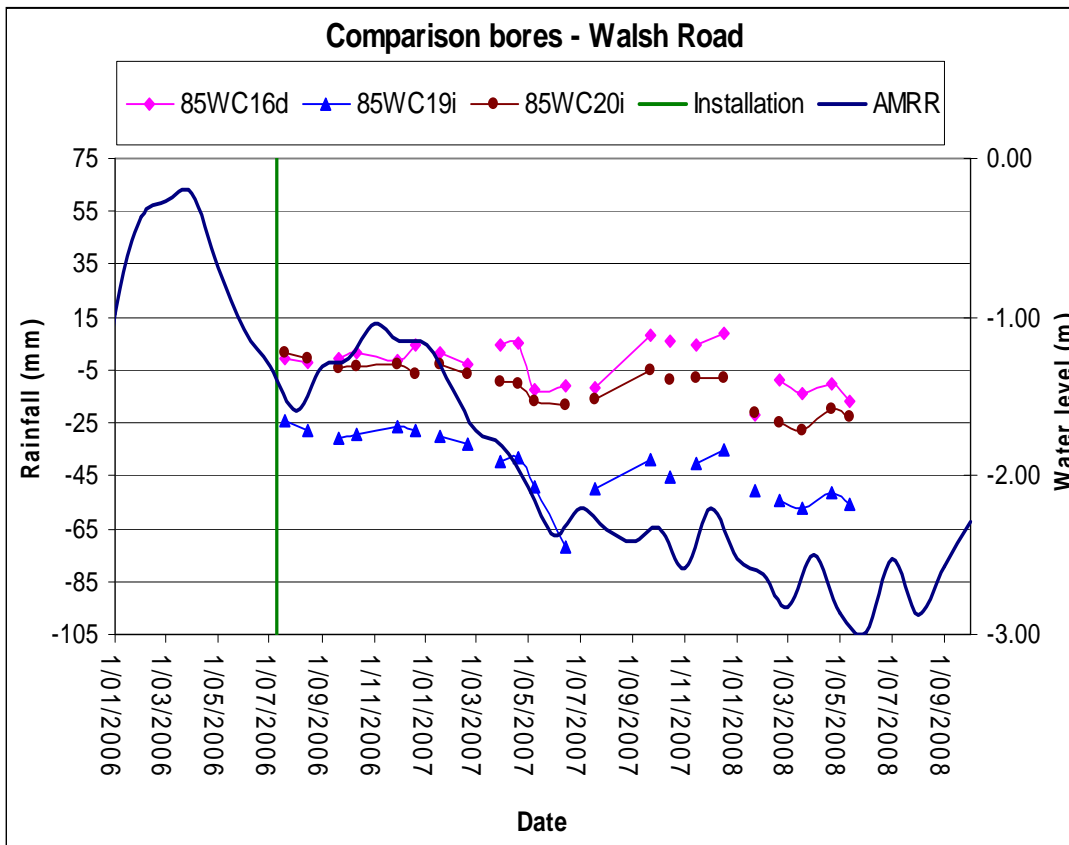


Figure 9 Comparison bores near Walsh Road

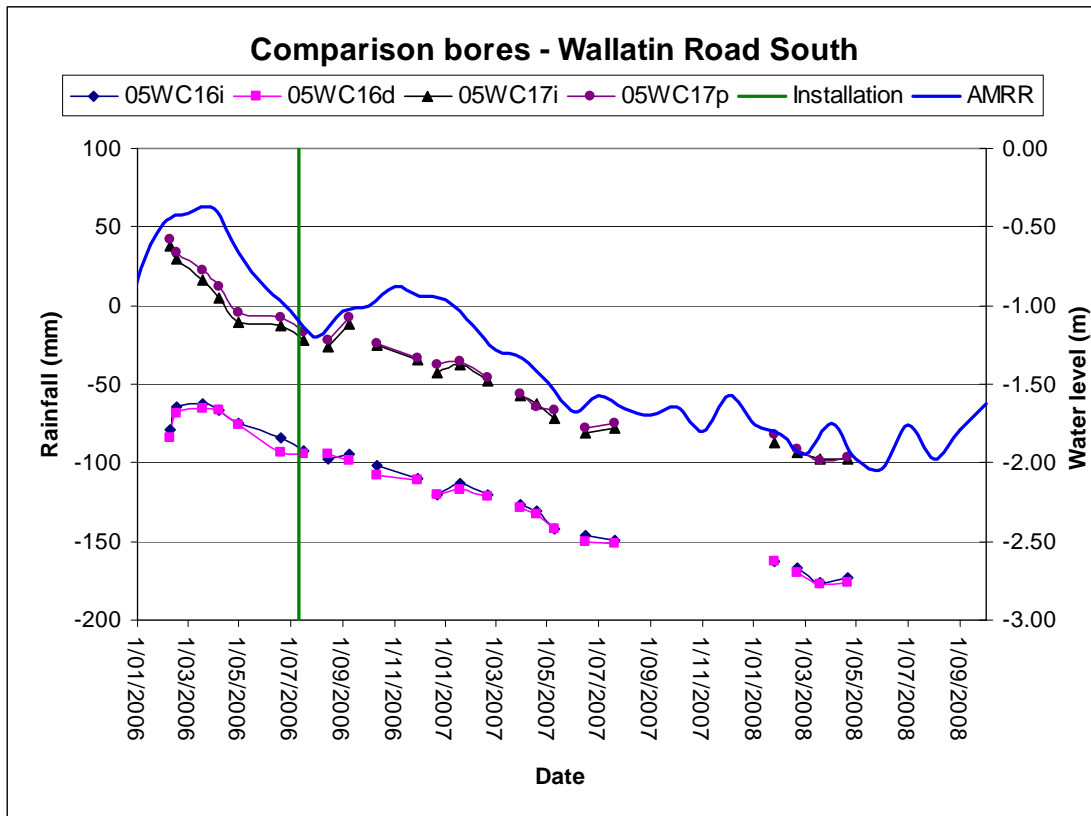


Figure 10 Comparison bores on Wallatin Road South

## Rainfall trends (AMRR)

Monthly rainfall was compared to mean monthly rainfall for the period between 1975 and 2008 to calculate the accumulated monthly (or annual) residual rainfall (AMRR, AARR). This was done to describe the patterns in rainfall variability and to help determine the effect of climate on the observed water level responses. AMRR was defined by comparison of raw rainfall data while AARR was derived using HARTT (Ferdowsian et al. 2001).

Bore 06WC33 is 17 m west of the drain and showed the greatest initial water level response after drain construction, while bore 06WC31 (178 m west) showed no initial response (Figure 6, Table 2).

The water levels observed before and after drainage for bore 06WC33 generally match the slope of the line established by the AMRR plot (see Figure 10). Similarly, the water levels for bore 06WC31 matched the trend in AMRR (Figure 12). The AMRR lines (monthly data) appear to precede water levels (daily data) due to the difference in data frequency.

The plot of AMRR and comparison bores 05WC16-17 (Figure 13) shows a similar trend to the bores on the drainage transect, with the slope matching the pattern derived from rainfall.

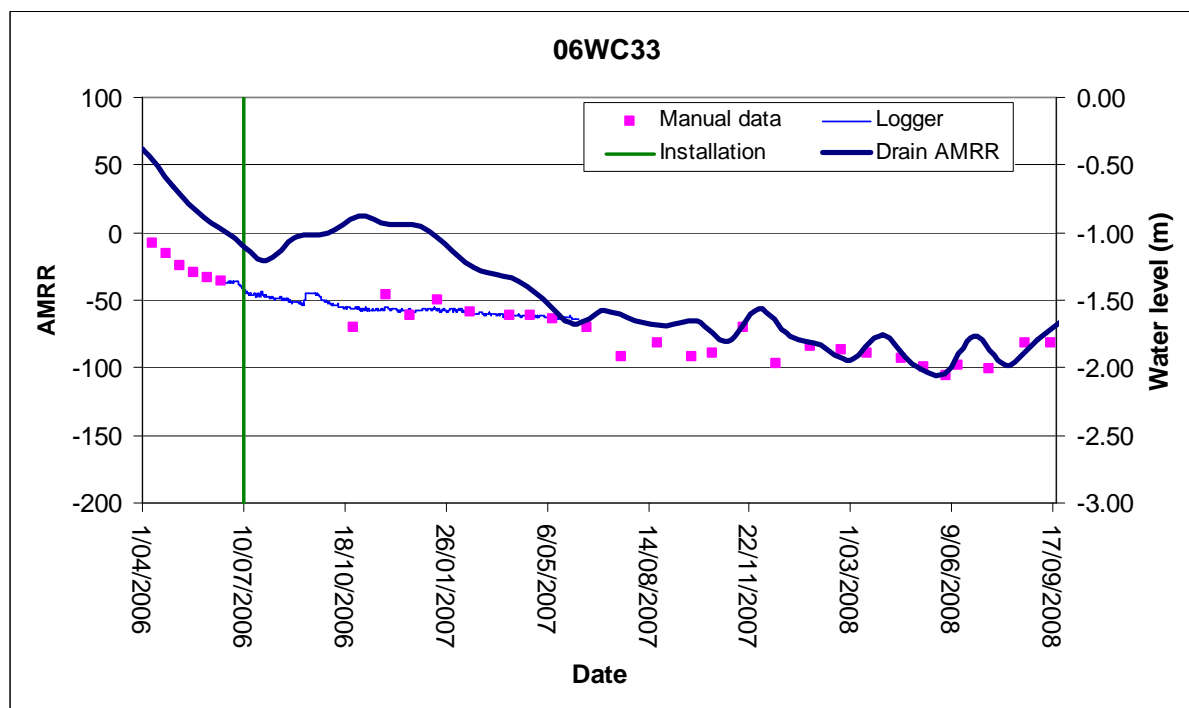


Figure 11 Accumulated monthly residual rainfall (AMRR) and water levels in 06WC33.

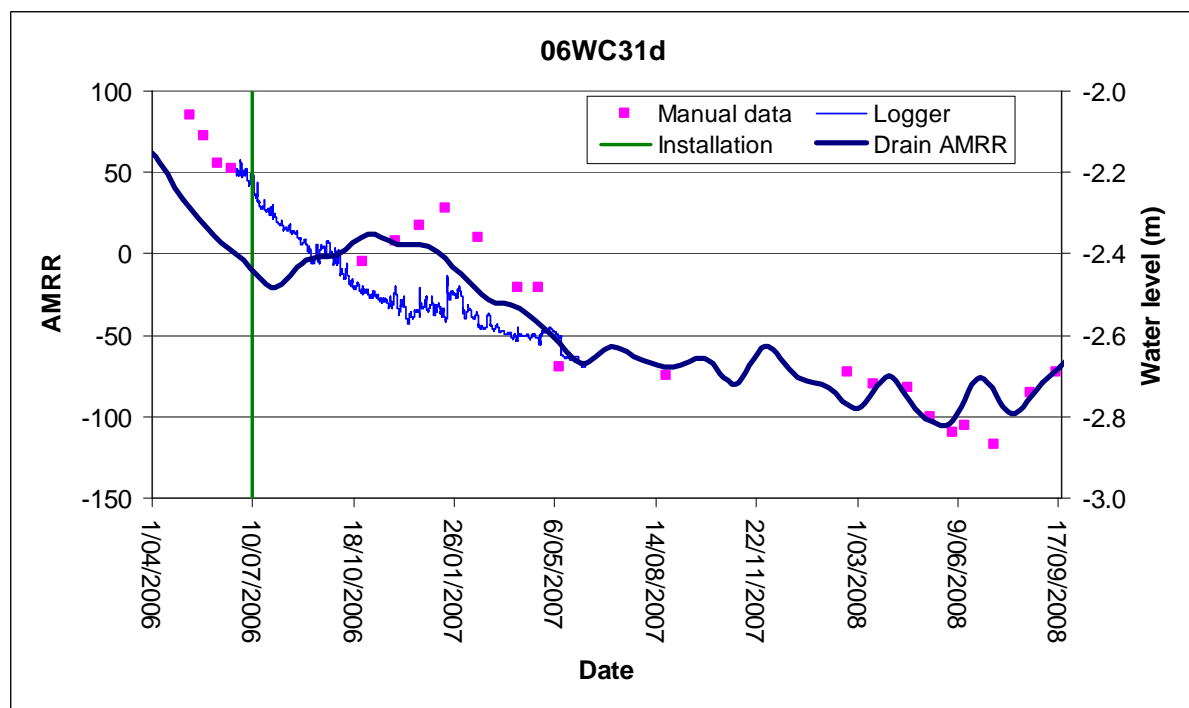


Figure 12 Accumulated monthly residual rainfall (AMRR) and water levels in 06WC31.

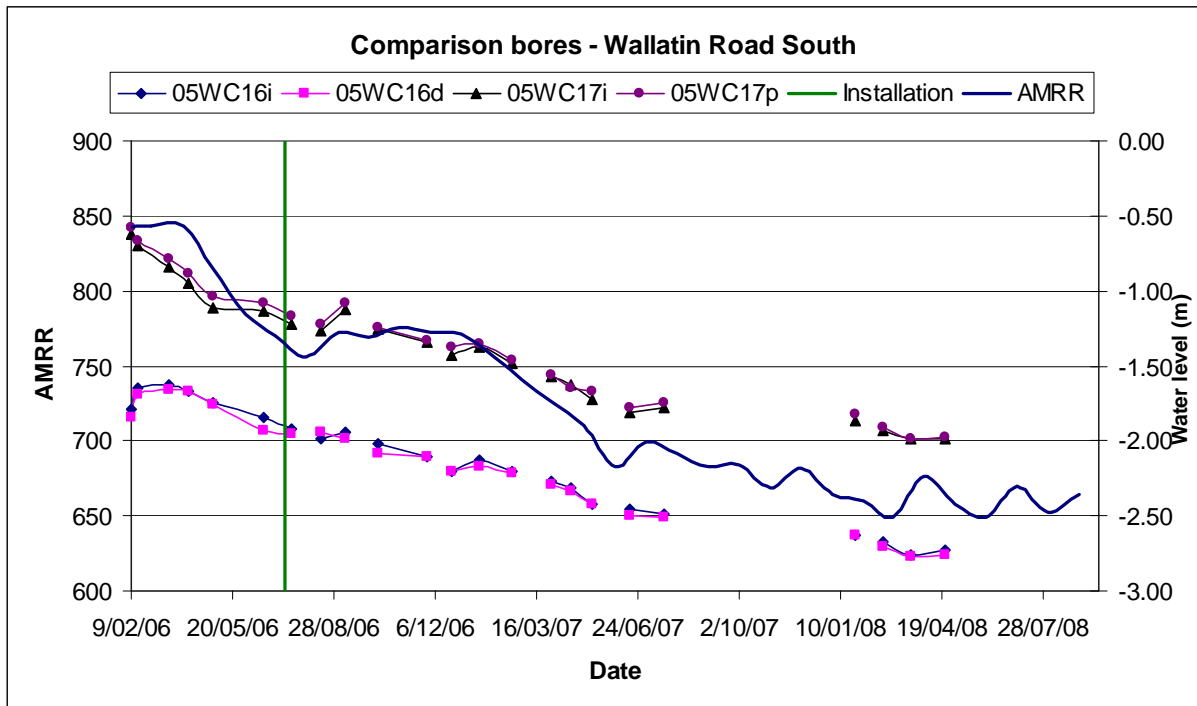


Figure 13 Accumulated monthly residual rainfall (AMRR) and water levels at comparison bores 05WC16 and 17 (nested bores).

## Discussion

### Effect of drain on groundwater levels

#### Initial response

The water level responses in observation wells located adjacent to the drain indicate a rapid, but small ( $< 0.2$  m) reduction 17 to 25 m from the drain (Figure 5). At a distance greater than this on the west side, and at a distance less than 51 m to the east, there was no clearly observable initial response.

The initial response was observable in bores near the drain over a period of 5 to 7 days from construction, after which water level responses were dominated by other factors (discussed below). The limited distance and small magnitude of the response suggests that the watertables were lowered by de-watering macropore systems of various scales (from root holes to sand seams) exposed by the drain construction.

Relating water level response to a primary cause (drainage) was difficult as the magnitude of impact was small. It can also be difficult to assess cause accurately due to confounding influences of rainfall, changes in barometric pressure and evaporation. Of these three factors, rainfall can be discounted as no rainfall above 2 mm occurred in the two weeks before and the two weeks after construction. The effect of evaporation is also expected to be minimal in winter. By contrast, responses of the order of 0.1 m or more are expected from changes in barometric pressure. Both the 06WC33 and 06WC34 data loggers show a decline in water levels on 3 July (7 days before construction) of the order of 0.1 m (06WC33) and potentially 0.05 m (06WC34). At all bores except 06WC33 (17 m west), water levels began to rise by 6 July. These upward trends levelled off after 7 July (increased barometric pressure) when the effect of construction of the drain was observed in the bores in close proximity to the drain.



Only one other bore, located more than 28 m from the drain, showed a possible response to drainage. Bore 06WC32 is located 69 m from the drain and recorded a 0.05 m response in the logger data immediately after construction of the drain. However this response and timing could also be explained by barometric pressure changes. Unfortunately inaccuracies associated with the use of capacitance probes and the lack of field barometric data correction mean that this effect could not be accurately determined.

### ***Longer term response***

Three methods were used to assess whether the drain caused a longer term response in water levels in monitoring wells after the initial period: (a) proximity to the drain; (b) comparison between water level patterns in drain and comparison bores; and (c) direct comparison of bores next to the drain and AMRR.

#### ***(a) Proximity to the drain***

Over the two years between May 2006 and May 2008 all transect monitoring bores showed a reduction in water level in the order of 0.5 to 1.0 m, irrespective of proximity to the drain. Figure 14 shows a cross-section of responses for each of the shallowest bores, starting from east (left) to west (right). If a pattern exists, it is that the largest response occurs at the greatest distance from the drain. This is the opposite of the effect that might be expected—that a fall in water levels would be greater near the drain—if the drain is having the dominant impact. The smaller water level changes in bore 06WC39, to the far east of the drain (left side of Figure 14), reflects its position on shallow basement.

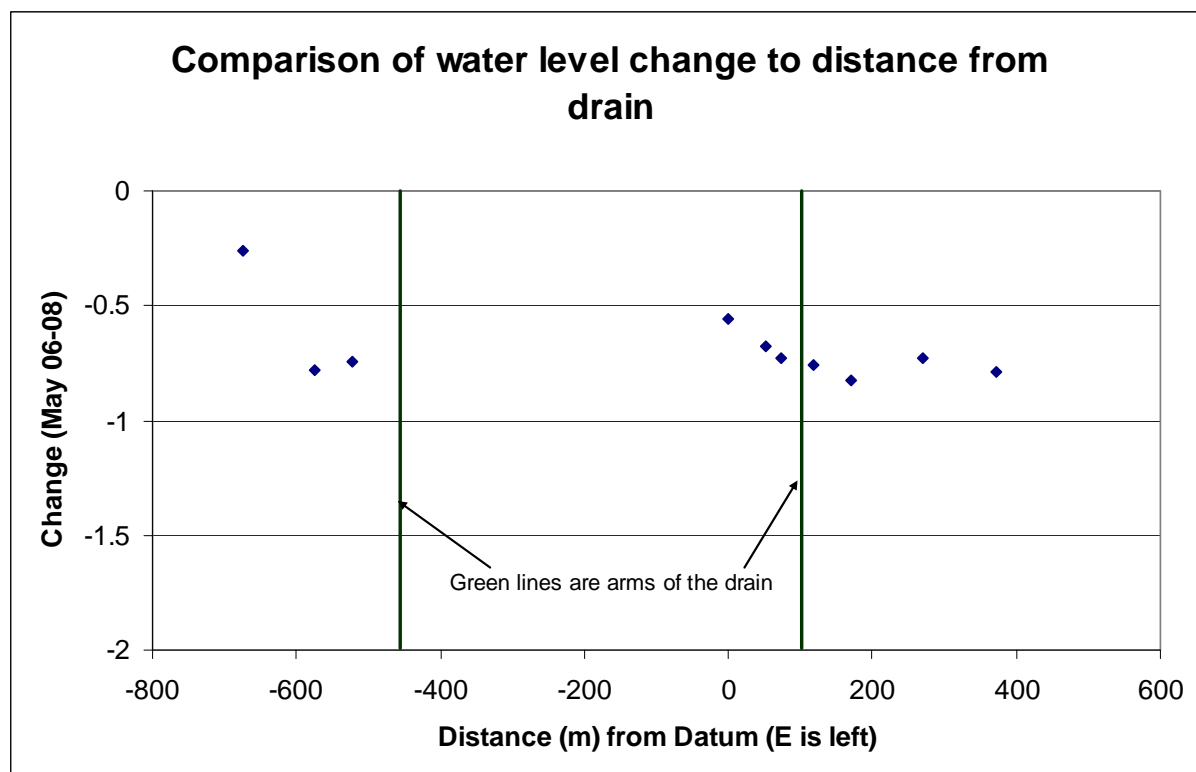


Figure 14 **Water level changes (May 2006 to May 2008) by proximity to drains.**

However not all bores near the drain show the same trend in water level. Bore nests 85WC04 and 85WC05, located ~20–30 m east of the main drain, immediately above the basement ridge (see Figure 7), showed no effect after drainage.

By contrast, the water levels in bores 05WC10 (d, s) show a well-established downward trend (see Figure 15) that preceded construction of the drain and was likely the result of low rainfalls. No obvious effect of the drain (located 19 m to the east) can be seen in the pre-drain and post-drain water level pattern.

What is also apparent is that the vertical groundwater pressure head gradient that existed between the shallow (7.5 m) and the deeper (41.5 m) bore has diminished (October 2007) or even reversed (June 2007). This response is consistent with the effects of reduced rainfall and may have resulted in the reduction of the shallower aquifer heads relative to those at depth.

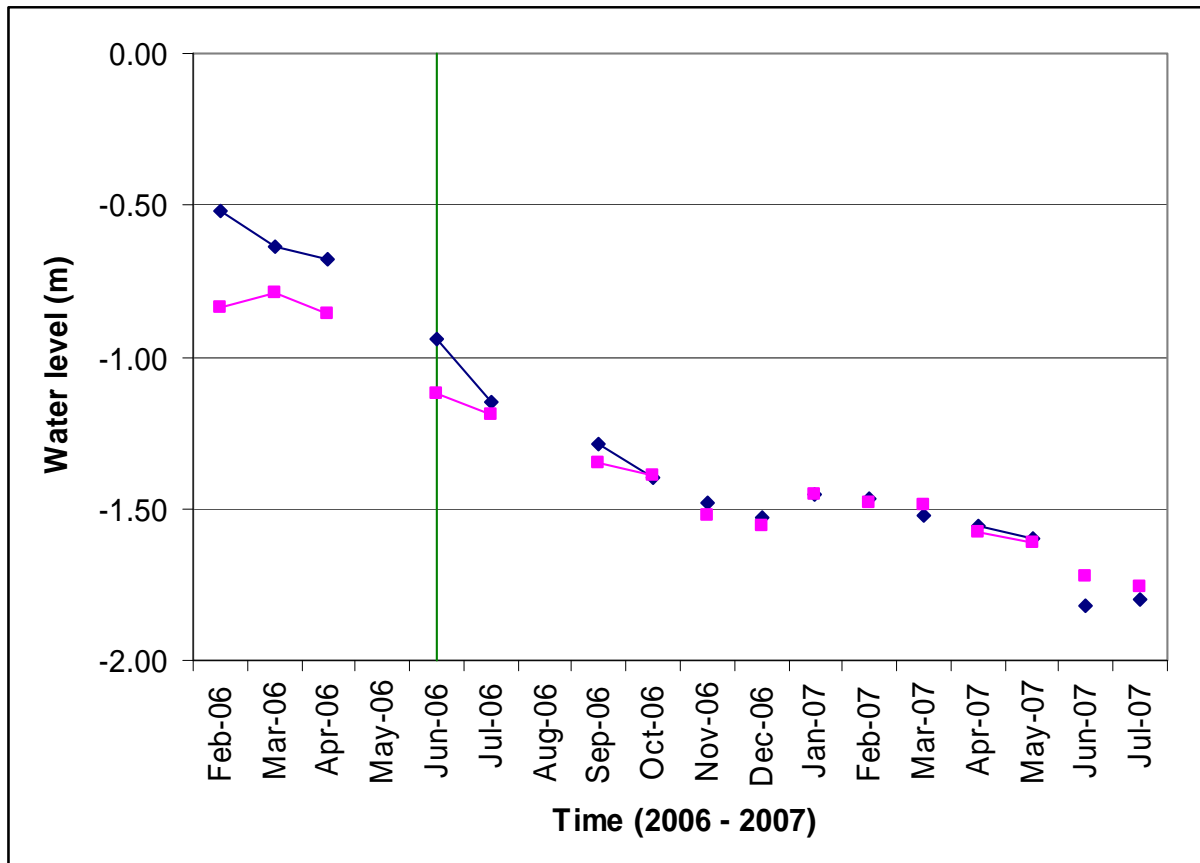


Figure 15 Comparison of pre and post drainage water levels in bores 05WC10 [deep (square symbol), shallow (diamond symbol)] located 19 m from the drain ~400 m south of the eastern transect.

### (b) Comparison and drain bores

The relative difference in the response of comparison bores (Figures 7 to 9) and drain bores shows that the downward trend observed in the bores adjacent to the drain is very similar to bores located greater than 500 m from the drain. This is best illustrated by reviewing the response of bore 06WC33 (which had the greatest initial effect), located 17 m west of the drain and 05WC17 (500 m east from the end of the drain). The two hydrographs show very similar rates of recession and suggest that a factor other than the drain is controlling the longer term response (Figure 16).

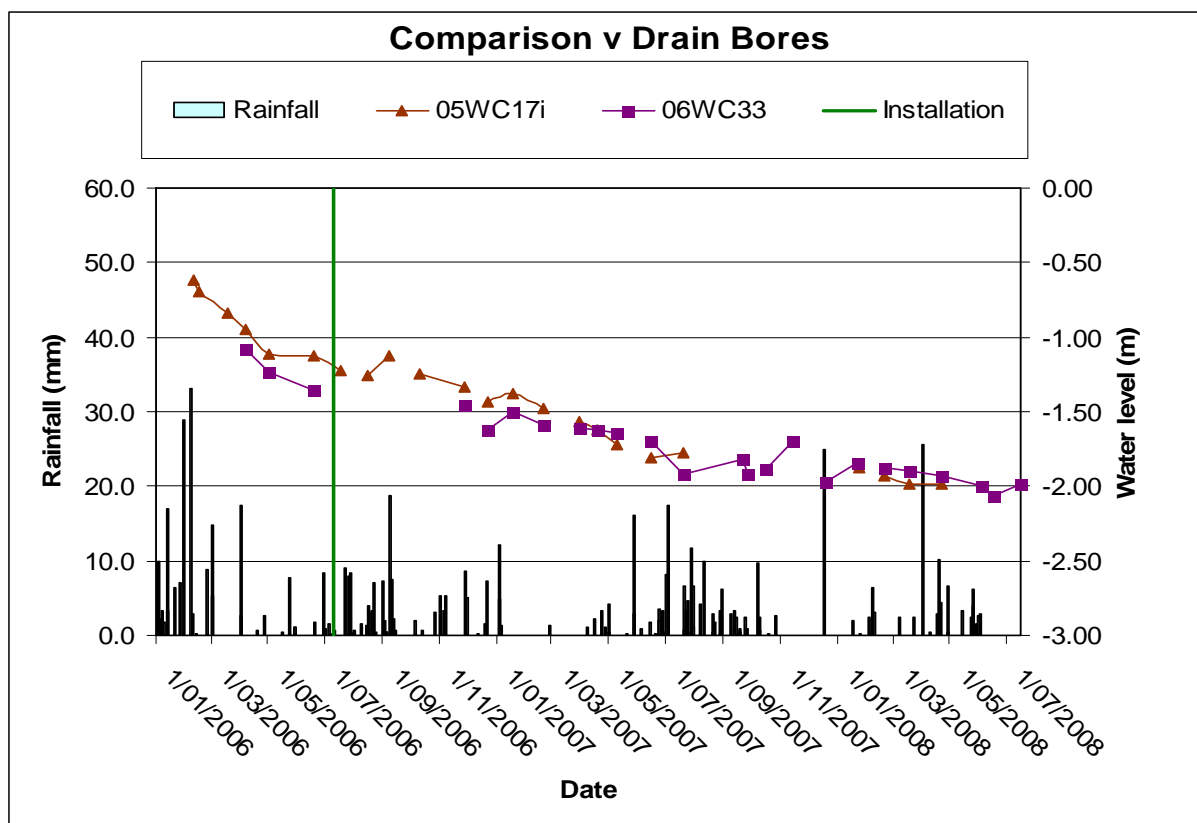


Figure 16 Water level changes in drain bores and comparison bores are similar.

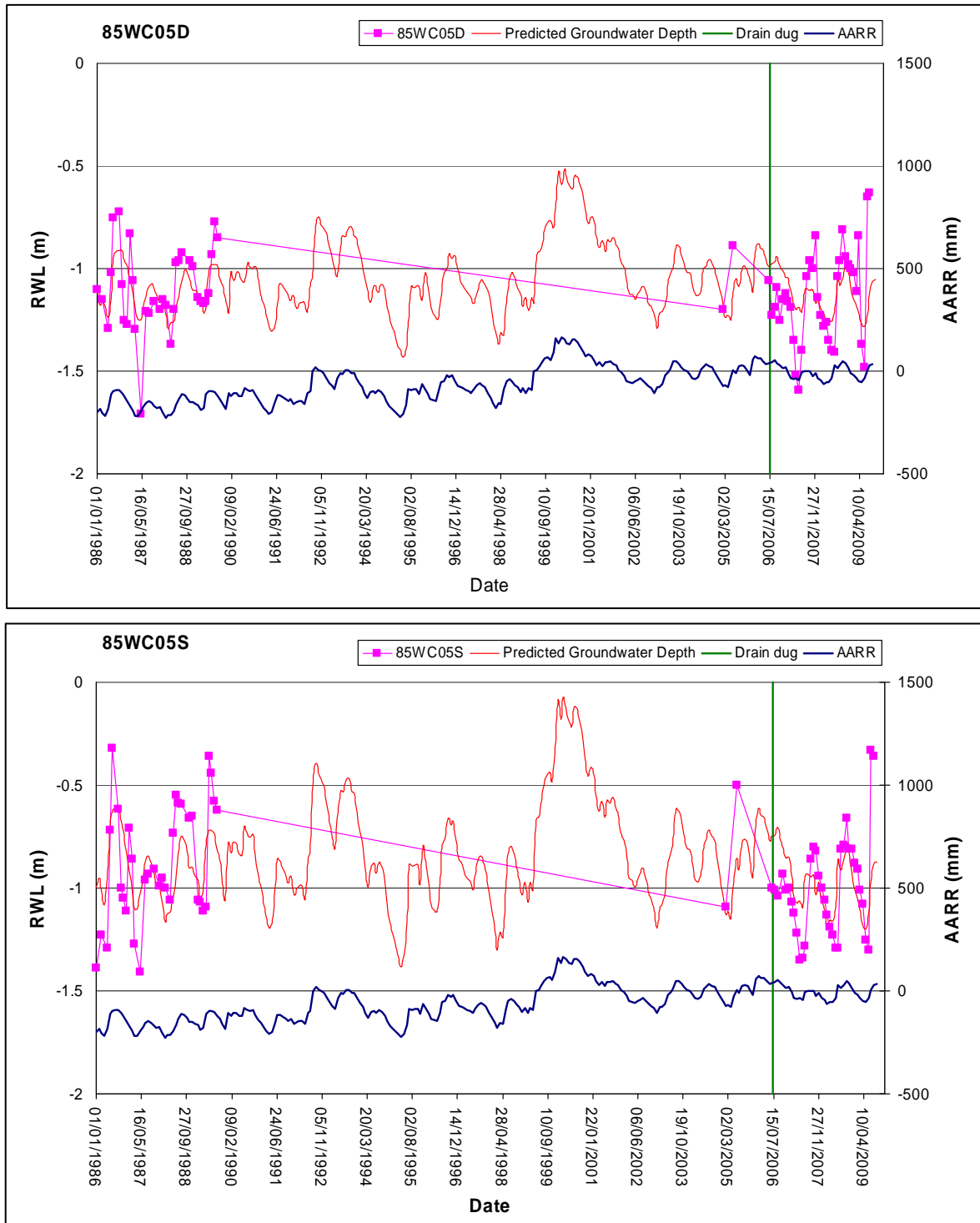
### (c) AMRR and long term trends

A comparison can be made between longer term rainfall trend data (AMRR) and water levels. Analysis of Figures 12 to 14 reveals that the patterns observed in bores, especially those located more than 28 m from the drain, are best explained by the dry conditions, not proximity to the drain.

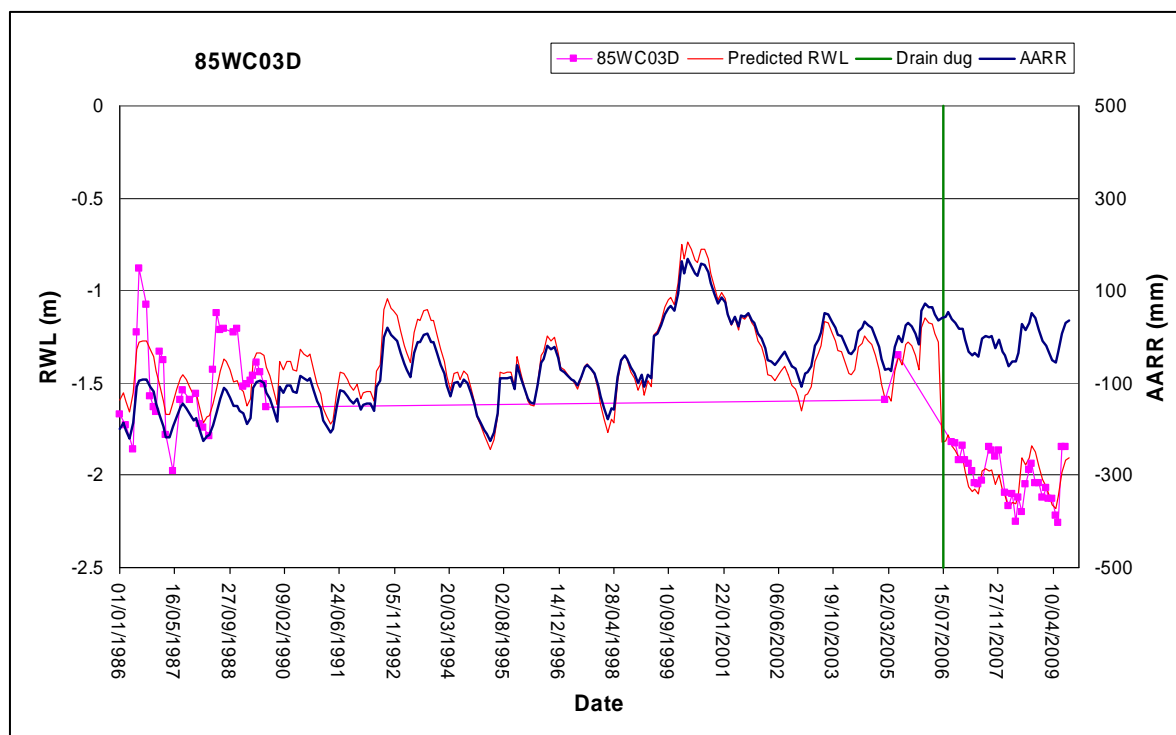
To further assess this relationship, historic water level data for bores 85WC05 and 85WC03, located ~30 m from the drain and 3 m from the edge of the eastern arm of the drain near the monitoring transect (Figure 2), were compared to the corrected drain AMRR, AARR and current (post-drainage) water level data. Bore 85WC05 analysis was undertaken with HARTT (Ferdowsian et al 2001) to determine this relationship statistically.

Figure 17 shows the effect of rainfall on 85WC05 water levels over the 24 year period. Statistics from the HARTT analysis indicated rainfall (AARR) was the dominant driver in the observed trends. The p statistic for residual rainfall was  $2.2 \times 10^{-6}$  and  $4.1 \times 10^{-5}$ , respectively. No impact of the drain could be determined from the analysis.

By contrast, Figure 18 constructed to match the patterns observed between summer water levels and rainfall data, suggests that post-drainage water levels are below what which would be expected without the installation of the drain. From this analysis, the response (3 m from the drain) caused by the drain appears to be of the order of 0.5 m. While this may be used as a guide when considering the expected long-term impact of the drain on nearby water levels, the location of the climate station and reliability of the methodology also needs to be considered.



Figures 17 HARTT analysis showing observed and predicted water levels for both deep and shallow bores at 85WC05.



**Figure 18 Bore 85WC03 pre-drain and post-drain measured water levels, predicted water levels and AARR data, about 3 m from the drain. HARTT analysis indicates that impact is statistically significant ( $r^2 = 0.77$ ,  $p = 4.4 \times 10^{-5}$ )**

## Effect of drain in summary

The data indicates that while the drain initially (in the first 7 days) lowered watertables by a maximum of 0.2 m within 28 m of the drain, it has had no additional measurable effect on watertables. While some effect may have occurred at a greater distance (between 28 and 69 m), it was likely to be very small ( $\sim 0.05$  m) and within the measurement error of the techniques used to assess water level changes. It also appears that some of the initial change in water levels (up to 0.1 m) may be due to changes in barometric pressure.

Because of the over-riding influence of low rainfalls on water levels, an unambiguous longer term effect of the drain could not be determined from the two years of data. Only by comparing the long-term water level and rainfall trends in bores less than 10 m from the drain (85WC03) could a localised 0.5 m impact be identified and verified by statistical analysis.

In addition to distance from the drain, proximity to salt-affected areas and aquifer characteristics also appear to be important in describing the magnitude of observed water level responses. Comparison bores at Wallatin North Road and Walsh Road show relatively less fall in water level over time than those immediately adjacent to the saline areas along the drain transect. By contrast, bores on the Thomas farm (e.g. 85WC05), adjacent to a shallower segment ( $< 1.5$ - $2.0$  m) of the drain (20–30 m), basement high, and creek, show little or no impact of the drain on water levels.

## Water balance

To assess the source and likely area of catchment responsible for flows observed in the drain, a simple water balance was undertaken on the stream-flow data (Figure 19). Since monitoring commenced 12 months after the drain was constructed, the observed flow is likely to be more representative of average conditions than if the 'first flush' of water had been included in the analysis.

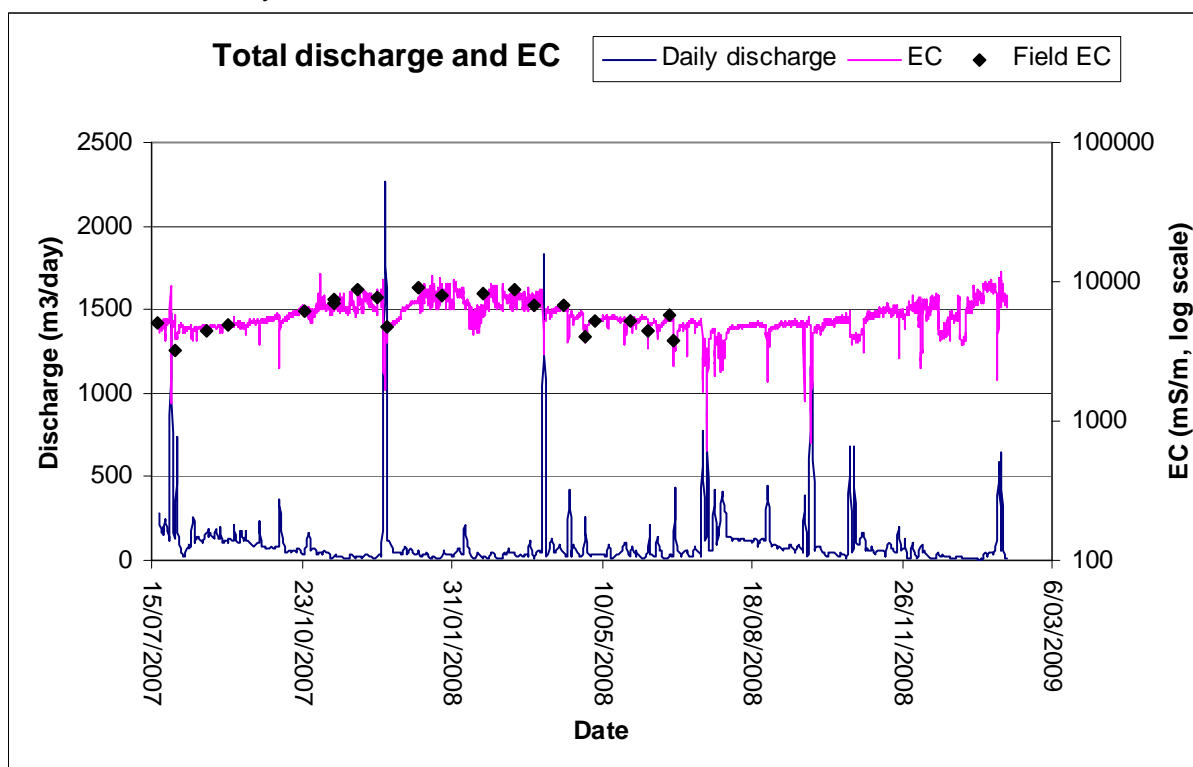


Figure 18 Measured daily drain flow, electrical conductivity (mS/m, log scale) and daily rainfall over 18 months July 2007 to March 2009. For further information, see Appendix 3.

As defined in the methods section, the flow of groundwater can be derived by rewriting the water balance equation such that:

$$\text{Groundwater flow} = \text{total drain flow} - \text{direct rainfall} + \text{direct evaporation} - \text{surface run-off}$$

$$26\,868 = 51\,888 - 16\,937 + 5082 - 13\,166 \text{ (kL)}$$

Total flow measured at the Department of Water gauging station over the 18 month monitoring period was 51 888 kL (see Figure 19). However, given the uncertainty in the data and calibration, daily flow data was de-peaked to exclude surface water (all events above 200 kL/day) from the water balance, reducing the volume to 38 722 kL.

Drain flow during rainless periods is assumed to be due to groundwater inflow. This assumption is supported when comparison is made between the mean electrical conductivity (EC) of the drain flow and of groundwater in nine 2–3 m deep pits installed prior to the drain. The results are very similar. Field data shows the mean EC of groundwater in the deep pits was 4780 mS/m, while in the drain flow it was 4790 mS/m (total salt flux 1740 tons), with an average pH of 3.50.

During a rainless period between October and December 2008, EC increased from 3500 to 7400 mS/m. This rate of increase, along with pan evaporation data from Merredin, was used to estimate losses of flow likely along the drain length due to evaporation. While some

seepage losses may occur in the lower drain area (where watertables are deeper), for simplicity we have assumed this to be zero in the following calculations.

Results of the de-peaked flow (38 722 kL), minus direct rainfall (16 937 kL) plus evaporation (5082 kL) indicate the groundwater component (baseflow) was 26 868 kL.

Dividing the groundwater flow during the monitoring period (564 days) by the number of days gives an average daily groundwater flow of 48 kL, or 2.4 L/m (or mm/m) of drain length.

## Recharge and groundwater

Two methods were used to estimate the potential source and area responsible for generating the measured flow. The first method (a) attempts to calculate the amount of water that may have been lost from storage over the two years of observation, and the second (b) attempts to determine the amount of recharge required to generate the observed flow.

The known (measured):

- Flow—total (26 868 kL) and daily flow
- Watertable impact—(longer term: 1 m) and initial (0.1 m over 17 to < 69 m)

The unknowns (estimated):

- Aquifer storage coefficient (volume released per unit watertable drop/rise)
- Amount of soil evaporation (assumed zero in the 'initial impact' zone of influence).

### Method A

The volume of water generated during the period of 'initial impact' was estimated to be the amount of water able to be released from a wedge of soil between the original watertable level and the level of the new (post drainage) watertable. This was measured to be 0.1 m at a 17–28 m (say 25 m average) lateral distance. At the edge of the drain we have assumed a watertable reduction of 1 m. The volume of two wedge-shaped areas (the sum of both sides of the drain) is estimated as:

$$\text{Length} \times \text{width} \times \text{height} (25 \text{ m} \times 0.1 \times 1 \text{ m}) / \text{storage coefficient}^{(2)} = \text{volume}$$

The same equation can be used to estimate the volume of dewatering removed as the watertable has continued to decline over the two years under observation. For simplicity, we assume a combined width of effect of 100 m (impact of 25 m to the west and maximum 69 m to the east) and total thickness dewatered of 1 m.

Under these conditions, the amount of water released could be about 9700 to 12 000 kL, or between 13 and 33 kL/day.

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<sup>2</sup> Storage coefficient is estimated to be between 0.02 and 0.05 (after George 1992).

### *Method B*

To estimate the contribution of local recharge to the observed flow (~48 kL/day), we again assumed that the composite area of maximum impact of the drain was ~100 m and that this was the sole source of flow. The observed annual flow was divided by the area to give an annual recharge of 18 mm. Thus to generate the observed flow from recharge alone would require 18 mm (or ~6 per cent) of the annual rainfall (304 mm) to be available for discharge. Hence:

$$\text{Annual flow} = \text{area (9700 m} \times \text{100 m)} \times \text{annual recharge (~18 mm)}$$

However, as noted above, during 2008 and 2009 watertables have been falling and between 13 and 33 kL/day of the observed flow could therefore have been derived from storage loss.

If so, the actual recharge contributing to drain flow would be less than 18 mm, putting it within the range of published estimates of recharge (6–15 mm) for the wheatbelt (George et al. 1997). In the future (since storage losses or gains are minimal) drain flow is likely to reduce or cease<sup>3</sup> and will be closely linked to annual rainfall.

Several sources of error may arise in these calculations. Firstly, the amount of groundwater flow may have been less than that estimated and surface run-off underestimated. This is considered unlikely as the data (Figure 19, Appendix 3) indicates flow exceeded 48 kL for much of the time, particularly during rainless periods. Secondly, the area of land contributing recharge (or groundwater flow) to the drain may be greater than that estimated. This is also unlikely given the watertable response data, although we recognise we have data from only one transect and only two other clusters of bores available for analysis.

Hydraulic head data shows a source of baseflow. The relative difference between deep and shallow bores indicates that a likely component of upward groundwater flow could be derived from the deeper sediments. Thus a small change in the gradient over a larger area could initiate upward flow of groundwater derived from a greater distance from the drain. In drier periods, this source of groundwater would dominate the hydrograph and its relevance would be more significant in areas where the drain never ceases to flow. If the drain ceased to flow, that would suggest a lesser role for the deeper aquifer.

In addition, spatial and temporal factors not able to be measured by the bores, such as the effect of recharge from the adjacent Wallatin Creek and the effect of permeable sand seams observed in some sections of the drain, could account for some of the variability in observed baseflows. In particular, some of the recharge would be rapidly moved to the drain by such features in wet periods.

In spite of this uncertainty, this analysis suggests that the source of the baseflow (~48 kL/day) was dominated initially by storage loss and more recently by groundwater from local recharge of rain falling on land adjacent to the drain.

Finally, given that the data has demonstrated only a minor impact of the drain on watertables, what caused the further decline in water levels of up to 0.5 m (near the drains) and between 1 m (Wallatin South Road) and 0.5 m (Wallatin North and Walsh Road), at comparison bores in the valley floor?

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<sup>3</sup> *In January and February 2009, flows at the weir ceased, though some flow was occurring above the basement high in the upper reaches of the drain. Seepage losses of < 5 kL/day were postulated in the area downstream of the basement high.*



We believe that increased soil evaporation is the likely answer to this. Using the parameters above, it can be shown that a 1 m reduction in the watertable can result from the loss of between 20 and 50 mm of water (at 2–5 per cent storage coefficient) by evaporation. With local pan evaporation rates of over 2400 mm/yr, this amount represents less than 1–2 per cent of the potential rate. However, it should be noted that large summer storms or a wet winter could refill this store and water tables could rise again.

## Conclusions

A 9.7 km length, 2.5 m deep drain was installed in the Wallatin Creek catchment in June–July 2006. Groundwater monitoring wells, some equipped with data loggers, were installed prior to construction of the drain. Other bores in the area were also monitored to provide comparison with the responses observed at or near the drain. A weir was constructed at the drain outlet to record the flow volume, salinity and pH levels.

Monitoring between 2006 and 2008 showed that groundwater was lowered by about 1 m below initial watertable levels after drainage, predominantly due to a lack of rainfall. Results of detailed water level monitoring indicate the drain only had a short-lived initial effect (within 7 days from construction) and a minor (~ 0.1 m) impact on water levels in observation wells ~25 m from the drain. No initial response in water levels was observed in bores further than this distance east of the drain and no discernable response was observed in several other bores (85WC04 and 05, 05WC10) adjacent to the drain, lower in the catchment.

Any initial and longer term impact of the drain has been overshadowed by the effect of low rainfalls during 2006–2008, as reflected in bores at the transect. Water levels in comparison bores fell at a rate and timing similar to rates and timing near the drain. In other words, during the two years of observation, the drain has had little or no measurable effect on water levels except directly adjacent to the drain (within 25 m). At this distance, the drain's effect was of the order of 0.2 m. The estimated 0.5 m response in bore 85WC03, located ~3 m from the drain, is consistent with these observations.

A simple water balance based on the likely zone of watertable impact revealed that the average baseflow of 48 kL/d observed could be derived by storage loss and annual recharge close to the drain (50 to < 100 m combined from both sides).

During the monitoring period, the drain had an estimated baseflow of groundwater of approximately ~26 868 kL. This groundwater had an average salinity of 4790 mS/m, a low pH (~3.50) and a salt load of 1740 tonnes for the total discharge over the period (51 888 kL).

While the drain has affected watertables, it was not responsible for lowering them to the critical depth required for the return of reliable crop growth. This was achieved instead by several years of below average rainfall. Watertables are now at levels low enough that flow into the drain has been diminished.

Whether recent climate-induced lowering of watertables results in reduced soil salt levels and subsequent crop recovery is the subject of a research project being conducted at the same site. Results for 2006–2007, summarised in Appendix 2, indicate that no reductions have occurred to date.

Finally, how the drain responds in wetter periods remains a question we wish to monitor. Data loggers have been placed in several key bores to enable measurement to take place in approximately two years' time.

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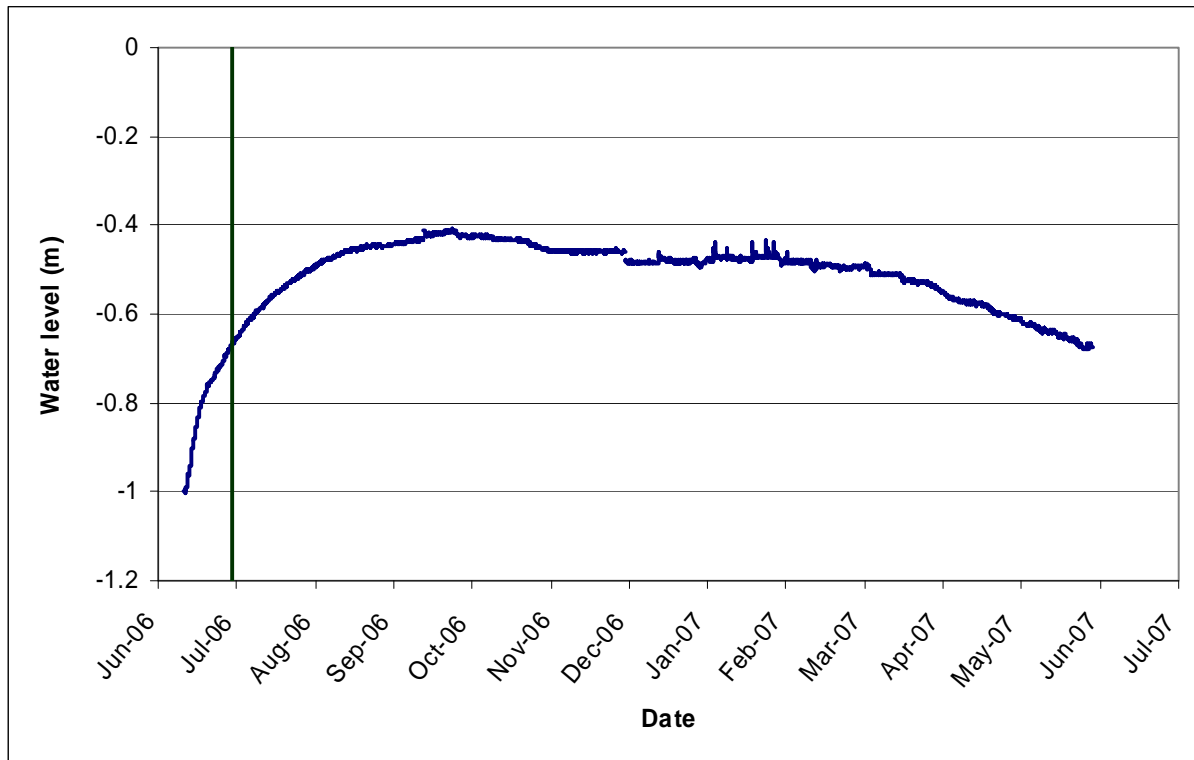
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## Appendix 1

A capacitance probe located 500 m north of the drainage transect was installed by Murdoch University for use in field trials of drainage response.

The logger record showed a monotonic trend—increasing 0.5 m throughout the installation period of July 2006 and stabilising in August—consistent with either a very low permeability or a data logger fault. The bore data was not analysed further.



## Appendix 2

### Extract from GRDC report on the project

Extract from 'The use and impact of deep drains on improving salt affected soils used for grain cropping in the WA Wheatbelt' GRDC 00138, a final report prepared for the Grains Research and Development Corporation (GRDC). 2008 crop yield data has been updated by Carlos Raphael (pers. comm. Sept 2009).

#### A. Crop (barley) yields Wallatin Creek 2006–2008 field trials

In 2006 there was a strong yield gradient, with distance from the drain reflecting the topsoil salinity gradient and seasonal rainfall. Yield next to the drain was close to zero, and increased to 2.7 t/ha at 70–100 m from the drain.

The drain was installed at this site immediately after planting in 2006, hence the barley performance reflects the pre-draining salinity with a strong salinity gradient along the length of the plots. The ECa values pre-planting decreased from 330 to 115 mS/m along the length of the plots. In 2006, there was no consistent effect of the treatments involving gypsum, lime and deep ripping on grain yield.

**Table 1 Grain yields of barley (t/ha) in 2006, 2007, 2008 at Wallatin Creek. For comparison, yields reported by the farmer from nearby sites are tabulated. Values are means of 4 replicates  $\pm$  standard errors. Note: Experimental plots were 100 m long with Zone A adjacent to the drain (generally within 40–70 m) and Zone C most distant from the drain (generally 80–120 m).**

	Method	Zone A	Zone B	Zone C	Yield	Soils
2006	Quadrat cuts	0.1 $\pm$ 0.01	2.2 $\pm$ 0.09	2.7 $\pm$ 0.05		Yes
	Crop harvester	0.3 $\pm$ 0.1	1.6 $\pm$ 0.1	2.4 $\pm$ 0.2	up to 2.4 (partly saline)	Yes
2007	Quadrat cuts	0.4 $\pm$ 0.06	1.7 $\pm$ 0.06	1.7 $\pm$ 0.06		Yes
	Crop harvester	0.8 $\pm$ 0.1	1.4 $\pm$ 0.07	1.8 $\pm$ 0.03	1.8 (non-saline)	Yes
2008	Quadrat cuts	0.7 $\pm$ 0.07	1.3 $\pm$ 0.04	1.4 $\pm$ 0.04	2.4 $\pm$ 0.2 (Control)	Yes
	Crop harvester	0.8 $\pm$ 0.08	1.2 $\pm$ 0.04	1.4 $\pm$ 0.02	1–2 (non-saline)	Yes

Sites generally showed a gradient in barley yield with the lowest yields closest to the drain (Zone A) and yields increasing with distance from the drain (Zone C). The crop yields close to the drain at Wallatin Creek (Zone A) in 2007 were only 0.4 t/ha, suggesting a slight increase compared to 2006 yields (0.1 t/ha). In 2008 the crop yield increased to 0.8 t/ha.

The barley yield results indicate an increase in yield two years after the drain was installed. Monitoring data indicates a lowering of the watertable that can be attributed to climate and the drain (depending on distance). However soil salinity data shows little change and suggests that soil constraints to crop production were still severe adjacent to the drain.

#### B. Soil properties Wallatin Creek 2006–2007

Soil sampling and analysis at Wallatin Creek, northeast of Kellerberrin, was conducted in June 2006 (pre-drain condition) and June 2007 in trial plots and at a control site by the Department of Agriculture and Food. Re-sampling took place in March 2009. Crop production was assessed in barley yield trials in 2006, 2007 and 2008.

Soils at the sites of deep drains varied in salinity levels. Near the location of the drain at Wallatin Creek, soil EC 1:5 exceeded 200 mS/m at the surface. Levels dropped to below

50 mS/m 100 m from the drain. ECa values also decreased strongly from 300 mS/m close to the drain to 120–170 mS/m at the end of the 85 m transect.

The initial pattern of salinity across the sites varied with distance from the drain. Sites at Wallatin Creek had the highest EC 1:5 and ECa values closest to the drain, decreasing with distance.

At each of the sites, the zone of land with salinity and water levels that would limit crop production varied in width. At Wallatin Creek, the ECa values were > 200 mS/m for up to 70 m to the west of the drain.

At Wallatin Creek, there was no indication that EC 1:5 levels in the 0–40 cm layer had changed between pre-drain samples in June 2006 and post-drain samples in June 2007.

## **C. Scientific papers and reports**

Bell, RW, Mann, S and Raphael, C 2008 'Salt-affected soils of south-west Australia: implications for deep drainage', presented at the 2nd International Salinity Forum, 31 March 2008–4 April 2008, Adelaide.

Bell, RW, Raphael, C and Mann, S 2008 'Salt-affected soils of south-west Australia: response to deep drainage'. Presented at the 2008 Joint Australia Society of Soil Science–New Zealand Society of Soil Science Conference held at Massey, New Zealand, December 2008.

## Appendix 3

This appendix contains separate graphs of the discharge and electrical conductivity measurements from the drain.

