

# MANAGING DEEP DRAINAGE FOR IMPROVED WUE: SOLUTE MONITORING AND GROUND WATER RESPONSE IN THE IRRIGATED LANDSCAPE

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## INTRODUCTION

The rise of ground water and salinity persist as potential challenging issues across irrigated agricultural landscapes. Additional water from irrigation may cause mobilisation of stored salts with subsequent local and off-site salinisation problems. Shallow root systems (<2 m) of irrigated annual crops such as cotton result in less extraction from deeper soil layers (than the original native vegetation). Also, unlike perennial native vegetation, annual crops generally do not utilize rainfall ex-growing season (Williamson 1973). Deep drainage (DD) - water that passes beyond the root zone - can be an important contributor in terms of recharging ground water as well as leaching salts from the root zone. However, DD may also contribute to rising ground water tables with increased solute concentrations. Although cotton is generally regarded as a salt tolerant plant, yield decline commences with electrical conductivity values above 7.7 dS/m with a 50% reduction in yield at 17.0 dS/m (Lin et al., 1997; Ahmad *et al.* 2002). In the past, water balance studies have focused mainly on infiltration, run-off and soil conservation (Freebairn *et al.* 1996). However, agricultural industries such as the Australian cotton industry have become increasingly aware of water losses due to DD in the furrow irrigated, heavy textured soils (Vertosols) where furrow lengths often exceed 800 m (Silburn *et al.* 2004). While the prime aim of the project was to directly quantify DD, a secondary aim was to monitor irrigation application efficiencies in terms of current irrigation methods. To this end, the study has been investigating the comparative efficiency of a lateral move irrigator *vs* furrow irrigation, in terms of lessened water applied and DD. Lateral moves (LM) are considered by many in the cotton industry as having great potential for positive impacts on water savings. More generally, Wiggington (2008) discusses the different influences on irrigation performance that will also impact quantities and temporal changes in DD, including infiltration characteristics, inflow rate, field length, soil water deficit and field slope.

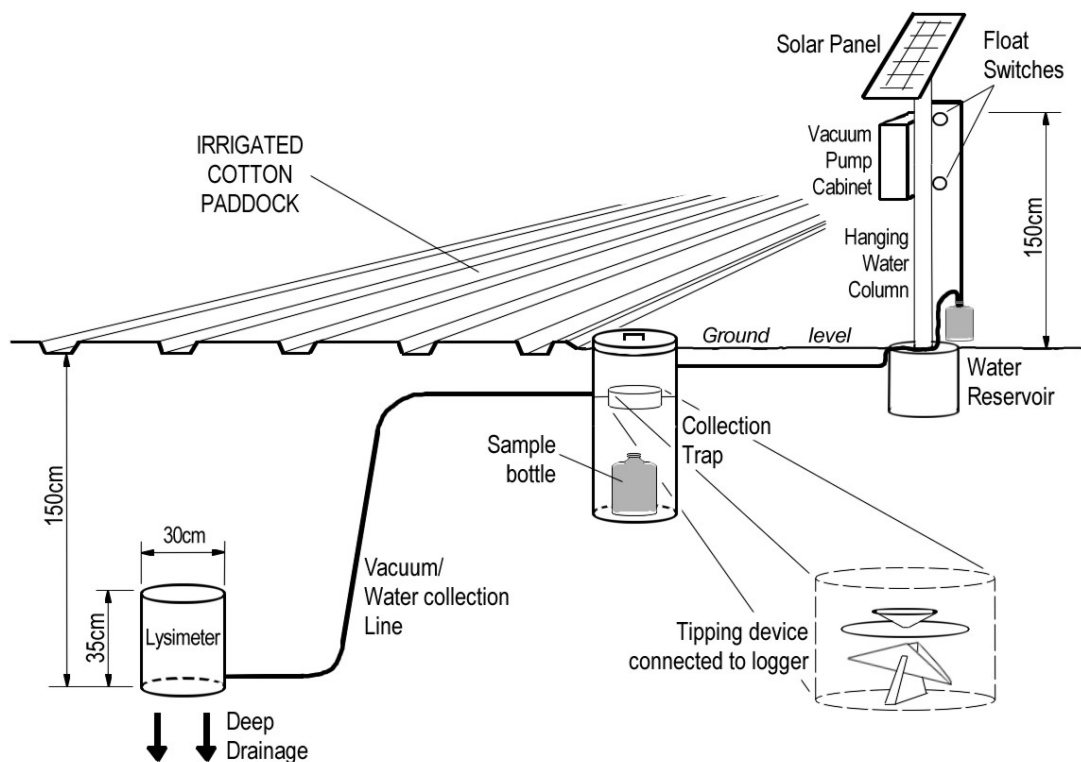
## METHODS

Thirty-five drainage lysimeters have been installed across the Condamine-Balonne-McIntyre-Namoi catchments of southern Queensland and northern NSW, on 10 commercial farms and at the Australian Cotton Research Institute, Narrabri (ACRI). Up to five irrigation seasons have been monitored, from 2002 to present. Three lysimeters have been installed at each site; one near each of the head and tail ditches, and at the mid point between the head and tail ditches (hereafter termed “head”, “mid” and “tail”). At one site (near Boggabilla, NSW), three lysimeters were thus installed in adjoining fields; one irrigated by LM, the other by conventional furrow irrigation.

Any one lysimeter system consists of three major components; an undisturbed soil core (within a PVC tube - 30 cm diam; 35 cm high, opened top with a sealed base) placed at 150 cm depth that has porous ceramic candles at its base to facilitate DD water extraction, the porous candles

connected by 3 mm vacuum line to a collection trap at the field edge that holds a tipping bucket device and data logger (to continuously monitor DD volumes), and a hanging water column to create the system's vacuum, driven by a solar panel / battery powered pump (Figure1). The system supplies a constant low suction applied to the porous ceramic candles at the base of the lysimeter; hence extracts the DD water passing through the lysimeter. The DD water then travels through a tipping bucket where the volume of water and event time are logged, before the leachate passes into a collection vessel. The water collected is measured (for cross-checking with the logged data) and also for EC and Chloride (ion) determinations; as too is the irrigation water being applied to each field. The lysimeters operate continuously.

In the 2005 – 06 cotton season, as part of the sub-project exercise of comparing LM and conventional furrow irrigation systems, data sets were collected for each of the five irrigation events in the furrow irrigated field at the Boggabilla site to facilitate SIRMOD (Walker, 1999) analysis. SIRMOD calculates the water infiltration amounts for each irrigation event using data inputs of flow rate (flow meters on irrigation siphons) and irrigation advance rate (advance sensors) down the field (both using IRRIMATE equipment), as well as irrigation duration and furrow length, field slope and furrow cross sections (throughout the season). Infiltration characteristics were then simulated using these data and *Infilt V5* (NCEA©) and these parameters used in the SIRMOD model to estimate the depth of infiltrated water at each of the head, mid and tail lysimeter locations. Total amounts of water applied by LM and by siphons were measured.



**Figure 1.** Schematic illustration of the system of any one lysimeter: collection trap, vacuum line and vacuum tower layout. One vacuum tower operates all three lysimeters in any one field.

In an attempt to link surface measures of DD (and associated weather data), 18 groundwater depth sensors have been installed in a nest of monitoring boreholes across the St George irrigation area. Twice a day (noon and midnight) the groundwater depth is logged and the sensors routinely downloaded, along with the necessary barometric pressure sensor (for correction purposes).

## RESULTS

Results across five seasons for all sites show large values of DD are possible but across-field (head to tail ditch) and seasonal variability provide a wide range of values (from 0 ML/ha to 3 ML/ha in a season) (Table 1); rationalisation of which continues towards developing best management practices. The potential for dramatically reduced DD from the use of a LM is evident in Table 1. Apart from one occasion, at the head ditch end of the field at the first irrigation (31 mm DD), there was zero DD under the LM, as compared to 105, 87 and 93 mm at the head, mid and tail locations in the adjoining furrow irrigated field. The DD data collected correspond well with the total amounts of water applied (in season) to each field (about 400 and 230 ML for the furrow and lateral move, respectively) that equates to 6.3 and 2.7 ML/ha. Crop yield was similar between the two fields. From the logged DD volumes, although DD was evident after each of irrigations at each field location, the contribution to the total (seasonal DD) greatly reduced as the season progressed. Taking the example of the “head” location, the largest contributions to DD occurred from early season rainfall (40% of the total), and after the pre-irrigation and first crop irrigation (88% of the total) (Figure 2). This decrease in DD has been found at almost all lysimeter sites and has been attributed to lessened irrigation application time, as the growing season progressed. SIRMOD simulation results shown in support the directly measured values of DD (Figure 3). It is evident that there was approximately 150 mm and 250 mm of infiltrated depth at the head location during the pre-irrigation and the first irrigation, which is far greater than the required application depth; generally assumed to be between 80 and 100 mm.

Electrical conductivity (EC) analysis of the DD leachates at the lysimeter sites apparently show salt loads being mobilised under all sites (Figure 4) with an increase (up to 60-fold) in EC between the irrigation waters applied to each field, and the water collected as DD leachate. The smallest increase in EC between applied and DD water was at the Macalister site (3-fold), despite the high EC (4.15 ds/m) of the irrigation water (mainly bore water) and a soil EC of 1.5 dS/m at 80-90cm depth. EC values >4 ds/m are regarded as deleterious to cotton growth and values >5 ds/m are deemed deleterious to aquatic ecosystem health (I. Gordon, pers. comm.). Analysis of soil and DD leachate EC with known rainfall, irrigation amounts and calculated ET are planned; for future reporting.

Data of the groundwater monitoring exercise are presented for one borehole (42220032); this being the inspection bore nearest the St George DD site - a site where DD data has been collected from 2002. Figure 5 presents 34 years of historic water levels from this borehole, collected by hand (weighted tape), mostly twice yearly. Figure 6 presents recent logged water level data from the same bore hole, logged twice daily in the period from 12 January 2007 to 26 January 2007. The historic data shows a rise of approximately 20 meters in water level from 1985 to 2005. Local growers confirmed that 1985 was the approximate year when on-farm storages (for the mass

storage of irrigation water) were first constructed and filled, in the St George area. The recent data shows short term rise and fall of the water level - a drop of 26 cm from 3 to 8 February and a rise of 29 cm from 8 to 21 February, 2007. Full analysis of these data is currently underway, particularly the construction of a conceptual groundwater model, calibrated using historic and current data to predict future trends. The EC of these waters is also under investigation; again with a view to long-term predictions of salt trends. The local growers at St George have been engaged to record surface water phenomena. eg full storages and channels, irrigations, large river flows, etc; aiming to investigate their link (if any) with the measured groundwater level fluctuations.

**Table 1.** Deep drainage (DD) calculated from the measured leachate volumes (mm/ha) at the head, mid and tail locations from the nine DD monitoring sites. Also presented is the DD data, expressed as the leaching fraction (*LF*) – *i.e.* DD as a % of the water applied.

Site	Crop	Irrigated depth (mm)	Season	Head		Mid		Tail	
				Vol.	LF	Vol.	LF	Vol.	LF
<b>Macalister</b>	Maize	**	02/03	<b>175</b>	**	<b>nf*</b>	-	<b>51</b>	**
	Sorghum	720	03/04	<b>5</b>	<i>0</i>	<b>nf*</b>	-	<b>33</b>	<i>6</i>
	Cotton	335	04/05	<b>41</b>	<i>12</i>	<b>101</b>	<i>30</i>	<b>0</b>	-
	Cotton	540	05/06	<b>12</b>	<i>2</i>	<b>10</b>	<i>2</i>	<b>0</b>	-
	Cotton	420	06/07	<b>31</b>	<i>7</i>	<b>26</b>	<i>6</i>	<b>0</b>	-
	Fallow	(542)*	07/08	<b>31</b>	<i>6</i>	<b>26</b>	<i>5</i>	<b>0</b>	-
<b>Goondiwindi</b>	Maize	**	02/03	<b>187</b>	**	<b>196</b>	**	<b>24</b>	**
	Sorghum	462	03/04	<b>235</b>	<i>51</i>	<b>101</b>	<i>22</i>	<b>21</b>	<i>5</i>
	Cotton	563	04/05	<b>104</b>	<i>18</i>	<b>23</b>	<i>4</i>	<b>19</b>	<i>3</i>
	Sunflower	420	05/06	<b>0</b>	-	<b>1</b>	<i>0</i>	<b>11</b>	<i>3</i>
	Fallow	-	06/07	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
	Fallow	-	07/08	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
<b>St George (S)</b>	Cotton	**	02/03	<b>14</b>	**	<b>68</b>	**	<b>37</b>	**
	Cotton	800	03/04	<b>104</b>	<i>13</i>	<b>91</b>	<i>12</i>	<b>18</b>	<i>2</i>
	Cotton	734	04/05	<b>40</b>	<i>5</i>	<b>92</b>	<i>12</i>	<b>50</b>	<i>7</i>
	Field pea	493	05/06	<b>5</b>	<i>1</i>	<b>37</b>	<i>7</i>	<b>33</b>	<i>7</i>
	Cotton	700	06/07	<b>0</b>	**	<b>33</b>	**	<b>0</b>	**
	Fallow	(532)*	07/08	<b>14</b>	<i>3</i>	<b>1</b>	<i>0</i>	<b>13</b>	<i>2</i>
<b>St George (N)</b>	Wheat	**	2004	<b>24</b>	**	<b>55</b>	**	<b>1.6</b>	**
	Cotton	693	05/06	<b>27</b>	<i>4</i>	<b>22</b>	<i>3</i>	<b>0</b>	<i>0</i>
<b>Pampas</b>	Cotton	963	04/05	<b>71</b>	<i>7</i>	<b>106</b>	<i>11</i>	<b>62</b>	<i>6</i>
	Sorghum	rainfed	05/06	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
	Fallow	-	06/07	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
	Sorghum	rainfed	07/08	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
<b>Dalby</b>	Cotton	465	04/05	<b>39</b>	<i>8</i>	<b>95</b>	<i>20</i>	<b>34</b>	<i>7</i>
	Soybean	400	05/06	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
	Sorghum****	100+rainfed	06/07	<b>0</b>	-	<b>17</b>	**	<b>0</b>	-
	Cotton****	100+rainfed	07/08	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
<b>Dirranbandi</b>	Cotton	926	03/04	<b>11</b>	<i>1</i>	<b>21</b>	<i>2</i>	<b>176</b>	<i>19</i>

	Cotton	600	05/06	<b>0</b>	-	<b>1</b>	0	<b>6</b>	1
	Fallow	-	06/07	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
	Fallow	-	07/08	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
<b>Boggabilla</b>									
<b>(a) furrow</b>	Cotton	628	05/06	<b>105</b>	17	<b>87</b>	14	<b>92</b>	15
	Fallow	-	06/07	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
	Cotton	450	07/08	<b>19</b>	4	<b>40</b>	9	<b>1</b>	0
<b>(b) lateral move</b>	Cotton	270	05/06	<b>31</b>	11	<b>0</b>	-	<b>0</b>	-
	Cotton	196	06/07	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
	Cotton	131	07/08	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-
<b>ACRI</b>	Fallow	(824)*	05/06	<b>200</b>	24	<b>96</b>	12	<b>61</b>	7
	Cotton	800	06/07	<b>310</b>	39	<b>112</b>	14	<b>65</b>	8
	Fallow	-	07/08	<b>0</b>	-	<b>0</b>	-	<b>0</b>	-

nf = non-operational lysimeter; replaced before the 2004-05 season

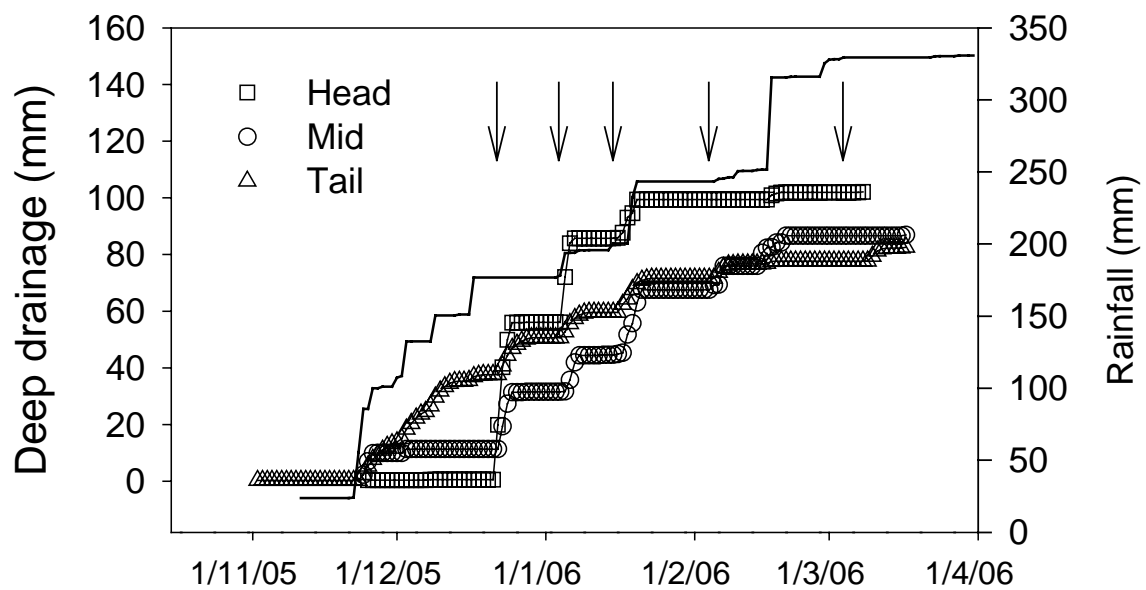
\* During season rainfall (*in brackets*), only – when DD measured during fallow periods

\*\* Irrigation waters applied, not known.

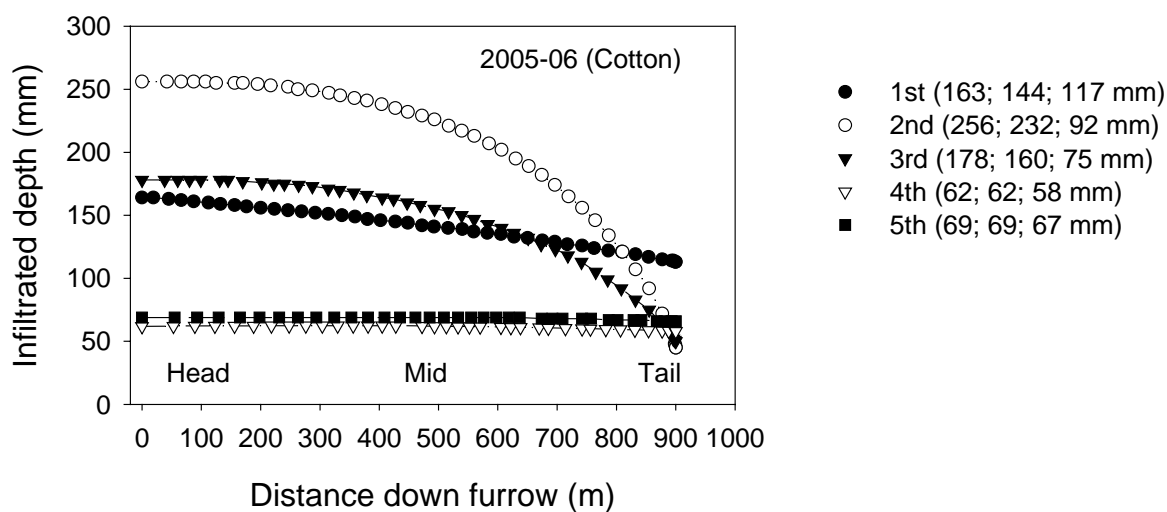
\*\*\* Sorghum irrigated to establish, only (note the 17 mm of DD resulted from the one irrigation)

\*\*\*\* Cotton irrigated only once on 9 Jan 08; 502 mm of in-crop rainfall received

**Note:** lysimeters were installed at different sites in different years



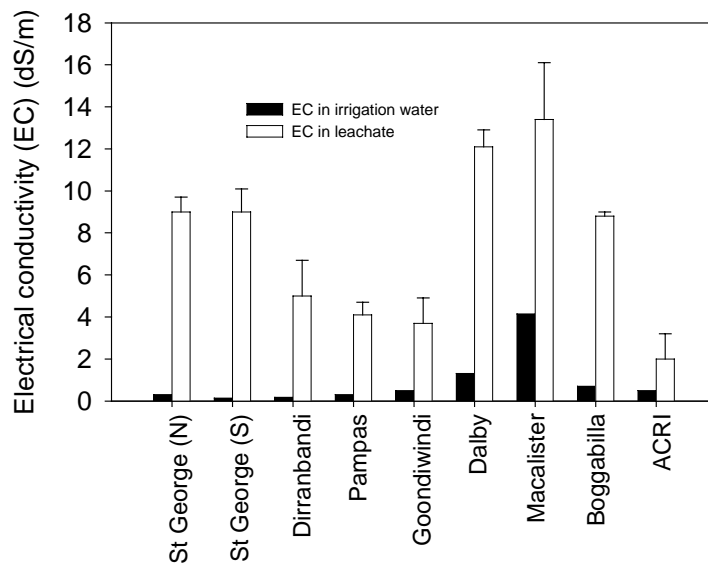
**Figure 2.** Cumulative deep drainage logged from the Boggabilla site (furrow irrigated) in the 2005-6 cotton season. Cumulative rainfall is shown as the continuous black line, and the vertical arrows indicate the five irrigation events.



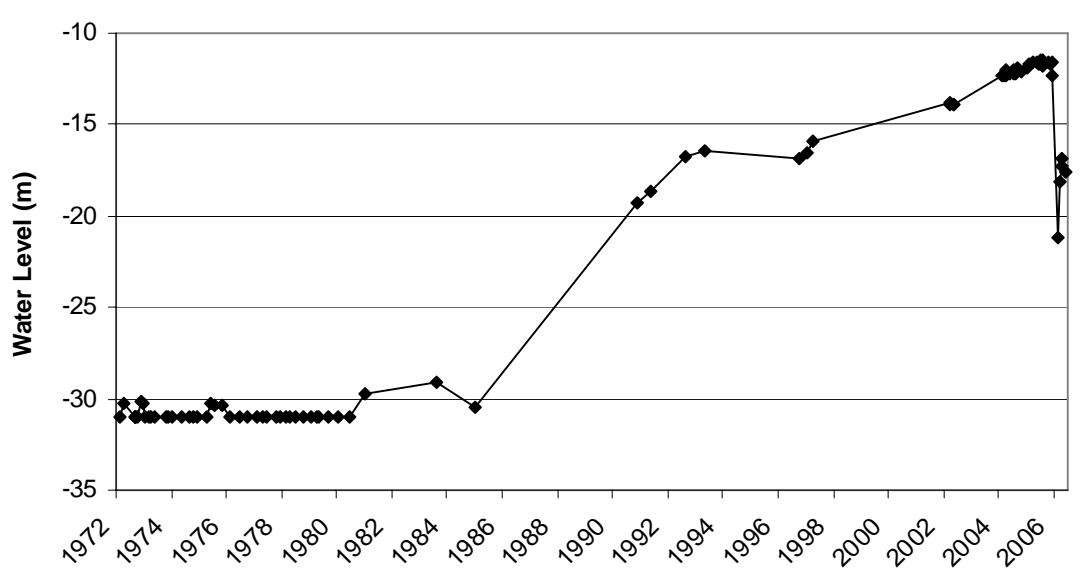
**Figure 3.** Infiltration uniformity simulated from SIRMOD down the furrow on the Boggabilla site for 5 irrigation events in the 2005-6 cotton season. The amounts of water infiltrated at each head, mid and tail locations for each irrigation, as calculated through inverse modelling, are given in the legend.

### GENERAL DISCUSSION

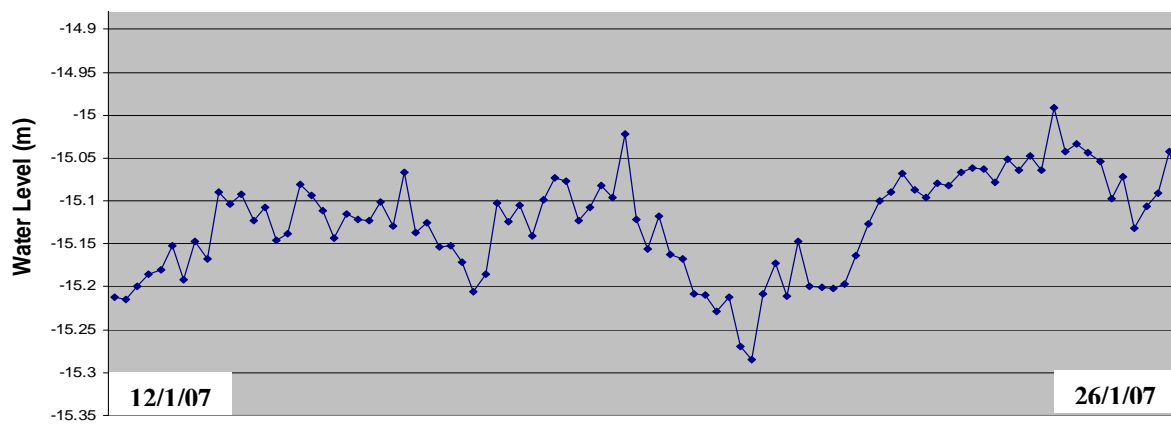
Cotton farms, in non-drought times, apply an average of 5 to 6 ML/ha/season. Using an average DD value of approximately 100 mm (i.e. 1 ML/ha/season), then there is potential for a 20% increase in water use efficiency. This water could be used to expand the area planted to cotton, or better irrigate the current cotton area, depending on circumstances. Potential methods of reducing DD, and concurrently increasing irrigation efficiency are several (Wiggington, 2008). In practice, and particularly with current tight economic circumstances in cotton production, altering the inflow rate (more and/or larger siphons) and associated “time to cut-off” of supply may mitigate DD and are cheaper options than reducing field lengths. Increasing field slope has little effect, though evening out field slopes will improve irrigation performance (Wiggington, 2008). In terms of groundwater impacts, 1 ML/ha of DD could lead to rising groundwaters. Examples of rising and/or spreading groundwater seem to have been observed in monitoring bores in the St George irrigation areas. However, these historical data were collected at varying intervals and require cross-checking with data from the current, short-interval monitoring program; that in itself requires interpretation and cross-checking with local growers in terms of surface water events. The quality of these groundwaters is another issue; a subject being investigated in the current groundwater monitoring program. It is likely that by reducing DD with more efficient irrigation management, a win-win outcome will be achieved for both the grower and for natural resource management, hence fulfilling the overall project goal of “less water used more efficiently with reduced leakage to groundwater aquifers”.



**Figure 4.** Water quality for the 2002-04 cotton seasons, in terms of electrical conductivity (dS/m), of both the irrigation waters applied at each lysimeter site and the water collected as deep drainage (leachate) in the lysimeter collection vessels. Data are the means of several irrigations and collection times for each water source.



**Figure 5.** Historic monitoring bore (bore no. 42220032) water level data (depth below the local soil surface) from 1972 to 2006; St George, Qld.



**Figure 6.** Recent (12 to 26 January 2007) water level data (below the local soil surface) from the same bore as in Figure 5. Data is logged twice daily (noon and midnight) and all data plotted

#### ACKNOWLEDGMENT

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