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. Excessive DD is economic poor practice and a potential source of rising ground water tables with increased solute concentrations; potentially challenging issues for irrigated agricultural landscapes and the communities therein. The project's prime aim was the direct quantification of DD across a wide, yet representative range of cotton soils and management systems, while concurrently assessing both salt balances of collected leachates and around-lysimeter soils, as well as crosschecking the measured DD data with less expensive, indirect methods of predicting DD (eg SODICS, SaLF and ET/SIRMOD). Secondly, to monitor irrigation efficiencies in terms of recent technology utilisation in the cotton industry, specifically the comparative efficiency of a lateral move irrigator (LM) *vs* adjoining furrow irrigation, in terms of lessened water applied and DD; LM considered as having great potential for positive impacts on water savings. Thirdly, to investigate linkages (if any) between surface water events (DD, irrigation, river flows, etc) with historic and current (logged) groundwater levels in the St George irrigation area (SGIA); checking for rising water and salinity risk. Instrumentation was 35 drainage lysimeters (constant suction) at three locations in one field on each of 10 commercial farms and at the Australian Cotton Research Institute. Up to five irrigation seasons have been monitored (2002 to present). Results show a maximum DD of 310 mm (3.1 ML/ha) in one season has been measured (representing ~39% of the applied irrigation water). However, of 69 sampling occasions across four growing seasons and all the lysimeter sites, only 14 occasions (~20%) provided DD values of >100 mm (1 ML/ha). Additionally, DD has been found to vary strongly across fields - from head to tail ditches, and there is strong between-seasons' variation in the lysimeter data at any one site, apparently linked to during-season weather and water (irrigation water) availability. Some sites that provided >150 mm (1.5 ML/ha) of DD in one season, gave a zero reading the following season. These unexpected variabilities in the DD data, though important to know and to begin to rationalise in terms of site practice and seasonal weather, cause difficulties in rationalisation of the main drivers (of DD) towards the development of industry-applicable BMPs. Water quality analysis of the DD leachates apparently shows salt loads being mobilised under all sites. Soil chloride analysis (over five years at some of the DD sites) shows increased salts in the root zone of certain fields. Close investigation of both data sets is current. The indirect methods of predicting DD have proven most poor in providing matches to the measured lysimeter DD values; in terms of both magnitude (of DD volumes) and correspondence with (at times large) measured in-field and seasonal variability in DD. Preliminary analysis of the historic borehole logs and real-time logging of groundwater levels suggests that the shape of the groundwater contours does not particularly illustrate the presence of a broad groundwater mound in the SGIA, but rather the development of more localised groundwater mounds probably reflecting zones of locally preferential accession of DD (most probably due to channel leakage and leakage from on farm storages). The depth to groundwater data suggest that groundwater levels have not yet approached the 2 m bGL level that is commonly viewed as posing a risk for soil salinisation *via* capillary rise of groundwater. Currently there are 28 operational lysimeters (2 sites having been recently de-commissioned) and 18 borehole loggers (logging aquifer level twice daily) that will continue monitoring to 2011. These additional data will aid clarity in the drivers of DD and associated groundwater response. Further DD leachate and soil salinity data will be collected to continue the salt mass balance study.

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Final Report to Cotton Catchment Communities CRC

Project 1.02.04 Deep drainage under irrigated Cotton
- surface and groundwater implications

September 2008

Australian Government
Cotton Research and Development Corporation

Cooperative Research Centre for IRRIGATION FUTURES

Queensland Government
Natural Resources and Water

Queensland Murray Darling Committee Inc.

Cotton Catchment Communities CRC

Background

Deep drainage (DD), defined as water that passes beyond the plant root zone, is an important contributor in terms of recharging ground water and also carries a certain amount of soluble salts, avoiding salt build up within the root zone. As such, DD is not an adverse component to the soil or landscape water balance. However, excessive DD, generally greater than the leaching requirement, is not only economically poor practice but may also lead to rising ground water tables and increased solute concentrations in these waters or elsewhere in the landscape. Salinity is one of the major hazards to the long term sustainable life of irrigated farming enterprises.

In the past, field-level water balance studies have focussed 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 field lengths often exceed 800 m (Silburn *et al*. 2004) and in-field water “dwell time” can be the order of 12 hours and more. This awareness contradicts an earlier belief in the cotton industry that “clay soils don’t drain” (Hearn 1998). In 2000, Gordon (2000) measured seasonal DD in cotton using a large lysimeter at Dalby, and reported values of 95 to 305 mm/year under drip irrigation, and 165 to 180 mm/year under furrow irrigation. Dalton (2003) stated, “DD in surface irrigated cotton systems has remained a contentious issue and one that has not been well understood or grasped by the Industry”. He calculated seasonal DD values under irrigated cotton of 100 mm and 200 mm, using water balance measurements (Dalton 2003). A review by Silburn and Montgomery (2001) suggested DD from irrigated agriculture could be between 50 and 300 mm and this was instrumental in helping the cotton industry change its view of "leak proof" Vertosols. Typically, small (0-100 mm/year) DD on floodplain soils in the Murray-Darling Basin (MDB) has been noted but much larger fluxes of DD (> 300 mm/year) are likely under levee soils (Bethune 2004).

Many indirect methods have been used extensively to estimate DD, mostly under rain-fed farming. Soil Chloride (Cl^-) mass balance, based on the solute (Cl^-) dynamics in soil solution, has being applied to slowly permeable soil to estimate DD under two different circumstances: (i) steady-state mass balance (USSL 1954; Walker, 1998) where the system is at equilibrium (i.e. Cl^- in = Cl^- out) and (ii) transient solute mass balance where the system is at non-equilibrium (non-steady state) (Rose *et al*. 1979; Thorburn *et al*. 1987; Slavich *et al*. 2002). A commonly used software package (SODICS) is used to estimate DD from this non-equilibrium state (Tolmie *et al.* 2003). SIRMOD is another indirect method of determining DD, by measuring the input and output components of the water balance model of individual fields. In this case, DD is described as the difference between the amounts of irrigation plus rainfall that have infiltrated the soil profile (Walker 1999) and evapotranspiration (ET) (commonly using look-up tables in the "FAO 56" publication) plus changes in stored soil water content. Despite their relative inaccuracy, the major advantages of these indirect estimations are that they are inexpensive and not site specific. Another commonly used indirect method of assessing DD is the Salt and Leaching Fraction (SaLF) model (Shaw and Thorburn, 1985). SaLF analysis is based on the assumption that soil leaching or DD is related to the soil hydraulic conductivity, which in turn is influenced by several, measurable soil and site characteristics, most importantly the amount of clay (%), clay mineralogy (defined by the ratio of CEC/clay %) and the soil exchangeable sodium percentage (ESP).

DD is also measured using direct physical methods such as soil water flux meters (Cary 1970; Dirksen 1974), lysimetry (Bethune and Wang 2004; Robinson *et al.* 2004) and environmental tracers (Cook and Herczeg, 1998). Despite the relative accuracy of these methods, there has been limited application to the measurement of DD, particularly under irrigated cotton (Silburn and Montgomery 2004) because of their time consuming nature, site specificity, cost and complexity of building and maintaining the equipment (particularly lysimeters). However, direct field measurements of DD are necessary to calibrate and validate indirect approaches.

The current project was conceived shortly after the finish of the first Queensland Government supported Rural Water Use Efficiency (RWUE1) initiative, in 2002. A principal finding of RWUE1 was that "the main water loss infield (under irrigated cotton) was from DD" and that "furrow irrigation had not been well monitored or well managed" (USQ media release 13th July 2000). While RWUE1 did much to develop practical ways for farmers to improve WUE, it did little to develop and test direct measurements of DD under irrigated cotton crops over a range of soils and environments.

The current groundwater investigation of this project, in the St George irrigation area (SGIA), aims to provide an assessment of past and current groundwater fluctuations, in perspective of subsurface geology, known aquifers (and their possible inter-linkages), past and recent surface water events (rain, dam building, water releases from Beardmore, river flows, rainfall, irrigation timings, etc). It is foreseen that the cross-interpretation of these data will lead not only to a far better understanding of the drivers of groundwater fluctuations in the SGIA but also long term modelling of likely groundwater rise, and the potential of salinity increases or break-outs to surface water areas (eg local rivers). This will aid future deliberations in such areas as the partitioning of responsibilities concerning groundwater, resolution of possible sources of groundwater rise, particularly in the light of potential future climate and land use change on groundwater resources for better integration of groundwater-surface water management and salinity induced by rising water tables, and other impacts of soil/groundwater interaction.

This second part of the project, as reported here, broadens the hydrological studies of DD in individual fields, to a more regional / landscape scale with potential socio-economic impacts if irrigation systems are compromised by rising and saline groundwaters. The economy of the states of Queensland and NSW are underpinned and supported by large and fragile hydrological systems, with a wide assortment of physical and social environments. These environments are undergoing stabilisation from the effects of European settlement over the last century and a half. The development of water resources began with the opening of the Great Artesian Basin in the late 1880s, and has been increasing rapidly since the 1950s through the building of dams to support ground and surface water irrigation areas. In Queensland, NRW is responsible under the Water Act for the management of groundwater in Queensland, and the Department and its predecessors have a long history of monitoring and evaluating the resource. Recent briefings by the director general have emphasised that the current drought, future climate change scenarios, and increasing demand on current groundwater resources all indicate necessity for the department to position itself to deliver effective groundwater planning and management.

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Objectives

The project had four inter-related objectives. (i) The prime aim of the project was to directly quantify DD across a variety of soils, climates and management systems/styles on a representative set of irrigated cotton growing sites. More specifically, this project aimed to expand on earlier studies (funded by the original Cotton CRC, CRDC, and RWUE1 and 2) through installing additional *in situ* drainage lysimeters at several sites across the southern cotton growing area of Queensland and northern NSW, with the aim of covering more of the soil types and management practices of irrigated cotton in these areas. Within this primary aim, the project continued the correlation (cross-checking) of the direct data obtained from the lysimeters with more indirect, relatively inexpensive DD measurement tools as well as the rationalisation of DD (as measured) with all natural and managerial inputs, towards rationalising the drivers of DD with the aim of deriving BMPs to minimise DD for improved water use efficiencies on-farm. (ii) A secondary aim was to monitor irrigation application efficiencies in terms of recent technology utilisation in the cotton industry; specifically the project investigated the comparative efficiency of adjoining lateral move irrigator *vs* furrow irrigation at one site, in terms of water use, yield and DD. (iii) Thirdly, the project aimed to conduct salt mass balance and salt dynamic scenarios through measuring salt levels (EC and Chloride) in each of three location-types, associated with the lysimeter installations, with time: the soils around many of the lysimeters over a period of 5 to 6 years; all DD leachate samples, and head and tail ditch waters and local supply water bodies that provided water to the lysimeter sites (rivers, dams, bores, etc)[1]. (iv) Furthermore the project has been monitoring long and short – term change in ground water levels in one irrigation area where DD is being monitored (at St George) with the long term objective of investigating links between surface water events (rainfall, irrigation, DD, river flow, dam releases, full and empty on-farm storages, etc) and groundwater response and the quality of these waters. Particular emphasis is being given to investigating any evidence of rising groundwater, particularly if these waters are saline or increasing in salinity[2].

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[1] The EC and Cl^- data (soil, source irrigation waters and consequent DD leachates) with analysis and interpretation in terms of salt balances is currently being fully investigated by an NRW-funded, independent consultant; and will be presented as a separate Report.

[2] Similarly, the historic and current (logged twice daily from early 2007) groundwater level data with associated regolith stratigraphy, water quality, dam (Beardmore) releases, rainfall and irrigation events for the St George irrigation area is being fully investigated by an NRW-funded, independent consultant; and will be presented as a separate Report. Appendix 6 will present results to date of this part of the study.

Methods

This report will be presented in two parts: (i) All results to date from the 10 lysimeter / DD sites and (ii) the results to date of the groundwater investigation in the SGIA (Appendix 6).

Over the period 2002 to 2007, a total of ten (10) sites have been chosen, where drainage lysimeters (sometimes known as barrel lysimeters) have been installed to measure DD. Across these ten sites a total of 35 drainage lysimeters (more correctly termed constant suction barrel lysimeters) have been installed in irrigated cotton fields, across the Condamine, Balonne, McIntyre and Namoi catchments (Figure 1). The lysimeters were installed in different years, as the project grew and as a result the DD and related data exist for different periods of time for individual sites; 3 sites were installed in 2002 (Goondiwindi, Macalister, St George (S)), 1 in 2003 (Dirranbandi), 3 in 2004 (Dalby, St George (N), Pampas), 2 in 2006 (ACRI and Boggabilla – 2 installations) and 1 in 2007 (Maules Creek) (Figure 1 and Table 1). The ACRI and Maules Creek installations are co-inputs (from NRW in this project) to other projects funded by the Cotton Catchment Communities CRC and CRDC; conducted principally by CSIRO and the University of NSW, respectively[3].

Each lysimeter is a 30 cm diameter (with 35 cm sidewalls) undisturbed soil core from the 115-150 cm depth, plumbed and subsequently buried in place at the original depth, in order to measure and collect the water exiting the cotton root zone (see Appendix 1 for illustrations of the lysimeter components and installation procedures). Water that passes through these lysimeters (at 150 cm depth) is deemed lost to the plant, so is termed DD. The lysimeters used in this project are "constant suction lysimeters" (as different from the one, CSIRO lysimeter installed at ACRI that is a variable suction lysimeter). The constant suction method applies a constant low suction to the base of the lysimeter with the aim of effectively removing the soil solution intercepted at the lysimeter base without unduly altering the hydrology of the profile above or within the lysimeter. The hanging water column (on the edge of each lysimeter field) is set to provide 150 cm of constant suction (vacuum) to the porous candles at the base of each lysimeter. In this way, the function of the suction mechanism is not to produce suction on the profile above the lysimeter, but simply to remove the drainable water as it arrives at the base plate (at 150 cm depth).

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[3] As the ACRI and Maules Creek lysimeter installations are joint projects with CSIRO and the UNSW, respectively, data reporting of these two sites, here, will restrict itself to site characteristics and DD data, obtained to date; recognising that these other agencies will fully report these data (back to CCC-CRC and CRDC) in the broader context of their complete site investigation, at a later stage. The ACRI report to date is Appendix 4 and the Maules Creek report is Appendix 5.

In the majority (8 of 10) of the irrigated fields where DD is being measured, 3 lysimeters have been installed; one near each of the head and tail ditches, and one mid-way between – hereafter called "head", "mid" and "tail". At two of the DD sites, four lysimeters have been installed; St George (N) has an extra lysimeter at the head ditch installed early in the project and supplemented by three others at the head, mid and tail locations at a later occasion; and the Maules Creek site has an extra lysimeter installed in an immediately adjoining field as a cross-check with the three, other lysimeters at the usual head, mid and tail locations. Each of the head and mid lysimeters were located at least 20 m (sometimes up to 50 m) from the head and tail ditch locations; particularly important at the tail location - aiming to keep the lysimeter clear of any waters backing-up from the tail ditch, during irrigation events.

The position of the lysimeters relative to the edge of the field has varied through the life of the project. Lysimeters at the four original sites were positioned close to the edge of the field to minimise disruptive excavations. Hence, at each of the Macalister, Goondiwindi, St George (N) and St George (S) sites lysimeters are located approximately 3 m from the edge of the field (3 m perpendicular into the field). At the Dirranbandi site the three lysimeters are positioned 6 m into the field. More recent (2004 onwards) lysimeters have been intentionally located much further into the field, to reduce potential edge effects. So, the Pampas, Dalby, Boggabilla (2) and Maules Creek lysimeters are all located 30 m into the field, perpendicular to the edge. The three lysimeters at ACRI are located in-line with the (large) CSIRO lysimeter, hence are approximately 3 to 4 metres into the field. Also, only at the ACRI site, the lysimeters were placed with their base at 200 cm, again to align them with the bottom of the collection trays of the CSIRO lysimeter, for comparability of data collected in each.[4]

The 10 lysimeter sites have been specifically located to cover many aspects of cotton growing in the Murray Darling Basin, to provide a good representation of DD in the cotton area (Table 1):

- the lysimeters were located on a wide range of cotton growing soils, based on NRW soil maps, discussions with growers and (when available) soil chemical analysis and include: (a) deep, well structured black clays (Macalister and Pittsworth), (b) brown / orange clays (north and south of St George), (c) grey, well structured clays (Narrabri and Goondiwindi) and (d) grey, moderately structured clays (Boggabilla, Dalby, Dirranbandi, Maules Creek).

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[4] Note: Two of the DD sites have been recently de-commissioned and ceased to operate; all equipment being removed at the request of the owners: St George (N) in 2006 and Dirranbandi in August 2008. The Report will present all data to those dates for each of these sites.

- field lengths range from 530 to 1290 m (though ACRI being in an experimental plot is 195 m long)
- siphon sizes of 50, 63 and 75 mm; one site with a 300 mm diameter mass volume (through the bank) method of irrigation supply; and one site with a lateral move (spray) irrigator.
- bed configurations; 1, 2 and 3 metres
- all sites practise crop rotations; eg maize/sorghum/cotton, cotton/maize/fallow, cotton/wheat/cotton/cotton, etc. More recently, since 2006, as a response to drought and World cotton prices, more of the sites are growing sorghum, chick peas, cereal crops (wheat and barley) and sunflower; as well as the occasional fodder crop. Cropping has also become more opportunistic, governed by weather (rainfall events) and irrigation water (river and across land flow) availability.

Installation of the lysimeters was conducted by NRW staff, actually constructing the apparatus on-site at every location. (see illustrations in Appendix 1). As far as possible, equipment construction and installation procedures were standardised to facilitate inter-site data comparisons, recognising the uniqueness of each site with regard to soil, field dimensions, management and cropping regimes. The suction to drive the lysimeters was produced by a solar powered 12v vacuum pump suspending a 150 cm column of water (supplied by a water reservoir at the bottom of the tower) in the vacuum tower, located on the edge of the field (most commonly at the mid location). This provided a constant suction of -150 cm, applied to three ceramic candles (all connecting tubing in the system was 6 mm od and 4 mm id flexible vacuum tubing; similar to tubing used in garden micro-irrigation systems), inserted in the base of the lysimeter (Appendix 1), in order to extract the water passing through the lysimeter and arriving at the 150 cm depth. Under the applied vacuum, the DD water travelled to the sample trap at the edge of the field at each of the head, mid and tail locations. This water (the DD leachate) first passed through a tipping bucket pluviometer in a vacuum sealed chamber. The "tips" of the pluviometer are logged as both number of tips and time of tips for subsequent conversion to DD volumes[5] (on a Tiny Tag ® logger; with memory for 56 days of data storage). These data will be reported as the "logged" data in this report. The water then bypassed the sealed chamber through the bottom of the tipping bucket container into two glass collection vessels (each 5 litres capacity) and stored there, awaiting collection. These data will be reported as the "volumetric" data in this report, being the actual water that passed through to the depth of 150 cm in the irrigated fields. The collected DD

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[5] The calculation is: Based on the surface area of the lysimeter (30 cm diam.) , volume (ml) is converted to height (mm) by = total number of tips / 7 and 7 tips = 70 ml so volume collected is divided by 70 to get mm

waters were tested for electrical conductivity (EC) and Chloride concentration. In all cropping seasons, irrigation numbers, frequency and the total amounts of water applied were obtained from the owner and/or farm staff on-site.

Each site also had an automated weather station installed comprising sensors to collect rainfall, temperature, humidity, solar radiation, vapour presser deficit and wind speed and direction.

Most commonly at the time of lysimeter installation, soil cores (5 cm diameter) were collected from each of the head, mid and tail locations and immediately beside the lysimeter location. Analyses were conducted in the NRSc Chemistry Centre (NRW, Indooroopilly) to determine soil physical and chemical properties on selected 10 cm increments to 1.5 or 1.8 m depth (sampled at 0.0-0.1. 0.2-0.3, 0.5-0.6, 0.8-0.9, 1.2-1.3, 1.5-1.6, 1.7-1.8 m; the latter where this depth was sampled).

Indirect measures of Deep Drainage

A. Water balance model

A water balance model was used in the current study, to provide an alternate and indirect method of estimating DD, for comparison of results to the actual DD amounts collected in the lysimeters. The model provides a partial water balance of the hydrological inputs and outputs of an irrigated crop, specifically: irrigation (I), precipitation (P), evapotranspiration (ET), runoff (R), change in soil water storage (ΔS) and DD. It was of the form:

$$\mathbf{DD = (I+P) - (R+ET+\Delta S)}$$

Two models, sourced from the University of Southern Queensland: SIRMOD and Infilt, and information from look-up tables in the FAO publication, termed "FAO-56", were used to estimate the components of the water balance equation. Infiltration for irrigation events was calculated using the surface irrigation simulation and design evaluation model, SIRMOD (Walker, 1999). Flow rate and advance time were measured using IRRIMATE advance sensors and flow meters developed by the National Centre for Engineering in Agriculture (NCEA). Infiltration characteristics were then simulated using *Infilt V5* (NCEA©) using field data collected at each crop irrigation: flow rates, irrigation duration, and irrigation advance time. Furrow length, field slope and furrow cross sections (throughout the season) were also measured as required model inputs. These parameters were used in the SIRMOD model to estimate the depth of infiltrated water at each of the head, mid and tail lysimeter locations. SIRMOD also estimated application efficiency, distribution uniformity and runoff. In-crop rain was recorded *via* the rain gauge. Evapotranspiration (ET) was calculated as described in the FAO irrigation and drainage paper (FAO 56) using daily weather data collected from the SILO (NRW) data base. These estimated components (I and ET) of the water balance model with measured rainfall (P) were used to estimate DD. The change in soil water storage (deficit) (ΔS) was considered as 100% for the pre-irrigation and 80% for successive crop irrigations.

B. SaLF

A second, indirect method of assessing DD is the "Salt and Leaching Fraction" (SaLF) model (Shaw and Thorburn, 1985). This model was run for all sites, specifically for the head, mid and tail locations separately (using the required soil data at these locations). SaLF analysis is based on the assumption that soil leaching or deep drainage is related to the soil hydraulic conductivity, which in turn is influenced by several, measurable soil and site characteristics: the amount of clay (%), clay mineralogy (defined by the ratio of CEC/clay %) and exchangeable sodium percentage (ESP). The soil physico-chemical properties used in the current analysis were clay (%), soil CEC (meq/100g), air dried moisture content (%), annual rainfall (mm), seasonal irrigation amount (mm), EC of the irrigation water (dS/m) and soil ESP at 0.9 m depth (meq/100g). As such, SaLF assumes that the soil profile is at a steady state where many of the parameters are unchanging (eg clay content, CEC, etc)

C. SODICS

SODICS (Thorburn 1986) is a transient salt mass balance model developed specifically for slowly permeable soils and provides information on predicted steady state soil chloride profiles and estimated time for the profile to reach equilibrium under the current management practices and water quality. Thorburn *et al.* (1987) developed the program to solve the transient solute mass balance and determine the drainage rate from soil chloride data. To date, the SODICS model has not functioned properly with data sets in the current project, principally as soil, chloride levels have been found to be increasing with time. This work is under current review to address and rationalise this apparent salinity increase in the project sites' soils.

Yield

Cotton yield data (bales of lint/ha) for as many seasons as possible were gained mainly from yield monitors, onboard cotton pickers (at sites where this was available) and the data presented as "down the paddock" means and standard deviations, from the head to tail ditch. In some seasons, at sites where yield monitors were not available and when due warning was given, hand picking of cotton was conducted; 3 x 10 m rows directly over the lysimeters at each of the head, mid and tail locations. The picked cotton was weighed and corrected to “lint yield” in bales/ha by multiplying the total (picked) weight (kg/ha) x 0.4 and multiplying by 227 (average bale weight in kg).

Groundwater studies

These have been conducted in the St George irrigation area (SGIA) from 2006. All results to date are presented in Appendix 6.

4. Results

4.1 Soil profile description

The geology of all ten sites is described as Qa – alluvium, alluvial plain landform with slowly permeable soil. Complete descriptions of landscape, classification and soil profile morphology are given in Appendix 2. Pampas, Dalby and Macalister soil surface condition was described (A. Biggs, NR&M Toowoomba) as periodic cracking and self-mulching. The Goondiwindi soil surface was described as periodic cracking, surface crust and self-mulching, the soil surfaces at St George (N) and (S), and Dirranbandi were described as periodic cracking and surface crusting.

4.2 Soil physico-chemical characteristics of experimental sites [6]

4.2.1 Particle size distribution

Results of the soil physico-chemical analysis supported the initial site selection process, where one aim was to conduct the experimental procedures on different soils, representative of irrigated cotton. A plot of the average clay %, silt, fine and coarse sand for all the lysimeter sites is given in Figures. 2a to d.

A wide range of clay % was recorded across the seven sites, ranging from 38% (St George (S) a Brown Vertosol) to 75% (Macalister; a Black Vertosol) (Figure 2a). Pampas (a grey/black clay) had almost 75% clay to 1 metre depth but this fell away rapidly in deeper layers. Several sites, Dalby (grey clay), St George north (brown-clay), Goondiwindi (grey clay) and Dirranbandi (grey clay) had similar clay contents (50 to 60%), in the immediate surface which remained almost constant with depth for all theses sites but Dalby gradually increased to > 65% by 1.8 m. By far the least amount of clay was recorded at the St George (S) site, with only ~40% throughout the profile.

The within-field variation (i.e. the data for each of head, mid and tail field locations) of soil physico-chemical properties at each lysimeter site is presented in Table 2 a - h. Evident is that clay content commonly varies commonly less than 10% across a field for any one depth. It is also evident that there is no trend in clay content linked to the in-field location; for example, shallow depths of the tail ditch location had the greatest clay % for Dalby and St George soils, and the least for the Goondiwindi soil (Table 2a - h).

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[6] The physico-chemical data for ACRI is restricted to a particle size analysis at the lysimeter installation depth (reported in Appendix 4). At the Maules Creek site, full physico-chemical analysis was conducted to 1.8 m depth at each of the head, mid and tail lysimeter locations in the main experimental field, and at the "mid opposite" location in the adjoining field. All data are reported in Appendix 5.

a. Boggabilla

Relative to the other lysimeter sites, the average clay content at the Boggabilla sites falls in the middle of the range (50-60%) and varies little with depth to 1.8 meters (Figure 2a). The Boggabilla sites have the largest average silt% to 1 m depth; up to 25% (Figure 2a).

The lateral (move) site at Boggabilla has quite uniform clay contents across the field, averaging the low to mid 50%, though coarse sand is far greater at the mid (14 to 22%) than either the head or tail (ranging 2 to 10%), whereas the silt content at the head and tail are greater than the mid (Table 2a). The furrow site at the head and mid has comparable clay contents to the lateral (43 to 58%), whereas the tail has significantly more clay (high 50s to 65%). The head on the furrow side is the sandiest of any of the lateral or furrow field locations, with total sand% in the 30s. Similar to the lateral site, all locations on the furrow side have quite high silt contents, in the 20s and up to 30%. This mixed textural classes where no one class dominates, typifies the near-river location such as here. Prior streams are clearly visible around these two fields on air photos.

b. Dalby

Relative to four of the other lysimeter sites (Dirranbandi, Goondiwindi, Boggabilla and St George (N)), the Dalby site has a similar clay content (55 to 60%) in the immediate surface layers but the Dalby site gradually increases to almost 70% by 1.8m depth (Figure 2a). In terms of the other two lysimeter sites close to Dalby town (Pampas and Macalister), the Dalby site has substantially less clay content (15 to 25% less) than the Macalister site throughout the sampled soil profile, and to 80 cm at Pampas. The silt content at the Dalby site (Figure 2b) to 1.8 m (10 to 15%) is similar to the majority of the other lysimeter sites, apart from Boggabilla and Pampas, both of which are greater. Though neither fine nor coarse sand (Figure 2c and d) vary much with depth (between 10 to 15%), it can be seen that the largest values of each (15%) occur on the soil surface at the Dalby site. Relative to the other lysimeter sites, the Dalby site has sand values in the middle of the range (Figure 2d).

In terms of variability in sand, silt and clay across the Dalby site, clay content is greatest at all depths at the head ditch, and the tail location has the least clay to 1.3 m of the three field locations (Table 2.b). The decrease in clay content from head ditch to tail ditch is associated with an increase in the coarse sand fraction at the mid and tail locations, relative to the head. This difference is particularly large on the soil surface and close to the soil surface, for example in the 0-10 cm layer clay where coarse sand is 59% and 11%, respectively, at the head and 50% and 20% at the tail. Less clay and greater coarse sand on the soil surface at the tail location would give less potential for cracking, more poorly structured soil, that would tend to seal quickly (with irrigation and rain), form a crust, and have less water holding capacity.

c. Dirranbandi

Relative to the other lysimeter sites, it is evident that the Dirranbandi site has the second least clay content, and especially below 50 cm depth (Figure 2a)

There is a substantial difference in clay content between the head and mid locations, and the tail; the latter having up to 10% more clay for equivalent depths, almost the whole way down to 1.8 metres (Table 2.c). Less clay is compensated by more coarse sand in the head and mid locations, relative to the tail. The effect of this would be less cracking, and generally a "tighter" less porous soil in the head and mid locations.

d. Goondiwindi

Relative to the other lysimeter sites, the clay content at the Goondiwindi site falls in the middle of the range (50-60%) and varies little with depth to 1.8 m (Figure 2a).

There is a substantial difference in clay content between the head and mid locations, and the tail (Figure 3). For every sampled depth, the clay content at the tail is less than each of the head and mid locations; particularly so from 0.6 to 1.8 m with up to 15% less clay content. In contrast, the mid location, from the soil surface to 1.3 m has the largest amount of clay; up to 62%. Less clay is compensated by more coarse sand in the tail location, particularly relative to the mid (Table 2.d). The effect of this would be greater hydraulic conductivity (water flow through the soil) with a potential for increased DD at the tail location.

e. Macalister

Relative to the other lysimeter sites, the Macalister site has the greatest average clay content throughout the whole soil profile to 180 cm (being 70% to almost 80%). The only other site with a similar average clay content was Pampas but only to a depth of 90 cm (Figure 2a). Corresponding to this trend in clay content with depth, the average silt content is the most constant, being 11 to 14% to 180 cm depth (Figure 2b). The Macalister site has the second lowest average sand content of any of the sites; fine sand being 5 - 10% and coarse sand <3% throughout the soil profile (Figure 2c and d).

In terms of variability in sand, silt and clay across the Macalister site, clay content varies little between field locations and with depth, being 72 – 80% throughout (Table 2.e). These small variations in clay % are mirrored in the fine and coarse sand %, and silt % throughout the soil profile; there being only small differences between field locations and depths for each of these size fractions (Table 2.e). The effect of the large clay values and small fine sand throughout the soil profile would be a most strong potential for deep and intensive cracking (into small soil structure units), giving a strongly structured soil with large water holding capacity, to depth.

f. Pampas

Relative to the other lysimeter sites, the Pampas site has the second greatest average clay content to 90cm (approximately 75%), second only to than the other "black" cracking clay at the Macalister site (Figure 2a). However, below 90 cm the average clay content at the Pampas site decreases rapidly, being only 57% at 150-160 cm. Corresponding to this trend in clay content with depth, the average silt content at the Pampas site is the most changeable of all the lysimeter sites, being 16 to 18% to 90 cm and then rising to 31% at the 150 - 160 cm depth (Figure 2b). The Pampas site has the least sand content of any of the sites; coarse sand always being <2% throughout the soil profile, and fine sand being 2% on the soil surface, then slowly increasing with depth to a maximum of 10% at the deepest sampling depth (Figure 2c and d)).

In terms of variability in sand, silt and clay across the Pampas site, clay content is greatest at all depths at the tail ditch relative to the head and mid, both of which are quite similar at all depths, except 170-180 cm where the mid rises to 65% (Table 2.f). The difference in clay content between the tail and the other two locations is accentuated below 120 cm where the tail has up to 37% more clay than the head or mid for a given depth increment. These lessened values of clay at the head and mid locations are compensated by the presence of more silt and, in particular, more fine sand (in deeper layers) for the mid and head (Table 2.f). The effect of this greater silt and fine sand at deeper layers would be less potential for cracking, a tighter and more poorly structured soil with less water holding capacity.

g. St George (N)

The average clay content at the St George (N) site is 50 – 60% (Figure 2a). In terms of the variability, there is not a great difference in clay content between the 3 field locations (Table 2.g). The head tends to have less clay, about 10% less (so more fine sand) than the mid and tail), especially on the soil surface. Coarse sand and silt vary little between field locations.

h. St George (S)

The average clay content graph with depth for all the lysimeter sites clearly shows clearly that the St George has, by far, the least clay and (hence) the most sand (Figure 2a). The average clay content to 180 cm is about 40% which is approximately ½ the clay content of the Macalister site. The immediate implication of this small clay content is that this soil will have the least cracking potential of all the lysimeter sites.

Large differences in clay content are evident between the 3 field locations with the tail having more clay than the two other locations to 80 cm depth and the mid location having consistently the least clay content to 160 cm depth (Figure 4).

Fine sand content is greater at the head location to 120 cm, followed by the mid then tail (Figure 5). Below 120 cm there is little difference between locations. Coarse sand content is much larger at the mid than the head location throughout the soil profile with the mid being half-way between the two (Figure 6). In summary, the mid location has the least clay, greatest coarse sand and mid-values of fine sand of all the field locations. At the other end of the spectrum, the tail location has the most clay to 80 cm, and the least fine sand to 160 cm and mid values of coarse sand. As such, more DD and less cracking of the soil would be expected at the mid location due to low clay and greater sand contents, and conversely less DD and more cracking (though not much due to small clay content) at the tail location.

4.2.2 Soil pH

a. Boggabilla

The average pH at the Boggabilla sites is noticeably larger than all other sites, particularly in the 40 to 120 cm (Figure 7a) with average values >9. For individual field locations on the lateral side, the mid and tail locations have large values (>9) in the 10 to 90 cm layers and generally the head location has values <8 in the two surface layers. The furrow irrigated field, generally, has larger pH values across the field, all values but one being >8. There is a small tendency for the head location to have more alkaline pH values.

b. Dalby

The across site average pH at the Dalby site is always alkaline (>7) through the soil profile and is fairly uniform with depth, never exceeding 8.5 (Figure 7a). For individual field locations (Table 2.b), there are very few values of pH <8 and no values >8.6, with little variability either down the soil profiles or between the three locations.

c. Dirranbandi

The pH is close to neutral (7) on the soil surface at all locations, becoming alkaline below 50 cm, though never above a pH of 8.5 (Figure 7a).

d. Goondiwindi

The across site, average pH at the Goondiwindi is alkaline (>7) to almost 1.5 m, then is approximately 6.5 to 1.8 m (Figure 7a). There are strong across-site differences in pH at the Goondiwindi site (Figure 8). The tail is alkaline throughout the soil profile, ranging from 8 to 8.7, whereas the head and mid, though alkaline to approximately 1 m, become quite acidic (pH of 5.5 and 5.2) at 1.7-1.8 m (Table 2.d)

e. Macalister

The average pH at the Macalister site is always alkaline (>7) through the whole soil profile and is quite uniform with depth, ranging from 8.2 on the soil surface to 8.7 from 150 cm depth (Figure 7a). Soil pH shows little variation between each of the field locations and with depth (Table 2.e).

f. Pampas

The average pH at the Pampas site is always alkaline (>7) through the whole soil profile and peaks at 8.8 at 75 cm depth (Figure 7a). The soil surface at the mid and tail locations are slightly less alkaline (7.4 and 7.6) but the remainder of the soil at these locations is >8 with little difference between the three locations (Table 2.f).

g. St George (N)

In contrast to the other lysimeter sites, the St George (N) site is the least alkaline and is acid below 1 m, reaching an average pH of just over 5 at 175 cm (Figure 7a). In terms of within site variation, the pH at the head ditch drops very quickly from alkaline to acid (down to 4.6) at approximately 90 cm (Table 2.g). The tail location is also acid, but not nearly as bad as at the head – dropping to a minimum of 5.4. Below 150 cm, the tail is also acidic too. The pH values of < 5 probably represent a severe barrier to root growth. Values < 7 show zones where plant nutrition would be poor.

h. St George (S)

The average pH of the St George (S) site is alkaline to 150 cm, then becomes acid (<7) to 180 cm, though not the strongly acid subsoils of the St George (N) site (Figure 7a). Looking at the individual field locations, the tail is alkaline throughout, being pH 8 to 8.5, whereas the head and mid are alkaline only to 150 cm, then acid to 180 cm; peaking there at pH's of 5.5 and 6 (Figure 9). These latter values represent a strong barrier to root growth as soil with such low pH commonly has very low nutrient availability.

4.2.3 Soil EC

a. Boggabilla

The across site average EC levels to throughout the sampled soil profile at the Boggabilla site are very low, being < 1 dS/m (Figure 7b). The across site values for both the lateral and furrow sites are all very low, with no real pattern to site variability. Only one value >1 was measured, in the 80-90 cm layer on the lateral side.

b. Dalby

The across site average EC levels to 25 cm depth at the Dalby site are very low (< 0.5 dS/m) and similar to all but one (Macalister) of the other lysimeter sites (Figure 7b). Below 25 cm, EC values increase to an average of almost 1 dS/m and remain at that level to 175 cm depth (Figure 7b). There is little variability in the EC values at each of the head, mid and tail locations of the Dalby site (Table 2.b) with, again, values increasing to just <1 dS/m from 30 cm depth. In terms of plant salt tolerance, EC values <0.5 in 70% of the root zone (in a soil such as this with 60-80% clay) indicate that even the least salt tolerant plants will grow without salt problems. Cotton, generally is tolerant of soils with EC values up to 7.7 dS/m. Shaw and Gordon (in the Salinity Management Handbook) describe this type of flat, low value EC curve (as at the Dalby site) as "recharge" which they say is "indicative of a soil with high hydraulic conductivity and seasonal or annual flushing of the small amounts of salt that accumulate as a result of evapotranspiration".

c. Dirranbandi

EC levels at the Dirranbandi site are extremely low for all depths at all three locations. This is most evident when the average values of head, mid and tail for the individual depths are plotted against the other lysimeter sites (Figure 7b). Dirranbandi values are by far the lowest of all the lysimeter sites. Interpretation of EC is not easy, particularly such low values. It appears that the soil salts in this Dirranbandi soil are very small. In terms of plant salt tolerance, these values <0.17 (in a soil with 40-60% clay) show that even the most salt intolerant plants will grow.

e. Macalister

The across site average EC levels at the Macalister site are large (> 1.0 dS/m) and are the largest values on the soil surface and to 60 cm of any of the lysimeter sites (Figure 7b). The soil surface at the head location tends to have a slightly smaller EC value than all other locations and depths, however the remainder of the profile has the largest EC values for equivalent depths to the other two locations (Table 2.e). The Salinity Management Handbook (Qld Govt, 1997) states that soil EC values > 1.18 dS/m show this large clay content soil (60-80% clay) to have a "very high" salinity rating and deem it suitable for only "very tolerant" crops. Values of EC >1.87 dS/m (nb the head location at 0.5-0.6 m is 1.83 dS/m) are "extremely" saline and are "generally too saline for crops". The tail location has the smallest EC values throughout the soil profile, being 0.2 to 0.3 of a unit less than the other two field locations. Cotton, generally is tolerant of soils up to EC values of 7.7 dS/m. Barley, however has a slightly less salt tolerance level of 5.3 dS/m (data of NSW, DPI).

f. Pampas

The across site average EC levels at the Pampas site are very low (< 0.5 dS/m) and are the second lowest for all the lysimeter sites, for all depths. (Figure 7b). The head location tends to have slightly greater EC values but the values are so small that no relevance can be given to this. Interpretation of EC is not easy, particularly such low values, though it appears that soil salts in this Pampas soil are present in very small quantities.

g. St George (N)

EC and Cl are within tolerance so problems are not expected (Figure 7b). But below 0.75 m to 125 cm EC values are large, peaking at 3.07 dS/m, indicating salt building up in the root zone.

h. St George (S)

Average EC is generally very low at the St George (S) site, though there is a rapid increase in EC values in depths below 80 cm to 130 cm that may well indicate accumulation of salt in this region (Figure 7b and c). Of interest is that the other St George site (N) is the only other lysimeter site to demonstrate this trend; large and sudden increase in EC in the 80 to 130 cm zone. In terms of plant salt tolerance, values that are >1.5 show that only moderate to high salt tolerant plants will grow without salt problems. The values here of <1.5 to 0.8 m should pose no problems to plant selection (in terms of salinity tolerance).

4.2.4 Cation exchange capacity (CEC)

a. Boggabilla

The average CEC values at Boggabilla are in the lower end of the lysimeter sites range, being 35 to 40 meq/100g throughout the soil profile to 150 cm (Figure 10). On the lateral side, there is a slight tendency for the mid location to have smaller values and all locations to have little variation with increasing depth. The head location on the furrow side tend to have smaller values than either the mid or tail, high 20s and low 30s rather than high 30s and low 40s. There is no major difference in CEC between the lateral and furrow sides of this site.

b. Dalby

The average cation exchange capacity (CEC) of the Dalby site soil is moderately high, being low to high 40s (meq/100g) throughout the soil profile with the greatest values at 155 cm, making it the third largest CEC values of all the lysimeter sites. (Figure 10). The individual field location CEC values correspond with the clay values (i.e. greatest values at the head ditch and smallest values at the tail ditch) and a slight increase in CEC from the soil surface to 160 cm at all locations (Table 2.b). The tail location has a CEC of 34 - 40 to 60 cm, whereas the head and mid have values of 40 - 46 for the same depths. Only the head location has values >50 and only in the zone below 100 cm. Large CEC values, together with large clay values, relate to good soil cracking and fine surface structure; so in these terms the Dalby site should have moderate levels of cracking and structure, with poorer quality at the tail ditch end; better at the head ditch.

c. Dirranbandi

The average CEC of the Dirranbandi soil is one of the three lowest of all the lysimeter sites, being low 30s throughout the soil. Head and mid locations, in particular are low, rarely being >30.

d. Goondiwindi

The across site average CEC of the Goondiwindi soil is the second or third smallest of all the DD sites, being mid to low 30s to 180 cm (Figure 10). The individual location CEC values correspond with the clay values and the variations in these values between locations and with depth; the tail location in particular below 90 cm having very low CEC values, down to 19 (meq/100g) – almost half the value at the equivalent depth at the mid location (Table 2.d). Moderate to small CEC values, together with moderate (55%) clay values, relate to some degree of soil cracking and fine surface structure; so in these terms the Goondiwindi site should have moderate levels of cracking and structure development at the head and mid locations, but below 90 cm at the tail the soil will tend to crack little and have low inherent fertility.

e. Macalister

The across site average CEC of the Macalister soil is very large, ranging from the low to mid 70s meq/100g, to 150 cm depth, making it clearly the largest CEC values of all the lysimeter sites (Figure 10). The individual location CEC values show no consistent trend with depth, all values being >68 meq/100g with a maximum of 79 (Table 2.e). There is a slight trend for the tail location to have larger values than the other two field locations, throughout the soil profile (ranging from 72 to 79 meq/100g). Large CEC values, together with large clay values, relate to good soil cracking and fine surface structure; so in these terms the Macalister site should have excellent levels of cracking and structure at the head, mid and tail locations. One index, used by soil scientists, to provide insight into a soil's potential for swell/shrink (crack and structure formation) is the ratio of CEC/clay. A soil with a ratio of >0.7 is classed as "high activity". The Macalister soil, at a ratio value of approximately 1, is therefore a very highly active clay soil.

f. Pampas

The across site CEC of the Pampas soil is very high, being mid to high 60s to 100 cm, then mid to high 50s to 175 cm, making it the second largest CEC values of all the lysimeter sites. (Figure 10). The individual location CEC values correspond with the clay values and the variations in these values between locations and with depth (Table 2.f). The tail location has the largest or equal largest CEC (64 to 73) to 160 cm, whereas the head and mid are in the 50s below 90 cm; corresponding with the reduced clay contents at those depths at both head and mid locations. Similar to Macalister, the Pampas site with these large CEC values, together with large clay values, will have good soil cracking and fine surface structure. This may be of slightly poorer quality, below 100 cm at the head and mid locations, relative to the tail.

g. St George (N)

The average CEC values at the St George (N) site are the 2nd to 3rd smallest of all the lysimeter sites, ranging from 30 to the low 30s down the whole soil profile (Figure 10). There is no real across site trend, all locations having high 20s to low 30s CEC (Table 2.g)

h. St George (S)

The St George (S) site has the smallest CEC values of all the lysimeter sites, being on average less than 30 meq/100g throughout the soil profile, and on average in the mid to low 20's at depth (Figure 10). There is no real across site trends in variability; all locations being in the low 20s to low 30s throughout the profiles.

4.2.5 Cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+})

a. Boggabilla

There is little variability in the values of individual cations (Ca, Mg, Na and K) either across the three field locations of each of the lateral and furrow fields, or between the two fields. The soils of each field tend to be slightly CA dominant (over Mg) to about 50 cm depth; generally linked to better soil structure – more cracks and fines seed beds in clay soils. Below that depth Mg tends to dominate, showing a tendency for these soils to have poor subsoil structure with reduced cracking (hence water entry and DD). Sodium levels are generally low, more so in the lateral field where only the mid location has ESP (sodium as a % of the total cations) of >20; showing a tendency for poor structure and small water infiltration rates. The furrow filed has ESP values >18 at all locations from 60 cm depth, showing that field to have a uniform tendency for poorer subsoil structure, hence less DD than the lateral field.

b. Dalby

Individual cations (Ca, Mg, Na, and K) show the soil to be Calcium and Magnesium dominant in all layers at all three field locations (Table 2.b). Generally, the soil is Ca dominant to 30 cm, then Mg dominant beneath that. In a moderately high clay content soil such as here, Ca dominance would be required (eg Ca:Mg ratios of at least 2:1 have been discussed as "best") to achieve a soil that would (naturally) be finely structured throughout, have a self-mulching (crumb-like) topsoil and crack moderately on drying. This soil has Ca:Mg ratios >1 only in the immediate topsoil (Figure 11), being 1.14, 1.1 and 1.06 for head, mid and tail locations, respectively. The ratio falls below 0.8 for depths below 120 cm for all field locations, with the tail particularly low (0.67 to 0.62) below 50 cm depth. So, though the topsoil structure may be a little self mulching (naturally crumb-like), the subsoil will tend to be poorly cracked (large, hard soil blocks with few cracks present). The impact of excess Mg (over Ca) in the cation suite is researched in a USA study[7] on a range of soils, and showed that soil dispersion (non-reversible breakdown into primary particles of sand, silt and clay) increased and water infiltration decreased with a relative increase in Mg.

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[7] Available from: http://topsoil.nserl.purdue.edu/fpadmin/isco99/pdf/ISCOdisc/SustainingTheGlobalFarm/P057-Dontsova.pdf

The site average ESP plot shows that the Dalby site has the largest ESP values in the top two layers sampled (0-10 and 20-30 cm, being 9.7 and 12.7). Below 50 cm, the Dalby site has the third lowest (approximately 10%) values, relative to the other lysimeter sites (Figure 12). Values of >6 and >15 for topsoils and subsoils, respectively, are required to class a soil as "sodic", with associated problems of hardsetting, poor structure development, and poor water and plant root penetration that follow. On this basis, even the immediate topsoils of the head, mid and tail locations can be classed as "sodic", having ESP values from 8 to 11.2 (Figure 13). Maximum ESP values for all field locations occur in the 25-30 cm layer, all values being >12; again causing this layer to be classed as sodic. Only the tail location maintains these high values (about 12) to depth; the head and mid dropping to 9 in the subsoil (Figure 13).

c. Dirranbandi

Individual cations (Ca, Kg, Na, K) show the soil to be Ca dominant in all layers at all locations. This is especially important in a low clay content soil such as here. Additionally, Ca is always >50% of the total CEC; again a positive aspect for a clay soil as Ca has good potential to aid structure formation, giving cracks and better water infiltration. Sodium levels are generally low with the average surface value of <5 and values of 12 throughout most of the subsoil, causing the site to be classed as "non sodic" (Figure 12). However, plots of ESP for the individual field locations shows that the head has large ESP levels below 50 cm, being up to 18 and 19% to 1.8 metres (Figure 14). Subsoil values of ESP > 15% are considered indicative of tight, non cracking subsoils with poor water penetration and low potential for root growth. Additionally, there is little that can be done with these high ESPs at these depths; being too deep for gypsum-based alleviation strategies.

d. Goondiwindi

Individual cation data show the soil to be Ca dominant in particular to 1.3 m depth at each field location (Table 2.d). With moderate clay content (40 – 60%) soil such as here, Ca dominance in particular shows that the soil will (naturally) be finely structured throughout, have a self-mulching (crumb-like) topsoil and crack moderately on drying. Table 4 shows there is little variability (pattern) in exchangeable Ca, Mg, Na and K between the head, mid and tail locations to 1.3 m depth. Much more variability in cations content can be seen below 1.3 m depth, in particular between the head and the mid and tail locations. In terms of ESP the site average values are >15 from 0.8 m; hence sodic subsoils are present (Figure 12). In particular the ESP levels are relatively large at the head and mid compared to the tail; being almost double with values up to 21%, classing these subsoils as "most sodic" (Figure 15).

e. Macalister

Individual cations show the soil to be Ca and Mg dominant in all layers at all locations (Table 2.e). In association with the very large clay contents at this site, this level of Ca dominance shows that the soil will (naturally) be most finely structured throughout, have a strong self-mulching (crumb-like) topsoil and crack strongly on drying into very small structure units. Table 2.e shows there is little variability (pattern) across the field in exchangeable Ca, Mg, Na and K between the head, mid and tail locations throughout the soil profiles. However, most evident is the reversal in the size of the Ca:Mg ratio with depth; all field locations being Ca dominant to 50 or 60 cm (Ca:Mg ratios >1), then Mg dominant below that, with strong Mg dominance from 80 – 100 cm at the head and tail locations in particular, and below 100 cm at the mid (Figure 16). Generally, Ca-dominance (in the exchangeable cation suite) is regarded as important for enhanced clay activity (good cracking and fine structure), whereas Mg dominance is considered to cause tight/non-cracking soils – especially when Mg is the dominant cation in the subsoil, such as here at Macalister.

Average sodium levels at Macalister are generally very large on the immediate topsoil (an average of 17 %) and increase to an average of almost 25% at 150 cm. (Figure 12). The head location, in particular has very sodic subsoils with no values of ESP <18 below 40 cm and peaking with an ESP of 25 at 150 cm (Figure 17). The tail location is >15 below 80 cm and the mid below 120 cm. These data imply that there will be quite severe surface and subsoil sealing (especially at the head location) when this soil is wetted; resulting in very tight subsoils with poor root penetration potential.

f. Pampas

Individual cations show the soil to be Ca and Mg dominant in all layers at all locations with a slight trend for Ca dominance to 50 or 60 cm depth, then almost equal Ca:Mg ratios (of 1) to depth (Table 2.f). Table 2.f shows there is little variability (pattern) in exchangeable Ca, Mg, Na and K between the head, mid and tail locations.

Sodium levels are generally very low and a plot of the average ESP shows that the Pampas site has the lowest (always <7%) values, of all the lysimeter sites (Figure 12), so no layers at the site are sodic.

g***. St George (N)***

Cations in the Table 2.g show a Ca dominance to at least 90 cm depth. The tail location in particular is Ca dominant to 180 cm. Of concern, however, are the large ESP values from 50 cm to depth for each of the head and mid locations; ESPs of 18 to 24, classing these subsoils as strongly sodic. The tail is less sodic, being >15 from only 80 cm and peaking at 22 in the deep subsoil. Little can be done to alleviate these large ESP levels at these depths. And these large ESP values are "additional" to the strongly acid subsoils, discussed earlier and most likely shows the St George (N) subsoils to be fairly hostile to plant root growth, have very low nutrition, and set hard when dry (high inherent density).

h. St George (S)

Individual cations (Ca, Mg, Na, K) show a Ca dominance at all depths in the soil profile at each of the head, mid and tail locations (Table 2.h). This is certainly a positive aspect for a soil with such small CEC and clay values, as here. Also, it is evident that the Ca ion, though it reduces in value and concentration (relative to Mg) with depth, is evenly distributed across the three field locations. One good thing is that with CEC : clay ratios (the "clay activity ratio") of approximately 0.5 to 0.6, this soil would be classed as "moderately active" so it can be interpreted that though the clay content is small, the type of clay is "good", so the soil will have some potential for swell/shrink and crack formation and will have some potential to hold charged ions (like fertilisers).

Of concern, however, are the large average values of ESP in the subsoil at this site (Figure 18). In particular, the head location has very large ESP values being >15 from 50 cm and peaking at 21 at 125 cm (Figure 18). Below 125 cm, both the mid and tail also have ESP values >15. These large ESP values, in association with the acid subsoils at the head and mid locations (Figure 9) show the subsoils at this site to be of very low quality, in terms of fertility and plant root penetration.

4.2.6 Organic carbon

a. Boggabilla

The Boggabilla site has the largest average organic carbon (OC) value of all the lysimeter sites (1.6%) though the values drop away quite quickly below another reasonably high value of 1.1% in the 10-20 cm layer (Figure 19). The head and tail have good OC values (1.57 and 1.78%) and the tail location only drops below 1% below 60 cm, representing good values at that location. (Table 2.a).

Similar to all cropping soils in the semi-arid zone (as with the 10 lysimeter sites), sustaining or improving organic carbon content should be seen as a *long term* plan, requiring the growing of a range of "break crops" that may well be left to rot or mulched-in (zero- or minimum-till back into cotton) to slowly build up and maintain soil surface organic matter. These may well be left to rot or mulched in (zero- or minimum-till back into cotton) to slowly build up surface organic matter. This is particularly the case in the more sandy sites (eg St George (S)) where building soil organic matter levels is most challenging.

b. Dalby

The average OC values show that the Dalby site has good OC status (values of 1% or more) to almost 50 cm, amongst the greatest of all the lysimeter sites to such depths (Figure 19). There is no strong pattern in OC between the individual field locations (Table 2.b) though apart from a large value on the immediate soil surface, the tail location drops below 1% from 20 cm depth, whereas the head and mid locations stay >1 to 60 cm.

c. Dirranbandi

The average OC values for Dirranbandi values are the lowest (by some margin) of all the lysimeter sites, never being above 0.6% (Figure 19). Every effort should be made to improve this, especially with the high values of sand present in the surface soil (up to 33% at the head). Low OC with high fine sand tends to give a surface crust and hence poor water infiltration and seedling emergence problems.

d. Goondiwindi

The average across site organic carbon (OC) values show that the Goondiwindi site has moderate OC status (values <1.5) in only the top 0.1 m, and then OC rapidly declines to 0.45% at 0.8 m and maintains these very low values to 1.8 m (Figure 19). There is very little difference in OC between the head, mid and tail locations for similar sampling depths (Table 2.d).

e. Macalister

The average across site organic carbon (OC) values show that the Macalister site has good OC status (values >1) to almost 80 cm, the greatest of all the lysimeter sites (Figure 19). There is no discernible pattern in OC between the individual field locations (Table 2.e).

f. Pampas

The average across site organic carbon (OC) values show that the Pampas site has good OC status (values >1) to almost 50 cm, amongst the greatest of all the lysimeter sites (Figure 19). There is no discernible pattern in OC between the individual field locations (Table 2.f).

g. St George (N)

The average OC values at this site are always <0.8% (Figure 19). In terms of individual field locations, no location has a value >1% even in the immediate surface layers, showing OC levels at this site to be very low. Every effort should be made to improve this especially with the high values of fine sand present in the surface soil (up to 33% at the head). Low OC with high fine sand tends to give a surface crust and hence poor water infiltration and seedling emergence problems.

g. St George (S)

Organic carbon (OC) values are very small at this site with average values less than 1% at all depths (Figure 19). Only one value is over 1%, on the soil surface at mid location (Table 2.g). Every effort should be made to increase these levels, particularly considering the very large values of fine sand present in the surface soil (up to 31% at the head), again leading to surface crusting with problems of poor water infiltration and seedling emergence.

4.3 Deep drainage

4.3.1 Lysimeters

a. Boggabilla

Agronomy & Deep drainage

The potential for dramatically reduced DD from the use of a LM is evident in Table 3. In all seasons since the lysimeters were installed, there has only been one DD event under the lateral move, at the head ditch end of the field at the first irrigation (31 mm DD). Apart form that, there has been zero DD under the LM in each of the three irrigation seasons, to date (Table 3). In contrast, in the two seasons when the furrow field was irrigated (2005-6 and 2007-8) there have been DD of 105, 87 and 93 mm in the first season at the head, mid and tail locations, and 19, 40 and 1 mm for the same locations in the 2007-8 season. The total amounts of water applied (in any one season) differ strongly between the two fields. The lateral had 2.7, 2.3 and 1.5 (to date this season) ML/ha applied in each of the seasons, as different to 6.3 and 4.5 ML/ha in the furrow field in the two years it was irrigated; representing a 57% and 67% reduction in water use under the lateral in each of the 2005-6 and 2007-8 seasons. Crop yield was similar between the two fields; approximately 8 bales/ha in each field. Hence, there is a strong difference between the two irrigation systems in yield achieved per ML of water used.

From the logged DD volumes in the 2005-6 season in the furrow field, although DD was evident after each of the irrigations at each field location, the contribution to the total (seasonal DD) greatly reduced as the season progressed (Figure 20). 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). This decrease in DD as the season progresses has been found at almost all lysimeter sites and has been attributed to lessened irrigation application time and increased evapotranspirational demand, as the growing season continues.

b. Dalby

Agronomy & Deep drainage

Three crops have been grown in the field in the course of the trial (Table 4): irrigated cotton, sown on 13 October 2004; irrigated soybean, sown on 9 December 2005 and dry land sorghum during the 2006-7 summer. At all other times the field has been maintained as bare-fallow. Amounts of in-crop rain and water applied as irrigation are given in Table 4.

By far the largest DD values were recorded during the 2004-5 irrigated cotton season (Figure 21 and Table 3). Zero DD was measured during the irrigated soybean season (2005-6) while small DD (0.17 ML) was measured at only the mid location during the dryland sorghum crop (2006-7) that had one supplementary irrigation.

The DD total for the 2004-5 season was greatest at the mid field location according to both the logged (99 mm, ie 0.99 ML/ha) and volumetric (95 mm, ie 0.95 ML/ha) data (Figure 21 and Table 3), with good correspondence between these two measures. At the head location the total seasonal DD was 28 mm (logged) and 39 mm (volumetric). Only volumetric DD was available for tail location (34 mm) due to a malfunction in the tipping bucket device (now repaired). At both the head and mid locations, the largest value of DD recorded was following the pre-irrigation with far smaller amounts of DD recorded after the in-crop irrigations, despite continued irrigations and 300 mm of in-season rainfall. In terms of leaching fraction (LF), where LF = DD as a % of applied water (irrigation water, alone), the largest DD volume (95 mm) represents a LF of 20% (the percent of the water applied, that is lost to DD). Evident is that as the season progressed, DD fell to zero; again a common trend at almost all the lysimeter sites. Rationalisation of this “through the season reduction in DD” is applicable to all sites where this has been found to occur; and includes greater potential for DD early in the season when there are small plants with low evapo-transpirational demand, as well as low daytime temperatures. Later in the season, larger more leafy crops with greater root systems extract the applied (irrigation and rain) water rapidly, leaving little to bypass the root zone. Additionally (and as evident in Figure 21), later in the season irrigations tend to be more frequent (to match increasing evapo-transpirational demand of larger plants in hotter environments, hence keeping the soil wet and non-cracked) with lesser volumes applied (so, again, less water available to bypass the root zone).

c. Dirranbandi

Agronomy & Deep drainage

Three crops have been grown in Field 16 in the course of the trial (Table 5): cotton, sown on 15-16 October 2003; a "winter" wheat crop, sown on 3 June 2004; and cotton, sown on 22 September 2005. There have been two bare-fallow periods; October 2004 to October 2005 and from April 2006 to present. In crop (or fallow) rain and water applied as irrigation are also given in Table 5.

DD data was collected in only one of the two irrigated cotton seasons; 2003-4. All equipment was fully operational throughout the entire 42 months of the trial, to the last data collection date, yet no DD has been collected. This will be rationalised, below.

Most interesting was the lack of DD in the 2005-6 cotton season, particularly in light of the facts that 9 ML of water were applied (irrigation) and the crop received an additional 209 mm of in-crop rain (Table 5). The 2005-6 season, however, was quite different to the 2003-4 season and remains unique from many seasons before, specifically in terms of high day and night temperatures. It has been reported that the 2005-6 season had both the greatest number of day degrees ever-recorded (1852) and the greatest number of "hot" days (>30 C), ever-recorded (58). The effect of this on plants and soil (at the Dirranbandi site) has been reported as "the cotton plants continuously appeared stressed though the soil was permanently wet" and "the soil was kept wet all season so no cracks appeared" (so minimal chance for bypass water flow) and there were "extremely hot nights so plants kept extracting soil water to keep themselves cool and hydrated" (so again no water available for DD). The cumulative effect was far greater than average evapo-transpiration, leaving little water to bypass the rootzone as DD.

In the 2003-4 season, there was good correspondence in the amounts of DD recorded both as tips and as actual water volumes at each of the head, mid and tail locations; being 11, 21 and 179 mm (volumes) and 13, 2, 157 mm (tips)[8] (Figure 22 and Table 3). That represents a maximum DD of 1.8 ML (179 mm), and only at the tail ditch end of the field. In terms of leaching fraction (DD as a % of applied water) that represents a maximum of 19%. However, there was strong differences in the amount of DD between field locations with the tail ditch recording far more DD (1.8 ML/ha; almost 40% of the applied water) than both head and tail locations for both tips and volume measurements (Figure 22). Two, reasons for this in-field difference can be given. Most evident, especially early in the season were routine blockages of the field water-exit system, causing water to back-up over the tail lysimeter location for extended periods. Adding to this, the inherent properties of the soil at the tail ditch (greater clay, less sand, greater CEC, greater Ca and less Na on the cation suite) will cause this soil to have greater crack potential and crack volumes, particularly compared to the head location. As a result, inherently, the tail location would have greater potential for by-pass flow (*via* cracks), hence DD. Evident also from the DD data (Figure 22) is the dominance of early season irrigation events in causing DD. As the season progresses, DD falls to zero (after the fourth crop irrigation). Rationalisation includes small evaporative and transpirational demand, early in the season, due to low temperatures and small (shallow rooted) crops. Later in the season, larger more leafy crops extract the applied water rapidly, leaving little to bypass the root zone, and irrigations tend to be more frequent (keeping the soil wet and non-cracked) and lower volumes (so less water available to bypass the rootzone).

d. Goondiwindi

Agronomy & Deep drainage

Four summer crops have been grown in the course of the trial (Table 6): maize (2002-3), sorghum (2003-4), cotton (2004-5) and sunflower (2005-6). There was one bare-fallow period; from October 2006 to May 2008; associated with drought conditions. In-crop (or fallow) rain and water applied as irrigation are given in Table 6.

The DD data collected from the tipping bucket device at the three locations at the Goondiwindi site are presented as plots of cumulative DD from each of the three field locations for the 2002-3, 2003-4 and 2004-5 seasons with the rainfall and irrigation events

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[8] Discrepancies such as this in the electronically measured DD and the actual waters collected in the sample bottles has been found to be the "norm" at all sites. The explanation of these discrepancies includes a variety of possibilities, such as peak (rapid) flows of DD may be "missed" by the tipping bucket device, the tipping bucket may sometimes become stuck, and the logger on the tipping buckets have been known to fail.

(when known) also plotted (Figure 23). The DD data from the total amount of leachate water collected in each of the six seasons, to date, is presented in Table 3.

In the 2002-3 season, DD of 114 mm (1.14 ML/ha), 55 mm and 14 mm at the head mid and tail, respectively, were logged (Figure 23) and 187, 196 and 24 mm were collected as leachate (Table 3). The values at the Goondiwindi site represent up to 50% of the applied irrigation water being lost to DD (ie the LF – leaching fraction – of Table 5). One trend, evident in Table 3, is for the head ditch location to have more DD than the mid and the mid to have more DD than the tail (the seasons of: 2002-3, 2003-4, 2004-5). Generally, with furrow irrigation the head ditch end of the field tends to remain inundated for long period of time. And because irrigation siphons tend to be stopped before the water reaches the tail ditch end of the field, lesser DD occurs there. In the 2005-6 season water was in very short supply on the Goondiwindi farm. As a result, sunflower was grown with only four irrigations. The result is evident in terms of DD with a maximum of only 11 mm at the tail ditch end (both electronic and leachate values). In the 2003-4 season, DD was 101 and 235 mm at the head location (logged and volumetric, respectively), with 21 mm and 16 mm (logged and volumetric) at the tail. Only 4.6 ML/ha was applied as irrigation in that year, again reflecting limited water availability. In 2004-5 water applied was 5.6 ML/ha and DD values were collected; 98 mm and 104 mm the head (logged and volumetric), with 6.3 mm and 19 mm (logged and volumetric) at tail. (Table 3). The field was in bare fallow during the 2006-7 and 2007-8 seasons due to drought and consequent lack of irrigation water.

In general as evident in Figure 23, at the Goondiwindi site the greatest amount of DD occurred at the pre- or first (in crop) -irrigation. The rationale for these phenomena has been presented, above.

The ranking of the amount of DD at the three in-field locations were the same during three seasons, with the head location contributing most DD, then the mid and the least at the tail location (Figure 23). The most apparent reason for this trend is the very long nature of the Goondiwindi site (920 m); the second longest of all the DD sites. Evident in each of the three years' of data is that the greatest quantities of DD, at all field locations, occurs early in the season – the pre-irrigation and the first two crop irrigations (when, especially at the pre-irrigation at this site, there are very long irrigation times). After that, the DD response becomes very "flat" (Figure 23). This was particularly true for the 2004-5 season. Cumulative DD increased markedly between the pre-irrigation and first in-crop irrigation for both the 2003-4 and 2004-5 seasons in periods when there was very little rainfall events. These two trends (greatest DD early in the season and most DD at the head, then mid and least at the tail) are common trends at many of the DD sites.

e. Macalister

Agronomy & Deep drainage

Five irrigated summer crops and one dryland winter crop have been grown in the field in the course of the trial (Table 7). Table 7 also provides the total amounts of in-crop rain (ie precipitation from sowing to harvest dates of each crop) and the water applied as irrigation. Evident is that the in-season (October to March inclusive) summer rainfall has never been more than the long-term average rainfall for the same period (being 449 mm at the Dalby PO BOM site) in not one of the six seasons when DD has been collected. The three seasons from 2002-5 received about 300 mm rain each, but the 2005-6 and 2006-7 were very poor being approximately one-third and one-quarter of the first three seasons' totals, respectively. However, the most recent crop (barley in the winter of 2007) received a very large amount of rain (322 mm), the largest in-crop rain to date (Table 7).

The data collected from the tipping bucket device at the three locations at the Macalister site are presented as plots of cumulative DD from each of the three field locations, together with the rainfall and irrigation events for three seasons where significant amounts of DD occurred (Figure 24). The DD data from the total amount of leachate water collected in each of the six seasons, to date, is presented in Table 3. The lysimeter at the mid location was not operational during the 2002-3 and 2003-4 seasons but was replaced before commencement of the 2004-5 season.

In the 2002-3 season, DD of 222 mm (2.2 ML/ha) at the head and 43 mm at the tail were recorded (Figure 24) and 175 mm and 51 mm were collected as leachate (Table 3). Small discrepancies such as this in the electronically measured DD and the actual waters collected in the sample bottles is the norm at all sites. The explanation of these discrepancies includes a variety of possibilities, such as peak (rapid) flows of DD may be "missed" by the tipping bucket device, the tipping bucket may sometimes become stuck, and the logger on the tipping buckets have been known to fail. The values at the Macalister field represent up to 30% of the applied irrigation water being lost to DD (ie the LF – leaching fraction – of Table 3). Generally, with furrow irrigation the head ditch end of the field tends to remain inundated for long period of time. And because irrigation siphons tend to stopped before the water reaches the tail ditch end of the field, lesser DD occurs there. In the 2003-4 season water was in very short supply on the Macalister farm. As a result, sorghum was grown with only three irrigations. The result is evident in terms of DD with a maximum of only 33 mm at the tail ditch end (both electronic and leachate values) and 5 – 10 mm at the head.

In the 2004-5 season, DD was 93 and 101 mm at the mid location (logged and leachate, respectively), with 5 mm and 41 mm (logged and leachate) at the head. Only 3.7 ML/ha were applied as irrigation in that year. In 2005-6 water applied was 5.4 ML/ha but very small DD values were collected; 12 mm and 10 mm at head and mid locations. 31 and 26 mm were collected at the same two field locations in the 2006-7 season.

Rainfed barley was grown in the winter of 2007 and the crop received 322 mm of rain. DD of 66 and 24 were collected at the head and mid locations, respectively, and zero DD at the tail, apparently following heavy rain. The timing of the rains and the (apparently) resultant DD are given in Figure 25. The DD at the head and mid locations occurred after the barley was harvested. Heavy rain (~100 mm in two days) fell between 23-24 November, just before harvest, and seemingly triggered DD that commenced mid-December at the head and slightly after that at the mid location. The second large rainfall event in early February (~140 mm in three days) contributed more DD at both head and mid locations. There have been no further amounts recorded, since. As such, this (latest) DD at the Macalister site represents a rare occurrence in the entire project – where DD occurred that could be directly attributed to rainfall (the barley being a rainfed crop). Apparently the field was deeply and strongly "cracked-open" at the end of the barley season, and it is assumed the resultant measured DD eventuated from the rain penetrating deeply into the soil through this extensive cracking.

In general as evident in Figure 24, the greatest amount of DD at the Macalister site occurred at the pre- or first (in crop) -irrigation as a result of longer irrigation time. Evident is that as the season progressed, DD reduced to zero; again a common trend at almost all the lysimeter sites. Rationalisation of this "through the season reduction in DD" has been presented above.

f. Pampas

Agronomy & Deep drainage

Two crops have been grown in the field in the course of the trial (Table 8): irrigated cotton, sown on 15-16 October 2004; and dry land sorghum during the 2005-6 summer. At all other times the field has been maintained as bare-fallow (the current field condition). Amounts of in-crop (or fallow) rain and water applied as irrigation are given in Table 8.

DD was only collected in the 2004-5 season; that being the only irrigated crop in this field to date (Table 3). DD collected as the logged data during the 2004-5 irrigated cotton season, with rainfall and irrigation timings are shown in Figure 26. The ranking of the amount of DD at the three in-field locations had a common trend with several other sites, where the head location received most DD (a seasonal total of 96 mm; 0.96 ML/ha), then the mid (41 mm) and the least at the tail (3 mm) location (Figure 26). Evident is that DD was recorded following only one irrigation, the pre-irrigation (Figure 16). After that irrigation there were no more "tips" or water samples collected, despite 5 irrigations and almost 90 mm of in-season rainfall. Water volumes collected from the head, mid and tail were 71, 106 and 62 mm, respectively; representing a maximum DD of about 1.1 ML/ha (106 mm) but only at the mid location of the field (Table 3). In terms of leaching fraction (where LF = DD as a % of applied water; irrigation water alone) the largest collected DD volume of 106 mm represents a LF of 11% (Table 3). Evident is that as the season progressed, DD fell to zero; as rationalised above, at other sites.

g. St George (N)

Agronomy & Deep drainage

At the St George (N) site, DD was evident after each irrigation in the 2004 season when a "late winter" wheat crop was grown (Figure 27). The logged DD data show 60 mm at the mid followed by the head (25 mm) and then the tail (2 mm) locations. It was also noted that DD response occurred only to the irrigation events, not the during-season rainfall, despite slightly over 200 mm of rain falling in the cropping period. In terms of the volumetric data in that season, there was 24, 55 and 1.6 mm collected at the head, mid and tail, respectively (Table 3). In the following season (2005-6) the DD volumes collected were 27, 22 and 0 mm for the same three field locations; very small amounts in terms of the LF – 4% being the maximum DD loss of waters applied (Table 3).

h. St George (S)

Agronomy & Deep drainage

Five summer crops have been grown in the course of the trial (Table 9): cotton (2002-03, 2003-04, 2004-05), field pea (2005-06) and cotton (2006-07). There was one bare-fallow period; from April 2007 to May 2008; associated with drought conditions. The field is currently under an irrigated (winter) wheat crop. In-crop (or fallow) rain and water applied as irrigation are given in Table 9.

The DD data collected from the tipping bucket device at the three locations at the St George (S) site are presented as plots of cumulative DD from each of the three field locations for the 2002-3, 2003-4 and 2004-5 seasons with the rainfall and irrigation events (when known) also plotted (Figure 28). Though DD occurred in the other three seasons (2005-6, 2006-7 and 2007-8) the values obtained were very small (Table 3), so the cumulative plots are not presented here. The DD data from the volumetric quantities in each of the six seasons is presented in Table 3.

In the 2002-3 season, DD of 34 mm (0.34 ML/ha), 16 mm and 12 mm at the head mid and tail, respectively, were recorded (Figure 28) and 14, 68 and 37 mm were collected as leachate from the same field locations (Table 3). Clear responses to irrigation events (3) are evident in Figure 28, though DD values are very small. It is also evident that DD stopped after the last irrigation (early January), perhaps associated with the very low in-crop rainfall totals (Figure 28).

Far greater values of DD were measured in the 2003-4 season; up to 85 mm at the head and mid (Figure 28) and 104, 91 and 18 mm at head, mid and tail as leachate (Table 3). The DD of 104 mm at the head in this season represents 13% of the irrigation water applied to this location (Table 3). This was the largest LF measured at this site, though the mid location had a LF of 12% in both this same season (2003-4) and the following season.

Though comparable amounts of irrigation water were applied to the field in the 2004-5 season (734 mm) as in the prior season, the DD at the head was far less (only 20 mm measured and 40 mm of leachate collected), though the mid was far greater in terms of measured DD (122 mm) and the same as the previous season (92 mm) and the tail greater (50 mm), in terms of leachate collected (Table 3).

The drought conditions of the 2005-6 season are evident when irrigation water was in short supply at St George. Only 493 mm of irrigation water was applied to the crop (field pea), with only four irrigations, and the in-season rainfall was the second smallest of all sampled years – 323 mm (Table 3). The impacts are evident in terms of very small values of DD with a maximum of 37 mm measured as leachate, again at the mid location, though the tail received 33 mm of DD leachate.

The cotton crop of the 2006-7 season received 700 mm of irrigation and the smallest in-season rainfall of any measured season (219 mm). The only DD measured was at the mid location, being 33 mm (Table 3).

In the 2007-8 season the site was left in bare fallow, due to a lack of irrigation water. There was, however the largest amount of in-season rainfall, yet (532 mm). DD was measured at both the head and tail locations; 14 and 13 mm respectively. This represents a maximum LF of 3%, based on rainfall received (Table 3).

Generally, at this site the greatest amount of DD occurred at the pre-irrigation or the first (in crop) irrigation. Also evident is that as the season progressed, DD reduced to very small values or even zero. Evident is a trend for the mid location of the St George (S) site to give the largest values of DD in the majority of seasons (Table 3). As presented above, the mid has the lowest clay content and the greatest coarse sand content of the three field locations. It is also the location with the smallest ESP values. As such, the mid will have a tendency for less cracking, more water penetration (due to more sand) and least soil dispersion (with associated less potential for blocking of soil crack and air spaces; hence reduced DD). So, there seems to be a rationalisation of the greater DD at the mid with its *in situ* soil properties. At most of the other DD monitoring sites, the head ditch location has tended to give the largest DD values, linked to long inundation at that location at every irrigation. At the St George (S) site this trend was apparent only in the 2003-4 season.

4.3.2 Leachate analysis

a. Boggabilla

Analysis of the water collected as DD (the volumetric water samples or leachate) apparently show a large amount of salt mobilised with deep drainage; increasing from 0.7 in irrigation water to 8.8 dS/m in DD water collected. (Figure 29a)

b. Dalby

EC and chloride concentrations were measured in samples of both the irrigation waters applied as well as in the leachate (the DD water collected in the sample bottles). Evident is that the irrigation water at the Dalby site is not as pure as at other sites (though still has a low EC of 1.31 dS/m), perhaps reflecting the sometime mixing of bore and rain water at this site (Figure 29). In strong contrast, the leachate water has an average EC of 8.34 dS/m, almost x7 the EC of the applied water. This value of 8.34 is the fourth greatest of all the lysimeter sites and is considered just above the soil salinity tolerance level (7.7 dS/m) of cotton (from the

Soil Salinity handbook of Roger Shaw and Ian Gordon), so is regarded as “of concern” in terms of crop growth at this site. Chloride concentration in the irrigation water is 210 mg/L and the leachate is 2580 mg/L; a more than x12 increase. In terms of leachate chloride levels, the Dalby site is the second greatest value of all the sites (Figure 29 a and b).

c. Dirranbandi

Evident is that the irrigation water at the Dirranbandi site is most pure (an average EC of 0.18 dS/m), whereas the leachate has an EC of 8.8 dS/m. Chloride concentration in the irrigation water is 32 mg/L and the leachate is 1804 mg/L) (Figure 29 a & b).

d. Goondiwindi

Evident is that the irrigation water at the Goondiwindi site (sourced from the Macintyre river) is fairly good quality with EC_w being mid range of all lysimeter sites (an average EC of 0.5 dS/m), whereas the leachate has an average EC of 3.7 dS/m (Figure 29a). This average value of 3.7 dS/m is the second lowest of all the lysimeter sites and is considered not critical in terms of a “value of concern” in terms of crop growth. It also appears that salt leaching is minimal in this site. Chloride concentration in the irrigation water is 79 mg/L and the leachate is 349 mg/L, so the Goondiwindi site is the lowest values in terms of Cl^{-1} in the leachate (Figure 29b).

e. Macalister

Evident is that the irrigation water at the Macalister site is of relatively poor quality with EC_w being the greatest of all the lysimeter sites (an average EC of 4.15 dS/m), whereas the leachate has an average EC of 13.4 dS/m (Figure 29a). This value is the largest of all the lysimeter sites and considered critical in terms of a “value of concern” in terms of crop growth. Chloride concentration (Figure 29b) in the irrigation water is 942 mg/L and the leachate is 4041 mg/L, showing the Macalister site to have the largest values of Cl^{-1} in both the irrigation water and leachate of all the sites. Additionally, the value for the irrigation water rates “high” in terms of water salinity rating, making it suitable only for “tolerant crops”, and the leachate figure rates “extreme” and “generally too saline” for crop production (from the Salinity Management Handbook, Qld Govt, 1997).

In recognition of the other data collected at the Macalsiter site (low Ca:Mg ratios, large ESP values, and large applied water and DD leachate data), samples of the irrigation bore water were collected in 11 September 2007. The hypothesis was to further investigate the nature of the water being applied to this field, to see if that aided explanation of other data sets. A sample was taken from each of the two bores that supply this field, ensuring that the pumps ran for at least 20 minutes before either sample was taken. The sample from each bore was analysed for chemical constituents by the NRSc Chemistry Centre (NRW, Indooroopilly) and the full analytical output is given in Appendix 3. Table 10 provides the more important data of the analysis conducted. Clearly evident are the very large EC levels and sodium adsorption ratio (SAR) values in the sample from each bore (Table 10). SAR relates the amount of sodium relative to calcium and magnesium in irrigation water. Values of SAR are used to determine the "sodium hazard" of irrigation waters because of sodium's specific negative effects on soil physical properties. Sodium tends to disperse (push apart) soil particles, leading to crusting, low water infiltration and permeability, and potentially seedling emergence problems. When the SAR is >9 there is a severe risk of increasing soil sodicity (ESP; exchangeable sodium percent) in most soils. The values of 15 and 16 at the Macalister site are extremely high for what is irrigation water. The Soil Salinity Handbook of Qld Government (their Table 39) presents a Table of "permissible SAR of irrigation waters to maintain a stable soil"; and for a "heavy clay with a very strong cracking potential" (such as the Macalister soil) the permissible SAR is 5. This again shows that the Sodium content of the irrigation waters is very high. Additionally, the Macalister EC_w values of 3.8 and 4.5 are also very high (Table 10). Such values are known to restrict the plants that can be grown (without known yield reductions) with these waters to the four salt tolerant species: safflower, canola, sugar beet and barley. In terms of salt being applied to this site, considering that 1 ML of irrigation water at an EC_w of 1 dS/m contains about 640 kg of salts, then the average EC_w value of 4, and the application of an average of 3 ML/ha applied in 2004-5 and 2005-6 seasons has added almost 8 tonnes of salt per hectare each season.

f. Pampas

The irrigation water at the Pampas site, is very pure (an average EC of 0.31 dS/m), and the leachate has an average EC of 4.1 dS/m (Figure 29a). This average value of 4.1 is the third lowest of all the lysimeter sites and is considered only marginal in terms of a "value of concern" in terms of crop growth. Chloride concentration in the irrigation water is 60 mg/L and the leachate is 1486 mg/L, again the Pampas site is the third lowest value (leachate) of all the lysimeter sites (Figure 29b).

g. St George (N)

Evident is that the irrigation water at the St George (N) site is very good quality with EC_w being amongst the smallest of all the lysimeter sites (an average EC of 0.31 dS/m) (Figure 29a). The leachate has an average EC of 9 dS/m; the third largest value of all the sites, and as such considered “critical” in terms of a “value of concern” in terms of crop growth. It also appears that salt leaching is considerable at this site. Chloride concentration in the irrigation water is very low at 7 mg/L but the leachate is 3144 mg/L (x 100 increase), though the leachate has the second smallest value of all the lysimeter sites (Figure 29b).

h. St George (S)

Similar to the St George (N) site, the St George (S) site also has very good quality with EC_w being almost the smallest value of all the lysimeter sites (an average EC of 0.14 dS/m) (Figure 29a). The leachate has an average EC of 9 dS/m; the third largest value of all the sites and apparently showing large salt movement in the soil at this site. Chloride concentration in the irrigation water is very low at 14 mg/L but the leachate is 1359 mg/L (x 100 increase), giving this leachate the second largest value of all the lysimeter sites, again supporting apparent large salt movements at this site (Figure 29b).

4.3.3 DD volumes vs EC and EC:Cl relationship

The relationship between DD volume and the EC of the leachate waters for eight of the lysimeter sites is given in Figure 30. The data were investigated in this way to see if large values of DD were related to small concentrations of salt, i.e. if there was a dilution effect. However, there appears to be no relationship between volume of water collected and the EC value, or between time of season and the EC values. As a result, the EC and Chloride values of the leachate waters can be regarded as “real” values, representative of the EC values being collected at the lysimeter sites irrespective of DD volumes.

A reasonable correlation ($R^2 = 0.78$) was found between electrical conductivity (EC) and chloride (Cl^{-1}) concentration measured from the DD water samples across all sites, though evident is that the Dalby samples are above mid-range in terms of all the sites experiment (Figure 31), and one value is the largest Chloride value recorded at any site in the current experiment (almost 24 ds/m).

4.3.4 Water Balance Model (FAO-56 & SIRMOD)

Irrigation uniformity

a. Boggabilla

Plots of the irrigation advance data in the 2005-6 season at the Boggabilla (furrow) site from the SIRMOD analysis show that the first three irrigations provided the greatest values of infiltration depth (163, 256 and 178 mm) and that the largest to smallest values for any one of these irrigations was always in the order of head>mid>tail locations, with the largest difference between head and tail being for the 2nd and 3rd irrigations (Figure 32). The last two irrigations (3rd and 4th irrigations) gave both very small values of infiltration depth (<70 mm) with little difference between head, mid and tail locations. Similar to the lysimeter data, the amount of infiltrated water reduced greatly from start to end of the cotton season.

b. Dalby

Plots of the irrigation advance data in the 2004-5 season, from the SIRMOD analysis show that the first three irrigations provided the greatest values of infiltration depth; 205, 100 and 115 mm), and that the largest to smallest values for any one of these irrigations was always in the order of head>mid>tail locations, with the largest difference between head and tail being for the 1st and 2nd irrigations (Figure 33). The last two irrigations (3rd and 4th irrigations) gave both very small values of infiltration depth (<50 mm) with almost no difference between head, mid and tail locations. Similar to the lysimeter data, the amount of infiltrated water reduced dramatically from start to end of the cotton season.

Data gained from application of the ET/SIRMOD water balance model showed zero DD in the 2004-5 season for each of the head, mid and tail locations (Table 11). This result appears linked to the large (measured) evapotranspiration (ET) values, compared to the small amount of in-crop rainfall and the small infiltrated depth during last two irrigations. However, as such these data bear no relationship to the measured DD volumes of 39, 95 and 34 mm for head, mid and tail in the 2004-5 season (Table 3).

c. Goondiwindi

During the 2003-4 season, the sorghum crop was irrigated four times. Plots of the infiltrated depths, from the SIRMOD analysis show that the all four irrigations provided the greatest values of infiltration depth; 175, 151, 94 and 114 mm at the head location, and for any one of these irrigations the largest to smallest values were always in the order of head>mid>tail locations, with the largest difference between head and tail being for the 1st and 2nd irrigations (Figure 34). The last three irrigations gave very uniform and small infiltrated depths (Figure 34).

During the 2004-5 season, the cotton crop was irrigated six times. Infiltrated depths during pre-irrigation and the first two in-crop irrigation events showed greatest values of infiltration depths, 170,167 and 155 mm at the head location, similar to the previous season (Figure 34). In 2004-5, however, the last three irrigation events gave almost 100% distribution uniformity;

i.e. similar water infiltration at all field locations. Similar to the lysimeter data, the amount of infiltrated water reduced dramatically (≈3 fold) from start to end of the cotton season (Figure 34).

Data gained from application of the ET/SIRMOD water balance model showed 70, 15 and 0 DD in the 2003-4 season for each of the head, mid and tail locations and zero DD at all locations in the 2004-5 season (Table 12). This result appears linked to the large (measured) evapotranspiration (ET) values (843 *vs* 1340 mm in the two seasons, respectively), particularly considering that the in-crop rainfall amounts were quite similar in the two seasons; 379 and 321 mm, respectively. However, as such these simulated DD values bear no relationship to the measured DD volumes, apart from the head>mid>tail trend in both simulated and measured data in the 2003-4 season (Table 3 and Table 12).

d. Macalister

Plots of the irrigation advance data for the 2004-5 season, from the SIRMOD analysis show that the first three irrigations provided the greatest values of infiltration depth; 131, 140 and 109 mm) and all of these values occurred at the head location, and for any one of these irrigations the largest to smallest values were always in the order of head>mid>tail locations (Figure 35). The largest difference between head and tail was for the 1st and 2nd irrigations, the difference being 52 mm and 117 mm. The last irrigation (3rd in-crop irrigation) gave almost 100% distribution uniformity; i.e. similar water infiltration at all field locations. Similar to the other lysimeter sites, the amount of infiltrated water reduced dramatically (up to 3 fold) from start to end of the cotton season.

Data gained from application of the ET/SIRMOD water balance model showed zero DD in the 2004-5 season for each of the head, mid and tail locations (Table 13). This result appears linked to the large (measured) evapotranspiration (ET) values, compared to the small amount of in-crop rainfall (as well as the small amounts of irrigation water applied, as in Table 7) and the small infiltrated depth during last two irrigations. As such these simulated DD values bear no relationship to the measured DD volumes in the same season of 41, 101 and 0[9] mm for the head, mid and tail locations (Table 3).

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[9] The repeated value of 0 mm DD (volume) at the tail location of Macalister site (in each of the past four seasons) is currently being investigated with consideration that the lysimeter has ceased functioning.

e. St George (S)

During the 2003-4 season, the cotton crop was irrigated seven times. Plots of the infiltrated depths (Figure 36), from the SIRMOD analysis show that the greatest values of infiltration depth fro any one irrigation occurred at the head location (336, 230, 144, 94, 76, 97 and 96 mm). Also, for all but one of these irrigations (the 4th) the largest to smallest values were always in the order of head>mid>tail locations, with the largest difference between the head and tail being for the 1st and 2nd irrigations (Figure 36). As such, this trend for head>mid>tail is the same as for the collected DD leachate volumes in the same season: 2003-4 (Table 3).

During the 2004-5 season, the cotton crop was irrigated seven times, though the pre-irrigation was missed in terms of this data collection (Figure 36). The head location for the first two irrigations had the greatest infiltrated (252 and 262 mm) a similar trend to the previous season. In the 2004-5 season, however, the last four irrigation events gave almost 100% distribution uniformity; i.e. similar water infiltration at all field locations and small values (43 to 93 mm) compared to the previous season. Similar to the lysimeter data, the amount of infiltrated water reduced dramatically (approximately 3 fold) from start to end of the cotton season (Figure 36). Dissimilar, however, is the trend for greater water infiltration at the head rather than the mid, as the case with the measured lysimeter data (Table 3).

Data gained from application of the ET/SIRMOD water balance model showed 203, 50 and 0 DD in the 2003-4 season for each of the head, mid and tail locations (Table 14). As such, this is the same trend as the actual DD volumes collected in that season but with quite different values (DD volumes were 104, 91 and 18 for head, mid and tail). For the 2004-5 season, the data from the model showed 70, 50 and 0 mm DD for each of head, mid and tail locations. This result appears linked to the decreased infiltrated depth in the 2004-5 season despite the smaller (measured) evapotranspiration (ET) value of 843 mm during 20034-5, particularly considering that the in-crop rainfall amounts were quite similar in the two seasons; 374 and 376 mm, respectively (Table 14). As such, these 2003-4 predicted values of DD have little relation with the measured DD volumes of 40, 92 and 50 mm for head, mid and tail both in magnitude and across field trend (Table 5).

4.3.5 SaLF

a. Boggabilla

The model output for each of the three seasons when the model was run (2005-6, 2006-7 and 2007-8) showed that the predicted DD values were always <16 mm and that the trend for DD of tail>mid>head in the first season was not carried over to the last season (Table 15). As such, these predicted DD values are far smaller than the measured DD volumes of up to 105 mm (Table 3), though the across field trend in the 2007-8 season matches between predicted and measured, where the maximum DD was at the mid (Table 3 and Table 15) though only ¼ the magnitude was predicted.

b. Dalby

The model output for the 2004-5 cotton season, showed that DD at the tail location was 50% greater than at either the head or mid locations (Table 16). For both the irrigated soybean and the (supplementarily) irrigated rain fed sorghum in the 2005-6 and 2006-7 seasons, the same trend was noted - showing 45% more DD at the tail location than either the head or mid; being 4.9 ML (490 mm) and 1.36 ML (136mm) losses at the tail during 2005-6 and 2006-7 seasons, respectively. However, the extremely large predicted DD values bear little relation to the measured DD volumes (Table 3 and Table 16), some particularly large differentials being 34 (measured) *vs* 522 (predicted) at the tail in the 2004-5 season, and zero DD (measured) at all field locations in 2005-6, *vs* predicted values of up to 480 mm. In this light the SaLF output for this site looks most "suspect".

In terms of these results from the SALFPREDICT model, it appears that the main drivers (governing DD differences in terms of field location) are clay content. At the Dalby site, clay gradually decreased from the head to tail locations with a corresponding increase in sand content. Results also show that variation in DD in particular between head and mid is small during all three seasons. Moreover, despite the large loss at tail location, predicted DD at head and mid during two irrigated seasons (cotton and soybean) accounted for approximately 25% loss of water applied (irrigation + rainfall). These leaching fractions (LF) are far greater than the leaching requirement to avoid possible salt accumulation within the root zone, and may help explain the very low soil EC values (<1.0 dS/m) on the Dalby site (4th least among the 8 lysimeter sites).

b. Dirranbandi

The SalF output showed that for each of the 2003-4 and 2005-6 cotton seasons, the predicted DD values increased from head to mid to tail locations (Table 17) and as such was in agreement with the lysimeter data from the 2003-4 season. However, the magnitude of the predicted and measured DD values are quite different, the measured values always being larger in both seasons and all field locations but one (the mid in 2005-6). Most outstanding is SaLF's inability to pick up the very large measured DD value, measured at the tail in 2003-4

(176 mm) and accounted for by water backing-up over the lysimeter due to a blocked water exit pipe (Table 3).

In terms of SALFPREDICT, it appears that the main drivers (governing DD differences in terms of field location) are clay content and ESP, leading to increased DD at the tail location. Results for the irrigated wheat during 2004 indicated same trend of DD recording greatest at tail ditch. Additionally, predicted DD accounted for up to more than 80% of water applied (irrigation + rainfall) during the two cotton seasons. Recorded LF are far greater than the leaching requirement (LR) to avoid possible salt accumulation within root zone, and may help explain the very low EC values of the Field 16 soil.

c. Goondiwindi

The model output for the 2003-4, 2004-5 and 2005-6 sorghum, cotton and sunflower irrigated crops, respectively, showed that the SaLF model predicted very small amounts of DD at each field location in each of the three seasons (Table 18). As such, this is quite the opposite to the measured DD values in this field (a range of 19 to 235 mm; Table 3) as well as the predicted DD values by the SIRMOD/ET model (in the 2003-4 season) of up to 70 mm. However, comparable to both of these previous data sets, DD was slightly greater at the head locations while very minimal DD resulted at mid and tail locations during three simulations (Table 18).

In terms of the SALFPREDICT model, it is very difficult (due to the very small values and the small variations between field locations) to discern the main drivers in terms of model inputs. There was minimal variation in clay content between field locations, though the ESP at 0.9 m was double (indicating less potential for DD) at the mid and tail. Moreover, predicted DD accounted only for 1% of water applied (irrigation + rainfall) during three seasons (Table 18). These leaching fractions (LF) are far lower than the maximum LF of 51% from the lysimeters.

d. Macalister

The model output for the three irrigated cotton seasons (2004-5, 2005-6 and 2006-7) and one rainfed barley season (2007), showed a consistent trend that DD ranked largest to smallest from mid to tail to head with approximately 20% less at the head than the mid in all seasons (Table 19). According to SaLF, DD was negligible under the rainfed barley. As such the SaLF output (predicted DD) bears little resemblance to the DD measurements by the lysimeters. Not only is the ranking of the largest to smallest DD different (the lysimeter data was always head>mid>tail, apart for the 2004-5 season) but the values at each location have little resemblance to the lysimeter data. In particular, the tail values from SaLF (up to 100 mm predicted) are strongly different to the four seasons of zero values from the lysimeters (see Table 3).

In the 2005-6 and 2006-7 seasons, SaLF predicted up to 5 times the DD, as collected at the head and mid lysimeters. In contrast, SaLF failed to predict the DD under the rainfed barley crop; the SaLF values being 13 and 45 fold less for the head and mid, respectively.

Furthermore, in terms of the SALFPREDICT model, it is most difficult to determine what model inputs are actually driving the model (to give the mid>tail>head ranking of predicted DD). Clay content varies little between the three field locations. ADMC is least at the mid by a factor of approximately 15%; as too is the ESP at 0.9 m – a factor of 20% less. Moreover, the SaLF predicted DD accounted for 10 to 17% of water applied during the cotton season. These leaching fractions (LF) are lower than the maximum of 30% from the lysimeters and greater than 0 % from the SIRMOD/ET modelling.

e. Pampas

The model output for the 2004-5 cotton season, showed that DD was double at the tail than at the mid (Table 20). The predicted DD values have no relation (in either magnitude or field location variability) to the measured DD values, that were 71, 106 and 62 mm for the head, mid and tail (Table 3).

In terms of the SALFPREDICT model, it is difficult to state the main drivers governing DD differences in terms of field location. Sodium (ESP) is more at the head than the mid and tail, and contrary to this clay content is greater at the tail throughout the soil profile and the head location generally the least.

f. St George (S)

The model output for the 2003-4, 2004-5, 2005-6, 2006-07 irrigated crops showed that the SaLF model predicted very small amounts of DD at each field location in each of the four seasons; always less than 10 mm (Table 21). These values are particularly small relative to the values collected by the lysimeters (up to 104 mm; Table3) and predicted (up to 203 mm in the 2003-4 season and 70 mm in the 2004-5 season; Table 14) by the SIRMOD/ET model. However, comparable to both of these previous data sets, DD was slightly greater at the head locations compared to the mid and tail locations during four simulations (Table 21).

In terms of the SALFPREDICT model, it is very difficult (due to the very small values and the small variations between field locations) to discern the main drivers in terms of model inputs. Clay content at the mid location was the least of the three field locations (inferring more DD possible), and the ESP (at 0.9 m) at the tail was greatest (indicating less potential for DD) (Table 21). Moreover, predicted DD accounted only for < 1% of water applied (irrigation + rainfall) during four seasons (Table 21). These leaching fractions (LF) are far less than the maximum LF of 13% (from lysimeter) and 19% (from the SIRMOD/ET modelling).

4.4 Lint yield

a. Dirranbandi

Cotton yield, from the picker yield monitor, at the Dirranbandi site in the 2003-4 season showed a steady reduction in yield from head to tail; 20% reduction in total (Figure 37). The implication is drought stress towards the tail, away from the head ditch location perhaps from cutting (irrigation) waters off too early in this very long field (1290 metres) – attempting to conserve water. As such, the yield data runs contrary to both the inherent soil properties (where the tail has more clay and less sand, as well as lower ESP values; both indicating better growing conditions at the tail ditch end of this field than the head) and the measured DD volumes where the tail had more DD (hence more water applied / available, there ?) in each of the 2003-4 and 2005-6 seasons.

b. Goondiwindi

The cotton yield data from the Goondiwindi site in the 2004-5 season is shown in Figure 38. Yields were significantly greater at the head and mid locations, than closer to the tail with a maximum yield of almost 10.5 bales/ha just up-field of the mid location; as different to 8.7 bales at the tail; a 17% yield reduction Again, this may be linked to the very long field lengths at the Goondiwindi site (910 metres) as well as a tendency to stop irrigation siphons as soon as the irrigation water reaches the tail ditch end (causing water stress).

c. Macalister

The cotton yield data (hand picked) from the Macalister site in the 2004-5 and 2005-6 seasons are shown in Figure 39. Yield in both seasons was low particularly in the 2004-05 season due to poor germination (giving a very “gappy” crop). However, in both seasons there was a pronounced yield reduction from the head to mid to tail locations (25% in 2004-5 and 20% in 2005-6), similar to other lysimeter field sites, across several seasons.

d. Pampas

The cotton yield data from the Pampas site in the 2004-5 season are shown in Figure 40. Yield decreased by 2 bales/ha from the head and mid locations to the tail location; almost 8.5 bales/ha at the head and mid to 6.5 bales/ha at the tail; a 24% yield reduction. Again, this is the similar trend found at other lysimeter sites.

e. St George (S)

The cotton yield data from the George (S) site in the 2004-5 season is shown in Figure 41. Evident is a distinct and significant trend for the greatest yields to be at the head location and fall away to the tail; from 8.9 to 7.2 bales/ha – a 20% reduction) Evident is that the yield response could be said to match the smaller water losses to DD at the head location of Table 5 (apart from 2003-4); the better yielding plants utilising more irrigation water, relative to lower yielding (and less water use efficient) plants at mid and tail.

5. Outcomes

The original project application did not specify "planned outcomes". However, stated were objectives and their expected outcomes, as follows.

> "The proposed project will **continue** these investigations of DD, improve on the measurements collected and work towards BMPs to minimise DD as well as monitor catchment-scale water table levels. In detail:
>
> - with time, the lysimeter data at the 21 locations will become more reliable and site-representative as the lysimeter "merges" into and becomes "one" with the soil in the field
> - to date, all growers with these lysimeters on their farms have continued their normal practice. In this way, the lysimeter data are reflecting "current industry practice", on a range of soils.
> - In the 2nd and 3rd years of the project there is capacity to begin to change on-farm practice in the fields overlying the lysimeter to reduce DD. Two ways are foreseen:
>   - on the current lysimeter sites: increase siphon size, field slopes, initiate shorter furrow lengths, increase "head" in the head ditch, create more rotabucks, etc
>   - on a new site, install lysimeters under each of furrow and travelling irrigated (TI) cotton – to investigate the potential water savings and reduced DD with TI."

As reported in the main section of this Report, all but one of these outcomes has been achieved. Not achieved was "changing management practices on the current lysimeter sites" to monitor impact on DD and related measures. The reason for this is singular – to date, between site and within site (across the three field location variability) has been so large, that there is no "benchmark" at any one site against which changes incurred by change of management practice could be matched. The reasons for this very high level of variabilities are partly understood, and include: drought conditions for some years of the project causing abnormal (and at many sites the total lack of) irrigation management; the very high seasonal temperatures in the 2005-6 year that greatly increased ET and reduced DD to nothing or very low values (eg the Dirranbandi site applied 9 ML but there was zero DD); and that fact that most of the co-operating growers are now not growing cotton – rather are growing a wide range of crops in almost "opportunistic" ways (when rain and water available and dependent on market price for the commodity).

In terms of "technical advances"; the project has shown the reliability and long-term usability of the lysimeters used in this project. As an example, the lysimeters at the Macalister site were installed in 2002 and only last month (August 2008) DD tips and volumes were collected from two of these six-year old apparatus. Also, there has been (to date) good correlation with the DD data from the project lysimeters installed at ACRI and the "big" CSIRO lysimeter in the same field. The data provided by the lysimeters (both DD and subsequent analysis of leachates for salt) provide data instantly understood and interpretable by our co-operating growers, many of whom have altered their cropping sequences and irrigation quantities / timings to suit the DD experimental methods and staff, enjoying being co-operators in this project and fully complementary of the data forthcoming.

In terms of “discoveries in methodology” it has become clear that the indirect methods of assessing DD cross-checked in this project (SODICS, SaLF, SIRMOD/ET) have little correspondence to the measured DD from the lysimeters. Since many growers (or more usually their consultants or advising Governmental staff) use these indirect methods (commonly due to their ease and low cost of usage) it is important to realise their (apparent) large inaccuracies in correctly predicting DD.

6. Conclusion

This project has for the first time in Australia provided long term (6 years to date) directly measured data on deep drainage (DD) under irrigated cropping systems covering 35 locations in irrigated landscapes, on 10 commercial farms, across a wide range of soils and management systems. The data clearly demonstrate that DD occurs mainly under irrigated cotton (and related crops and rarely in rainfed crops). And it can be large but also can be zero, in times of water scarcity and high seasonal ET conditions. The example of "recent technology utilisation" for cotton production, investigated here – a lateral move irrigator – has been shown to decrease water use by up to 67% and have almost no measured DD while producing the same cotton yields as the adjoining furrow irrigated field. The indirect measures of DD, used by some in the cotton industry to gain appreciation of DD, have proven repeatedly to be poor indicators of actual, measured DD. Additionally, this project has shown that salt appears to be mobilising under these irrigation systems; all DD leachate waters are far more salty than the irrigation waters being applied and the soils in the fields being monitored appear to show increasing salt contents with time. Great care is being taken in analysing (fully) and reporting these data as salt has been the downfall of many irrigation schemes, and all data must be fully analysed before definite statements made, to ensure true reporting of all parts of the salt balance in the project sites. Groundwater rise has occurred in the St George irrigation area but the preliminary analysis suggests localised "mounds", seemingly linked to local DD sources (selected channel leakage and farm storages) and the groundwater levels have not, to date, approached the 2 m below-ground level, commonly viewed as posing a risk for soil salinisation. Measurement in all these areas of DD, soil and leachate salinity, innovative practices and groundwater response are planned to continue to 2011, to enrich current data sets towards establishing long-term industry trends and BMPs for additional water use efficiencies and landscape protection within the Australian cotton industry.

7. Extension Opportunities

Detail a plan for the activities or other steps that may be taken:

(a) to further develop or to exploit the project technology.
(b) for the future presentation and dissemination of the project outcomes.
(c) for future research.

Three inter-related extension initiatives have been realised during the course of this project:

Initiative #1.

1. In the last year of the project, six individual reports have been written and delivered to the individual co-operating farmers who have lysimeters installed on their farms. The aim of these reports was to not only inform the individual growers and their farm and advisory-consultant staff of the Project's results to date, but also to seek their feedback and comment on work to date, to aid formulation of future work.

Initiative #2.

2. The project has always aimed at contributing fully scientifically supported information to the Cotton industry BMP program. However, to date the large scale variability in data (in no small part linked to years of drought conditions, providing atypical growing / irrigating conditions) has caused difficulties with creating singular, industry-wide applicable BMPs

As a "move towards" the production of industry relevant BMPs on DD, the project officers contributed the following to the recently published article by Graham Harris and others (Australian CottonGrower Magazine, August 2008) on "Deep Drainage Mythbusters".

1. When I irrigate throughout the season my consultant told me the soil seals reducing infiltration therefore I do not have Deep Drainage

There are two important parts to this statement, that may or may not be inter-linked: (i) that a soil has a tendency to seal and (ii) that this becomes worse as the season progresses, reducing infiltration of irrigation waters.

- It is true that some soils under cotton have a tendency to seal (close over or form a surface crust) but this is not generally true for the majority of cotton growing soils. For example, of the 10 current Deep Drainage (DD) project sites, only 3 have a tendency to seal, after rain or irrigation. Several soil properties commonly act together to cause this sealing action. In soils with more than about 45% clay content, high sodium levels (as a proportion of the exchangeable cation suite) tend to lead to seals as the sodium breaks up soil aggregates, wetted by rain or irrigation. If fine sand is also present (more than about 20% of the soil mineral fraction) then the tendency to seal is even greater. Low organic matter levels, again, add to the risk. If you have soil with these properties, adding gypsum and/or in the long run organic matter (crop residues) may help reduce the sealing problem.

- One part of the consultant's comment is partly correct – that DD decreases as the season progresses. As measured at almost all sites in all years of the project. However, this is not necessarily because water infiltration lessens or because the soil begins to seal over. Rather, as the cotton season progresses, the above-ground biomass and the plant root system of the cotton crop develop and grow larger, and the day time temperatures greatly increase. The cumulative effect is greatly increased evapotranspiration (water demand). Though the irrigation frequency increases to match the increased evapotranspiration (if water available), the crop demand is so large and daytime temperatures so high that almost all the infiltrated water is rapidly used. SIRMOD analysis, measured across 4 of the current DD trials clearly shows decreased infiltrated depths of irrigation water during the last few irrigation events of the season (see 4th & 5th irrigations in Figure 1). Data from the current DD trials show that, commonly, from the 3rd or 4th in-crop irrigation, there is no measured DD.

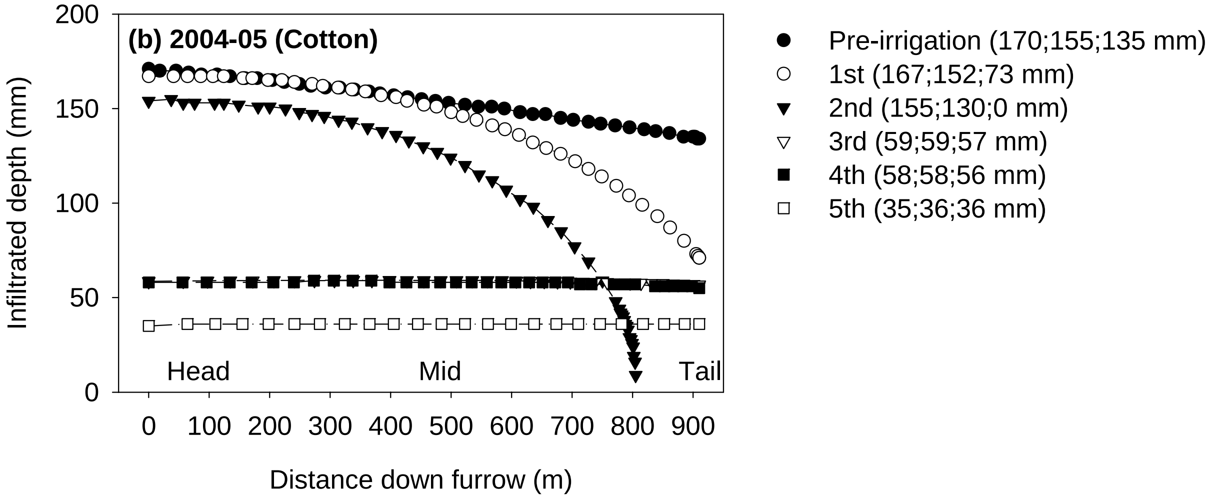

Figure 1 Infiltration uniformity as simulated from SIRMOD analysis down the furrow on the Goondiwindi site for 6 irrigation events in the 2004-5 cotton season. The modelled amounts of water infiltrated (in millimetres) at each of head, mid and tail locations are shown (in brackets) in the legend.

2. Groundwater tables have been falling over the last few years and you're telling me there is Deep Drainage on my farm

The general drop in groundwater levels in cotton growing districts is usually linked to pumping (stock and irrigation supply), for example in the Dalby – Pittsworth areas. In an irrigation area where there has been (till recently) ample surface water supply, like St George, the historic inspection borehole data seems to suggest rising water tables, in specific locations. To investigate this more rigorously (the historic water level data was collected at best twice yearly), the current DD study has installed 18 groundwater level loggers in the monitoring bore holes of the St George irrigation area (recording two groundwater level readings a day). These data will be compared to DD data collected in the St George area, and also to local growers' records of surface water events (river flows, full dams and channels, etc) to begin to understand the drivers of changing aquifer levels. It may be that DD measured in one paddock is not specifically linked to aquifer dynamics in that area; inter-woven sand beds below the soil surface may well carry water some distance before aquifers are affected.

3. There is no indication on my soil moisture monitoring tool that Deep Drainage is happening

Soil moisture monitoring tools (like capacitance and neutron probes) are poor devices to gain insight into DD. Three reasons can be given:

- The output from these devices shows change in soil water content (between times). That the line does not change, at say 100 cm depth, throughout a season, shows only that there has been no change in soil water content at that depth. However, the water at that depth may well be flowing through the soil, by-passing the root zone as DD. This bypass flow can occur down cracks or old root holes and as such will not be picked up by a soil moisture monitoring tool.
- Also, data from the DD project shows large variation in DD within any one paddock as well as between seasons, and certainly during the season. As given in Item 1, above, the largest values of DD, measured in the current project have tended to be early in the cotton season at the pre- and first-irrigations. Most soil moisture monitoring tools are only installed when the crop emerges – to ensure proximity of healthy plants to the probe. In this way, the early season events (eg large water application at the pre-irrigation, low temperatures and small transpirational demand) that seems to contribute greatly to DD are missed.
- Depending where the soil moisture monitoring tool is located, it may or may not show change (at depth) in soil water content. Unless moisture probes are installed at head ditch, middle of the paddock and tail ditch locations, and monitored throughout the season, including before and after pre-irrigations, it is not reasonable to conclude that there is no DD. Unlike soil moisture monitoring tools, the device used in the current project to provide DD data is a lysimeter. This is not a soil water content measuring device - rather it continuously collects the actual water arriving at 150 cm depth, ie the DD water. The amounts collected are recorded electronically and the actual DD water is collected routinely (for salinity assessment) during site visits by the project staff.

4. I have a storage and it does not leak

Storages are known to be highly variable in terms of their “leakiness”. This has been clearly demonstrated by recent studies from the NCEA (see Australian Cotton Grower, April-May 2007; page 21 “Towards better storage management”). This is not to say that, in leaky storages, the whole floor of the storage leaks equally. Sand lenses just under the storage floor may give a leakage “hotspot”. The story is similar for DD measurement in a paddock. Over the course of the DD project, field measurements have demonstrated far more DD near the head ditch than tail ditch end of paddocks. The explanation is the far longer “dwell time” of water at the head ditch end of the field. This is especially true where growers “pull” siphons as soon as water reaches the tail ditch. Water may have been lying over the head ditch area for many hours but only briefly at the tail ditch end of the paddock. On a few (measured) occasions, however, blockage of a tail ditch exit pipe has led to the backing-up of water over the lysimeter location near the tail ditch – with subsequent large DD measured.

5. I irrigate efficiently so no deep drainage occurs

Two indicators can be used to measure efficiency of an irrigation event: “application efficiency’ (the % of applied water that infiltrates into the soil) and “distribution uniformity” (the uniformity of infiltrated depth down the paddock from head to tail ditches). These are illustrated in the SIRMOD data given in Item 1, above. At the first irrigation, there was 54% application efficiency (Ea) and 71% distribution uniformity (DU). That is 54% of the irrigation water applied actually infiltrated, so was available for the crop to use. By the 5th irrigation event, however, Ea was only 35% showing less water available for crop use (from drier soil at time of irrigation, from large evapotranspiration mid-season, as well as less water applied) but DU was 99%, showing an almost uniform distribution down the paddock (though with far less water than at the start of the season). In the same figure, infiltrated depths at all head, mid and tail locations for the pre-irrigation are well over the required depth contributing to deep-drainage. In conclusion, a general result from the current project is that around 70% of measured DD can be attributed to the pre-irrigation and the first two in-crop irrigations.

Initiative #3.

The project has formed the “Growers around the St George Irrigation Areas inspection boreholes” group, who meet annually (formally) and more frequently when the project staff visit the borehole sites for routine downloading of loggers.

This group was formed to not only provide a local industry forum for feedback of results but also to seek their input into rationalising the recent (logged twice daily) groundwater level data. In particular, each grower (who farm in the vicinity of at least one groundwater inspection borehole) has been recording "surface water phenomena" (full dams, channels, irrigation events, heavy rainfall, long dry spells, etc) to aid interpretation of the logged groundwater fluctuations. The final reporting will be an amalgam of monitored data and grower provided input on surface water events.

8. Publications

Technical Reports

1. Gunawardena TA, McGarry D (2007 – 2008). Technical reports on deep drainage studies on five commercial cotton farms (Dirranbandi p32, Pampas p33, Dalby p31, Macalister p34 and Goondiwindi). Provided to individual Grower co-operators.

Conference Proceedings

1. McGarry D, Gunawardena TA, Gardner EA, Millar G, McHugh AD (2005) Improved measurement and prediction of deep drainage under irrigated cotton fields in the Condamine – Balonne – McIntyre catchments and likely ground water responses. *Irrigation Association of Australia, National Conference 2005.* May, Townsville.

2. McGarry D, Gunawardena TA, Gardner EA, Millar (2006) Deep drainage and irrigation management. In "*Proceedings of the 13th Australian Cotton Conference*." 8 – 10 August 2006, Broadbeach, Australia.

3. McGarry D, Gunawardena TA, Gardner EA, Millar (2006) Deep drainage under irrigated cotton – surface and ground water implications. In "*Proceedings of the Irrigation Association of Australia, National conference*" 9 – 11 May 2006, Brisbane, Australia.

4. Gunawardena TA, McGarry D, Gardner EA, Stirzaker R (2008) Improved Irrigation Efficiency through controlling Deep Drainage, and monitoring solute signatures and groundwater response. *"Proceedings of the Irrigation Australia 2008 Conference.* 20 -22 May, Melbourne, Australia.

5. Gunawardena TA, McGarry D, Gardner EA, Stirzaker R (2008) Managing Deep Drainage for Improved WUE: Solute Monitoring and Ground Water Response in the Irrigated Landscape. In "*Proceedings of the 14th Australian Cotton Conference*." 12 – 14 August 2008, Broadbeach, Australia.

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. Excessive DD is economic poor practice and a potential source of rising ground water tables with increased solute concentrations; potentially challenging issues for irrigated agricultural landscapes and the communities therein. The project's prime aim was the direct quantification of DD across a wide, yet representative range of cotton soils and management systems, while concurrently assessing both salt balances of collected leachates and around-lysimeter soils, as well as crosschecking the measured DD data with less expensive, indirect methods of predicting DD (eg SODICS, SaLF and ET/SIRMOD). Secondly, to monitor irrigation efficiencies in terms of recent technology utilisation in the cotton industry, specifically the comparative efficiency of a lateral move irrigator (LM) *vs* adjoining furrow irrigation, in terms of lessened water applied and DD; LM considered as having great potential for positive impacts on water savings. Thirdly, to investigate linkages (if any) between surface water events (DD, irrigation, river flows, etc) with historic and current (logged) groundwater levels in the St George irrigation area (SGIA); checking for rising water and salinity risk. Instrumentation was 35 drainage lysimeters (constant suction) at three locations in one field on each of 10 commercial farms and at the Australian Cotton Research Institute. Up to five irrigation seasons have been monitored (2002 to present). Results show a maximum DD of 310 mm (3.1 ML/ha) in one season has been measured (representing ~39% of the applied irrigation water). However, of 69 sampling occasions across four growing seasons and all the lysimeter sites, only 14 occasions (~20%) provided DD values of >100 mm (1 ML/ha). Additionally, DD has been found to vary strongly across fields - from head to tail ditches, and there is strong between-seasons' variation in the lysimeter data at any one site, apparently linked to during-season weather and water (irrigation water) availability. Some sites that provided >150 mm (1.5 ML/ha) of DD in one season, gave a zero reading the following season. These unexpected variabilities in the DD data, though important to know and to begin to rationalise in terms of site practice and seasonal weather, cause difficulties in rationalisation of the main drivers (of DD) towards the development of industry-applicable BMPs. Water quality analysis of the DD leachates apparently shows salt loads being mobilised under all sites. Soil chloride analysis (over five years at some of the DD sites) shows increased salts in the root zone of certain fields. Close investigation of both data sets is current. The indirect methods of predicting DD have proven most poor in providing matches to the measured lysimeter DD values; in terms of both magnitude (of DD volumes) and correspondence with (at times large) measured in-field and seasonal variability in DD. Preliminary analysis of the historic borehole logs and real-time logging of groundwater levels suggests that the shape of the groundwater contours does not particularly illustrate the presence of a broad groundwater mound in the SGIA, but rather the development of more localised groundwater mounds probably reflecting zones of locally preferential accession of DD (most probably due to channel leakage and leakage from on farm storages). The depth to groundwater data suggest that groundwater levels have not yet approached the 2 m bGL level that is commonly viewed as posing a risk for soil salinisation *via* capillary rise of groundwater. Currently there are 28 operational lysimeters (2 sites having been recently de-commissioned) and 18 borehole loggers (logging aquifer level twice daily) that will continue monitoring to 2011. These additional data will aid clarity in the drivers of DD and associated groundwater response. Further DD leachate and soil salinity data will be collected to continue the salt mass balance study.

Contact: Des McGarry, NRW (Indooroopilly): mcgarrd@nrw.qld.gov.au

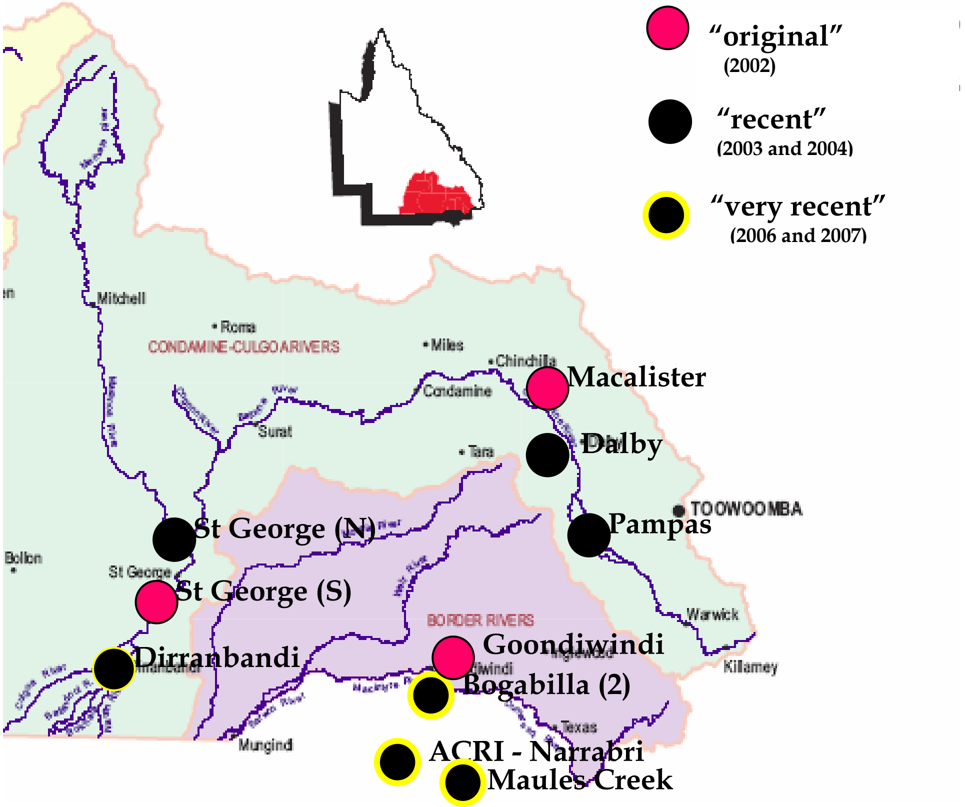

Figure 1 The Deep Drainage sites; across southern Queensland and northern NSW with timelines of installation years

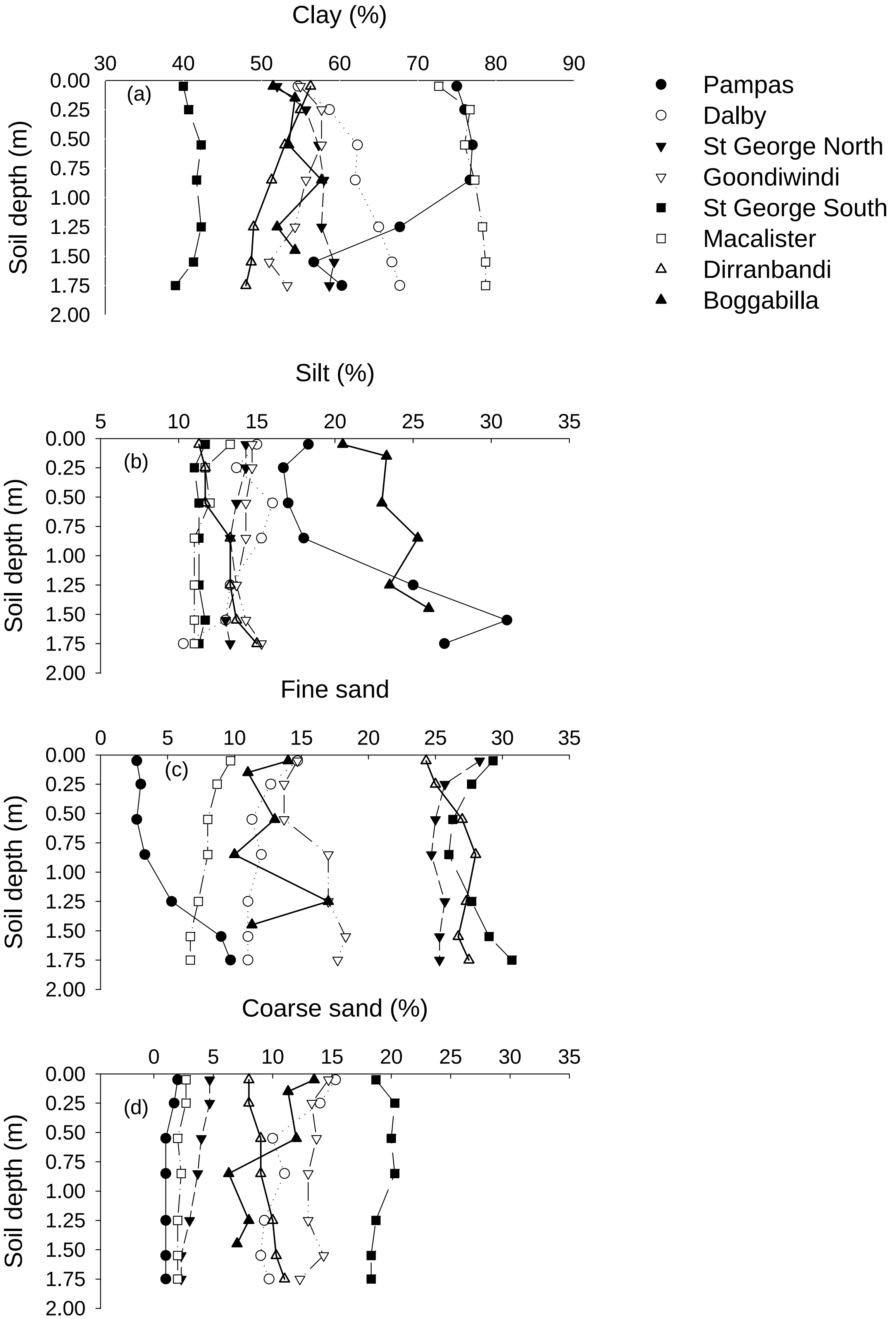

Figure 2 (a) Clay, (b) silt, (c) fine sand and (d) course sand contents (%) to 1.8 m depth at each of the eight lysimeter sites. Data are the means for selected 10 cm depth increments of a soil core sampled at the head, mid and tail locations in each monitored paddock.

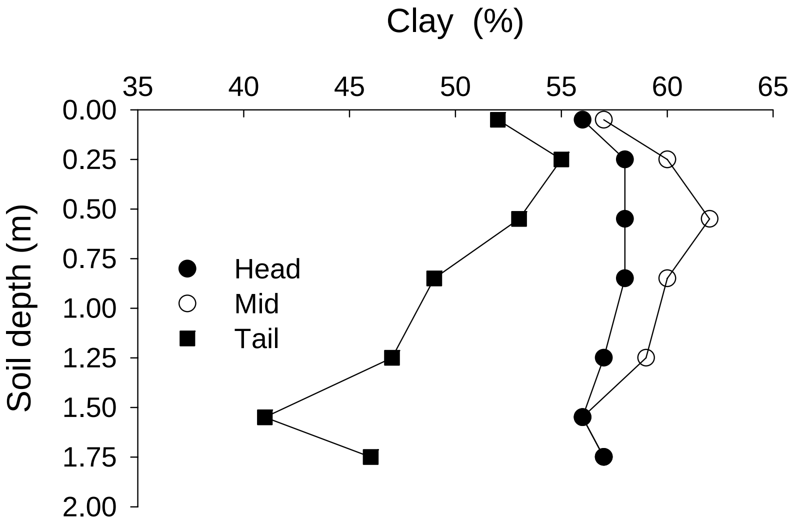

Figure 3 Clay content (%) to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at Goondiwindi.

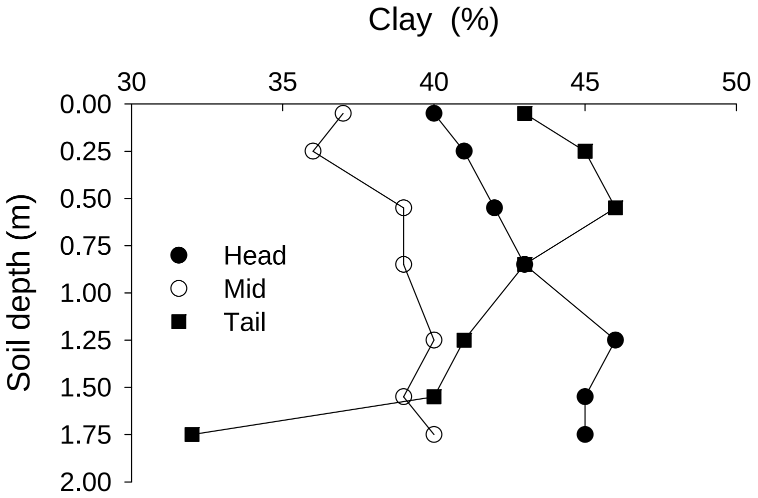

Figure 4 Clay content (%) to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at St George (S).

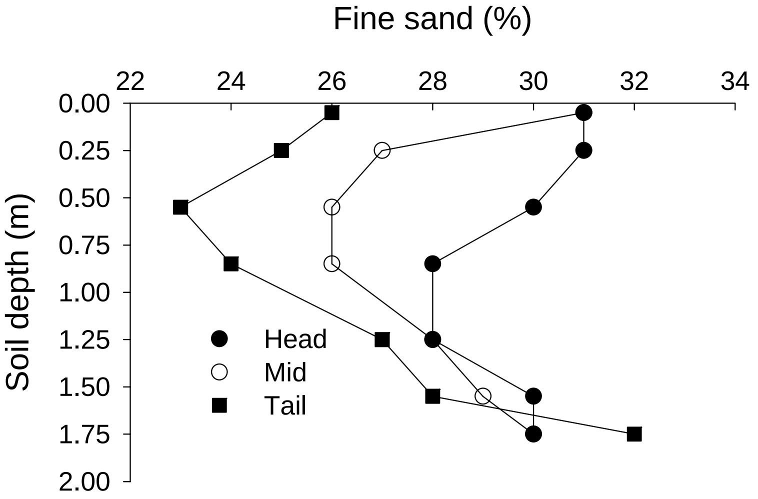

Figure 5 Fine sand content (%) to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at St George (S).

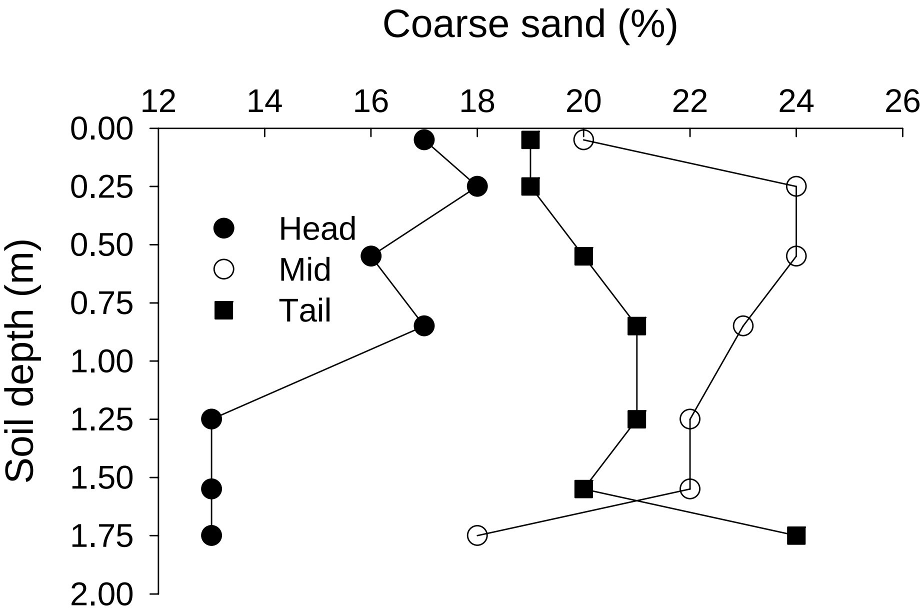

Figure 6 Coarse sand content (%) to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at St George (S).

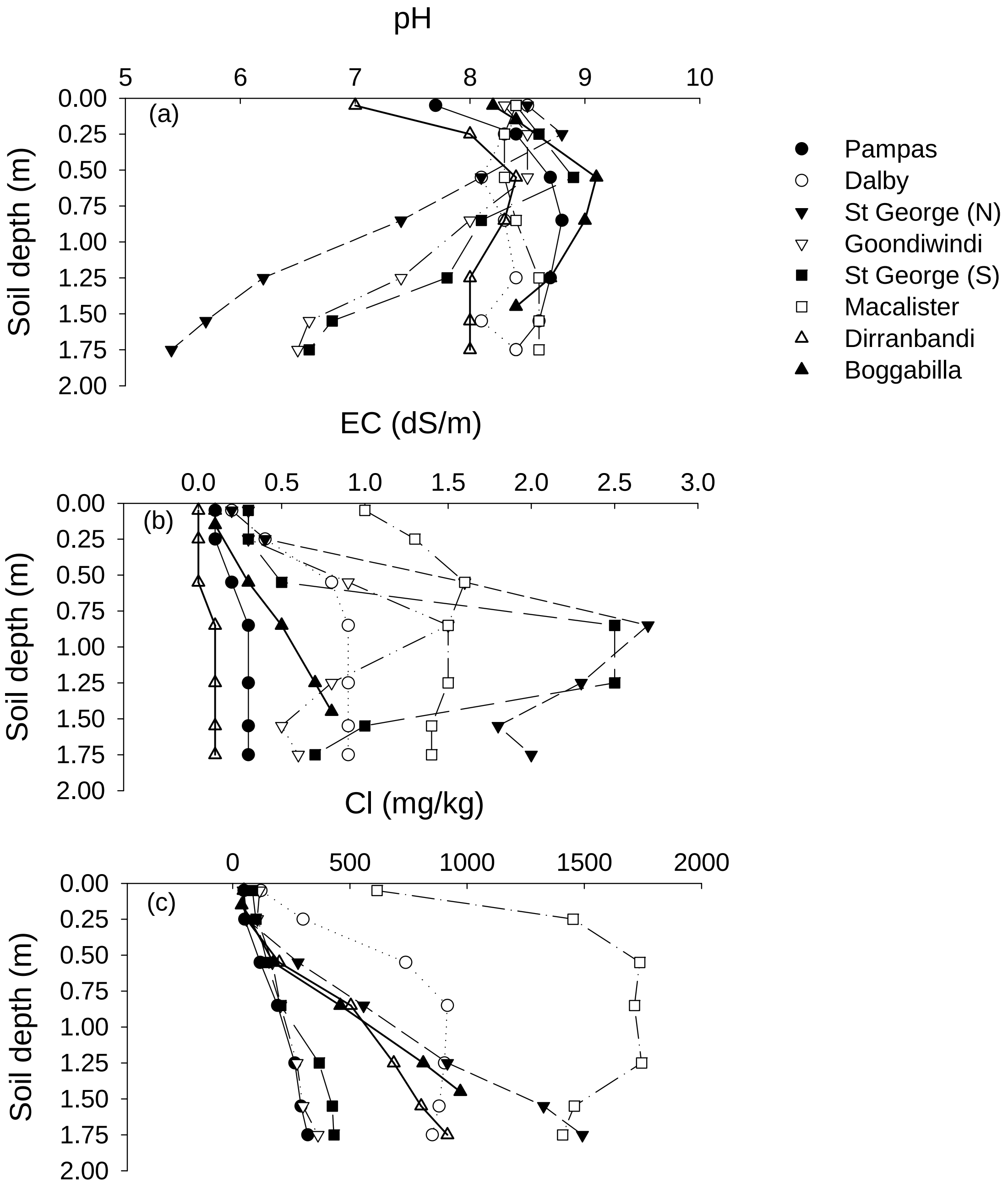

Figure 7 Plots of soil (a) pH, (b) electrical conductivity (EC) and (c) chloride (Cl) to 1.8 m depth at each of the eight drainage lysimeter sites. Data are the means for selected 10 cm depth increments of a soil core sampled at the head, mid and tail locations in each monitored paddock.

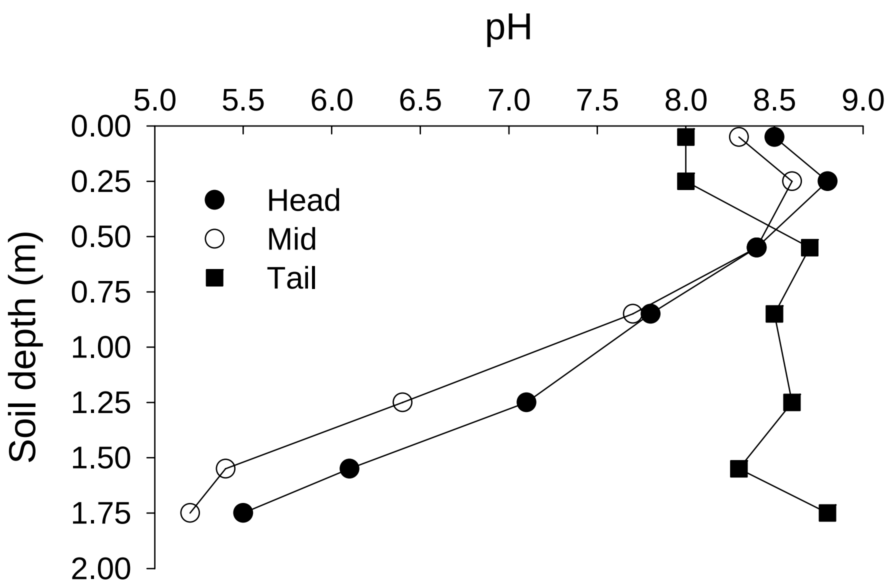

Figure 8 pH to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at Goondiwindi.

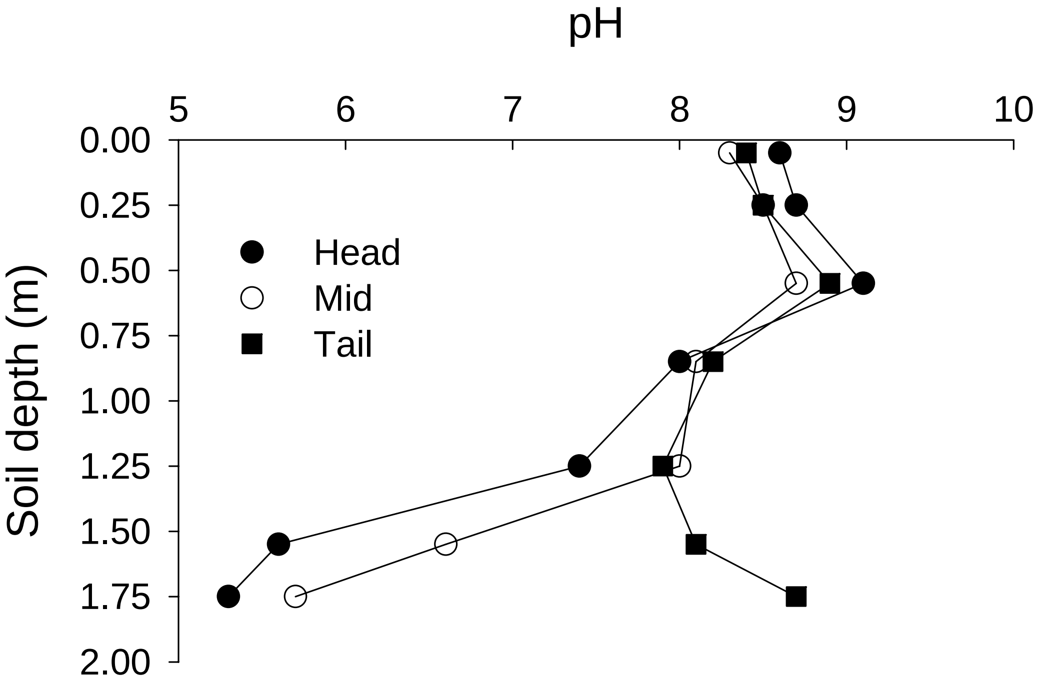

Figure 9 pH to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at St George (S).

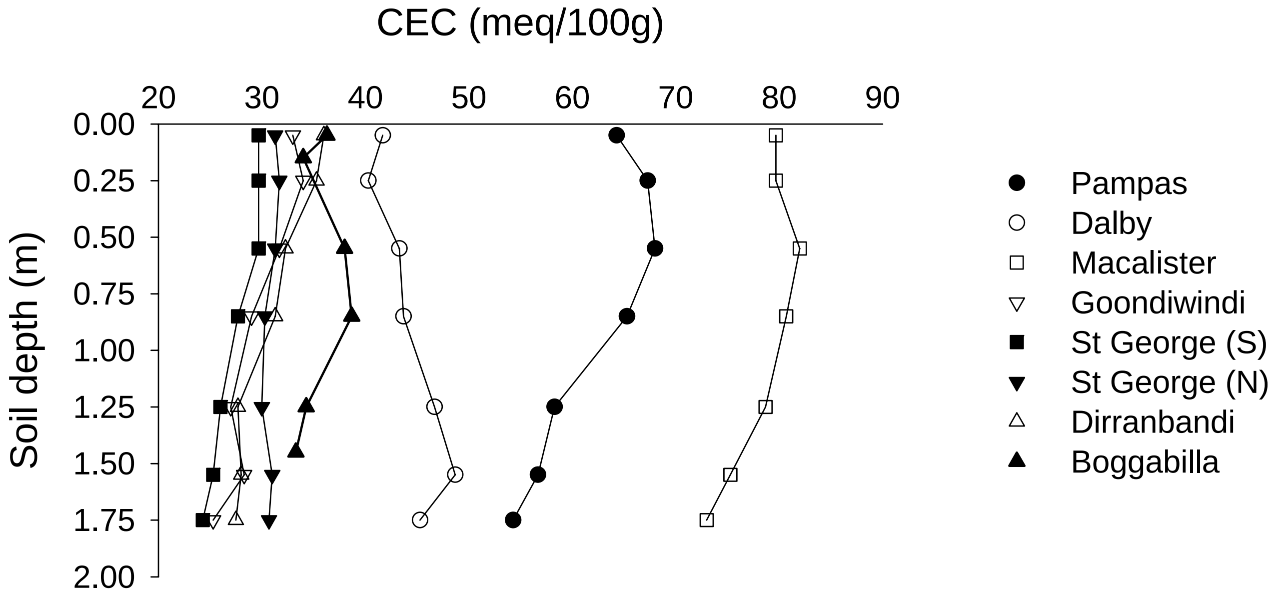

Figure 10 Cation exchange capacity (CEC) to 1.8 m depth at each of the eight drainage lysimeter sites. Data are the means for selected 10 cm depth increments of a soil core sampled at the head, mid and tail locations in each monitored paddock.

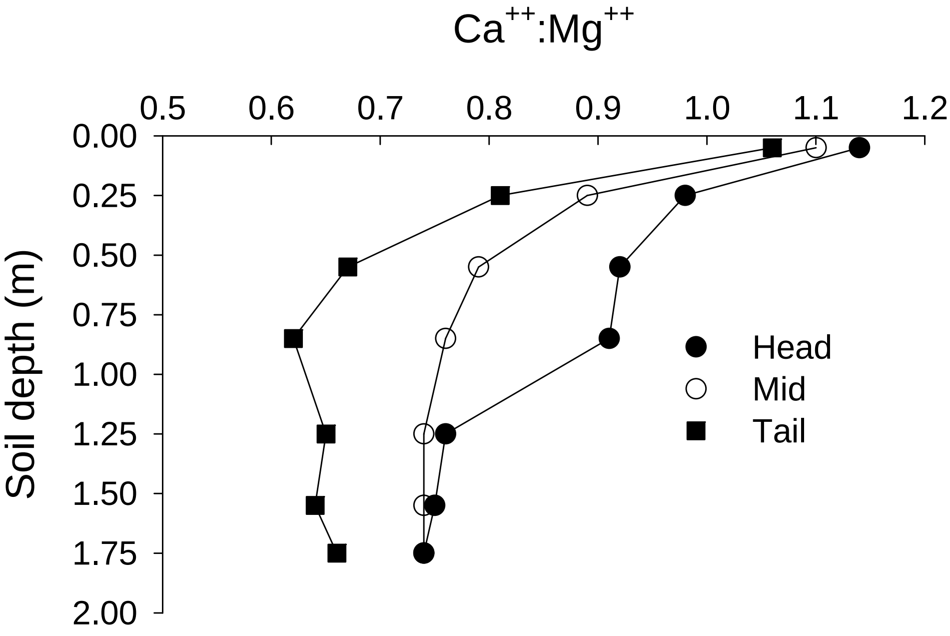

Figure 11 Calcium (Ca^{++}) to Magnesium (Mg^{++}) ratio to 1.8 m depth at each of the head, mid and tail locations for the Dalby site.

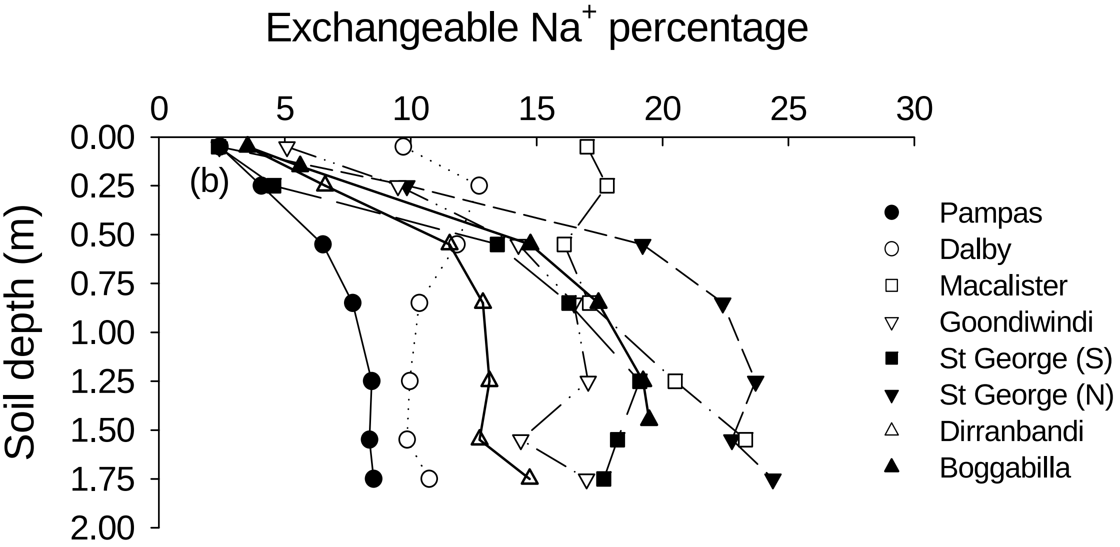

Figure 12 Exchangeable sodium percentage (ESP) to 1.8 m depth at each of the eight drainage lysimeter sites. Data are the means for selected 10 cm depth increments of a soil core sampled at the head, mid and tail locations in each monitored paddock.

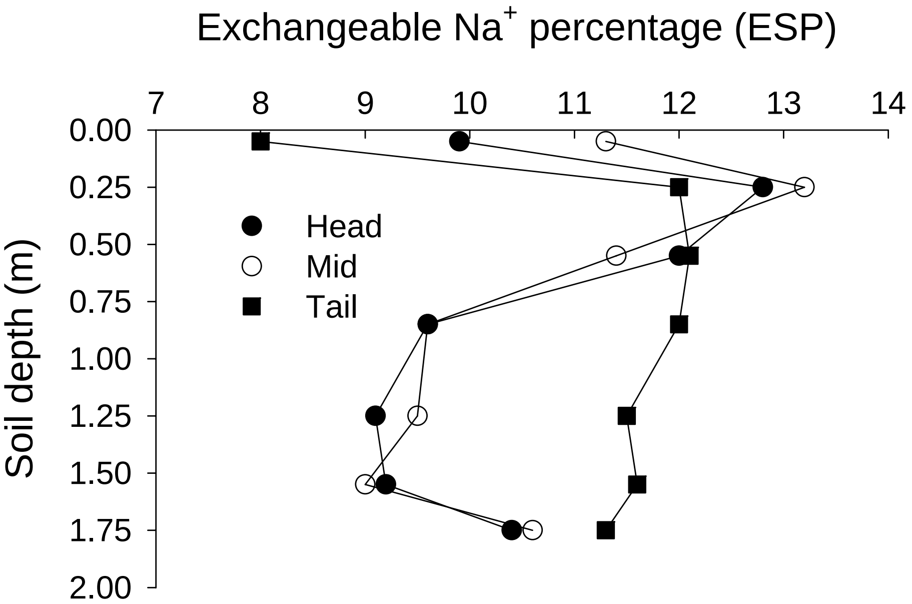

Figure 13 Exchangeable sodium percentage (ESP) to 1.8 m depth at each of the head, mid and tail locations at the Dalby site.

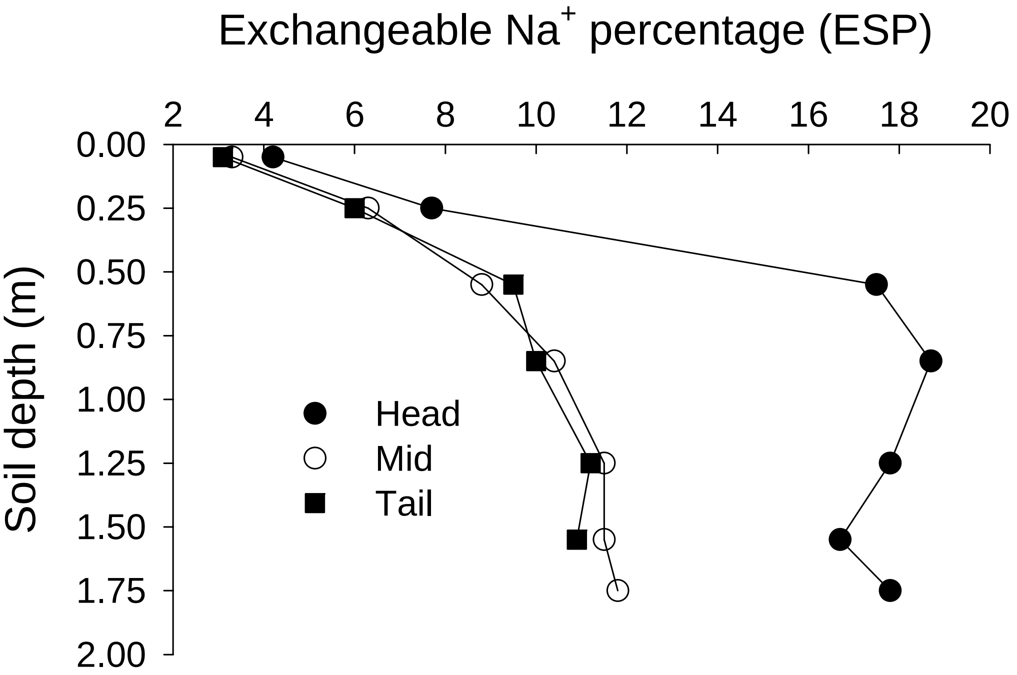

Figure 14 Exchangeable sodium% (ESP) to 1.8m depth at each of the head, mid and tail locations in Field 16, the Dirranbandi site.

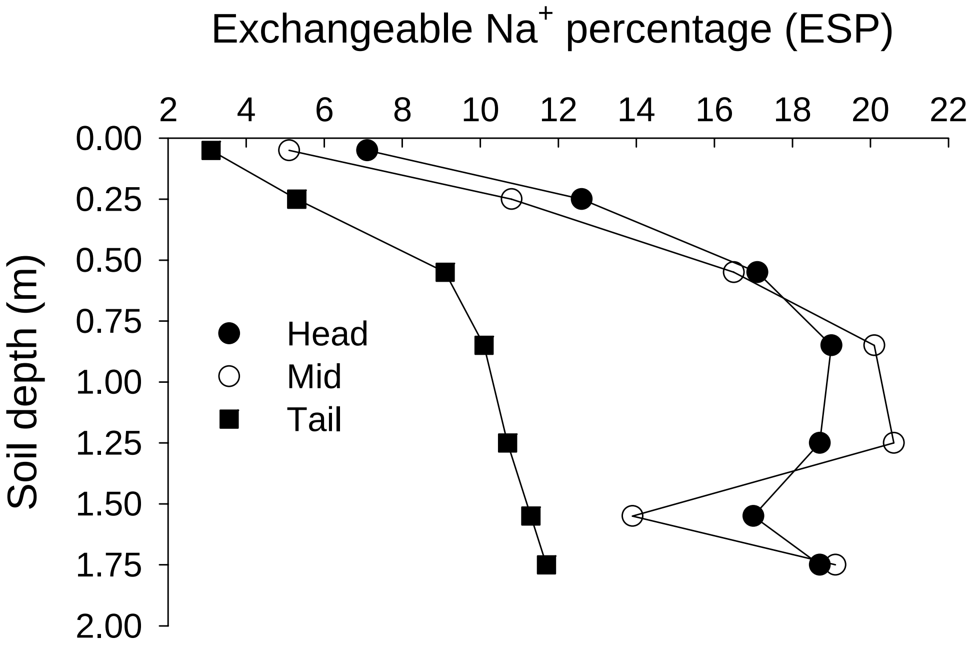

Figure 15 Exchangeable Sodium percent (ESP) to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at Goondiwindi.

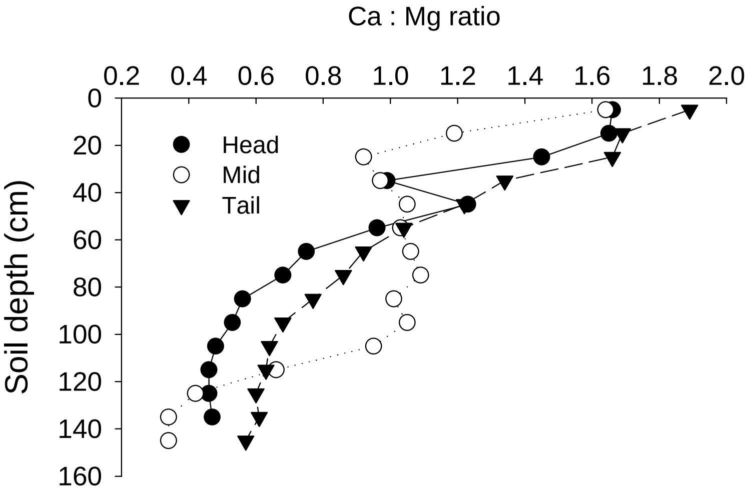

Figure 16 Calcium : Magnesium ratio (Ca : Mg) to 1.5 m depth for each of the head, mid and tail locations in the lysimeter field at Macalister.

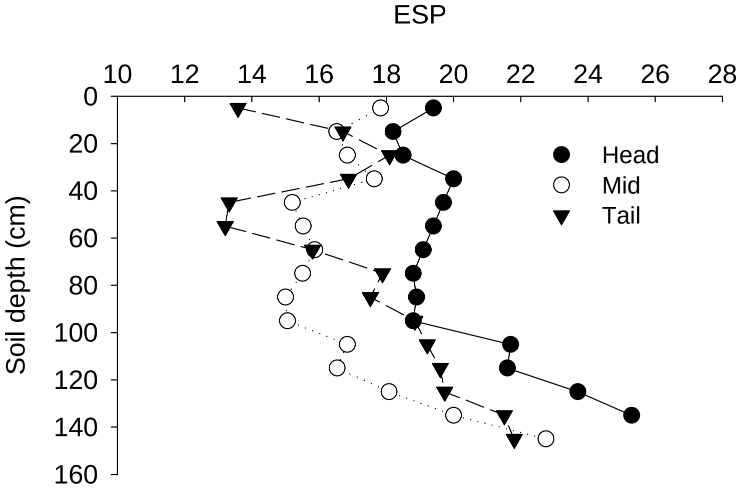

Figure 17 Exchangeable sodium percentage (ESP) to 150 cm depth for the head, mid and tail locations at the Macalister site.

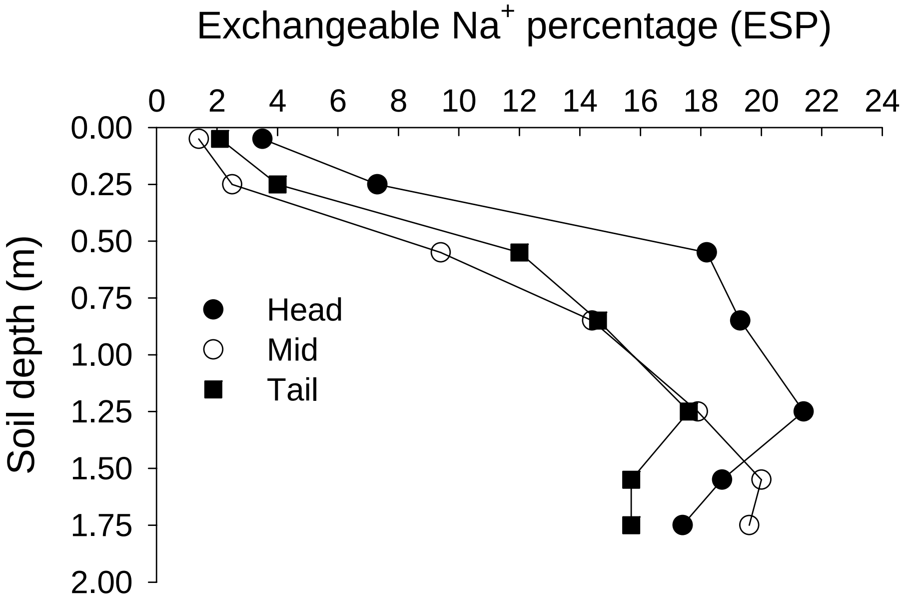

Figure 18 Exchangeable Sodium percent (ESP) to 1.8 m depth for each of the head, mid and tail locations in the lysimeter field at St George (S).

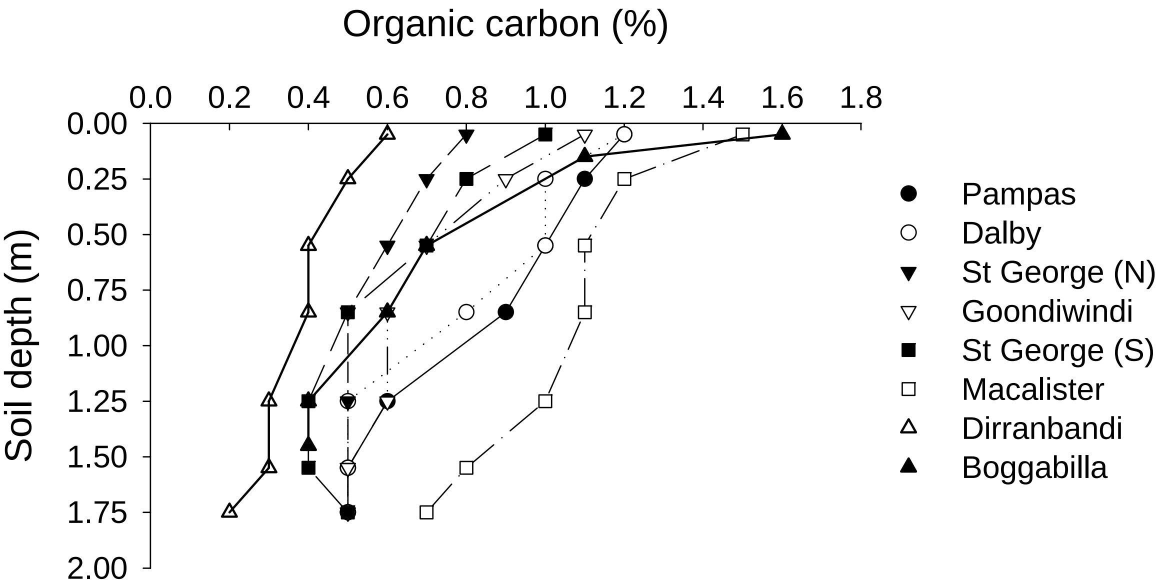

Figure 19 Soil organic carbon (%) to 1.8 m depth at each of the eight lysimeter sites. Data are the means for selected 10 cm depth increments of a soil core sampled at the head, mid and tail locations in each monitored paddock.

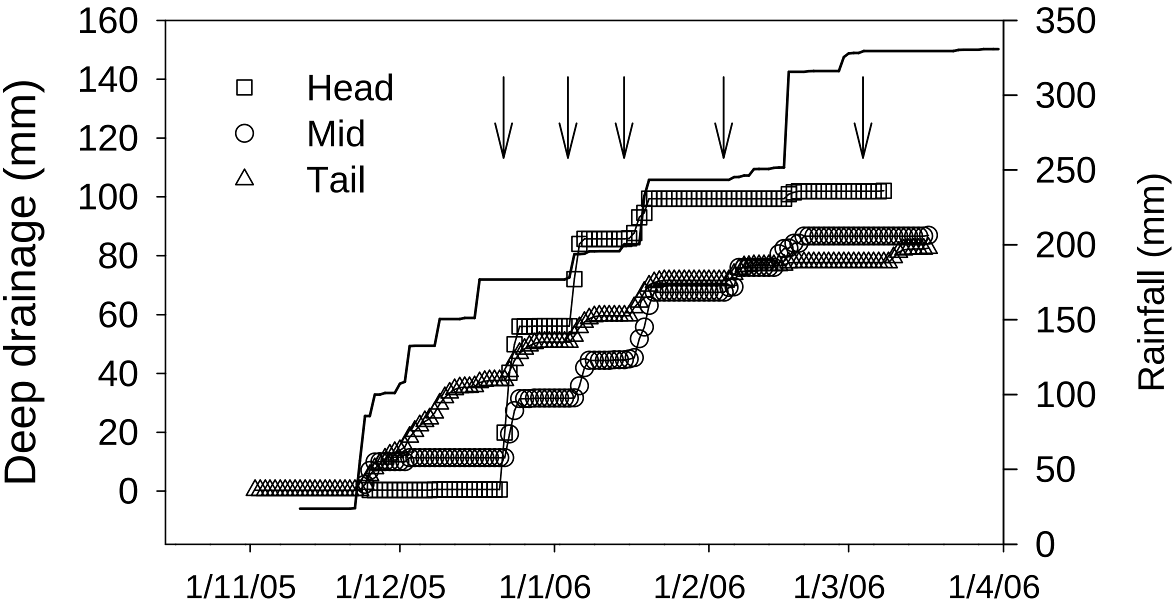

Figure 20 Cumulative deep drainage logged from the Boggabilla site during 2005-06 cotton season. Cumulative rainfall is shown as the continuous black line, and the vertical arrows indicate the five irrigation events.

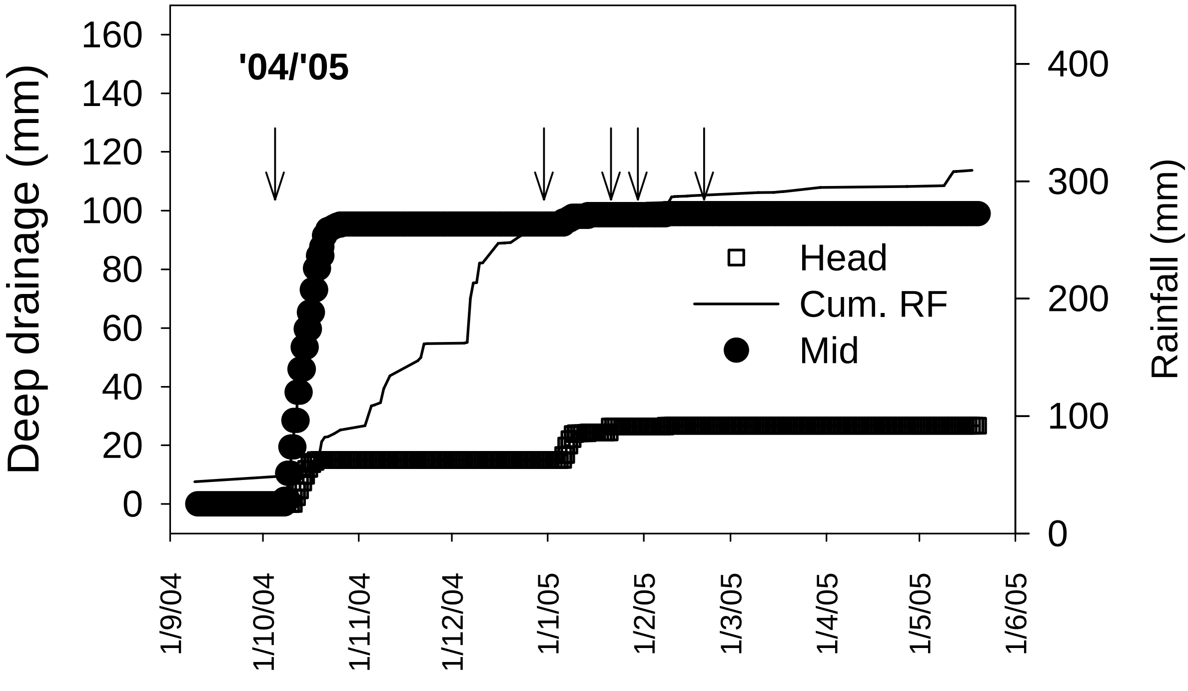

Figure 21 Cumulative deep drainage recorded (electronic tips) from the Dalby site during the 2004-5 cotton season. The actual volumes of water collected for each of the head, mid and tail locations were 39, 95 and 34 mm, respectively. Arrows show irrigation events. The cumulative rainfall is plotted as a dashed line.

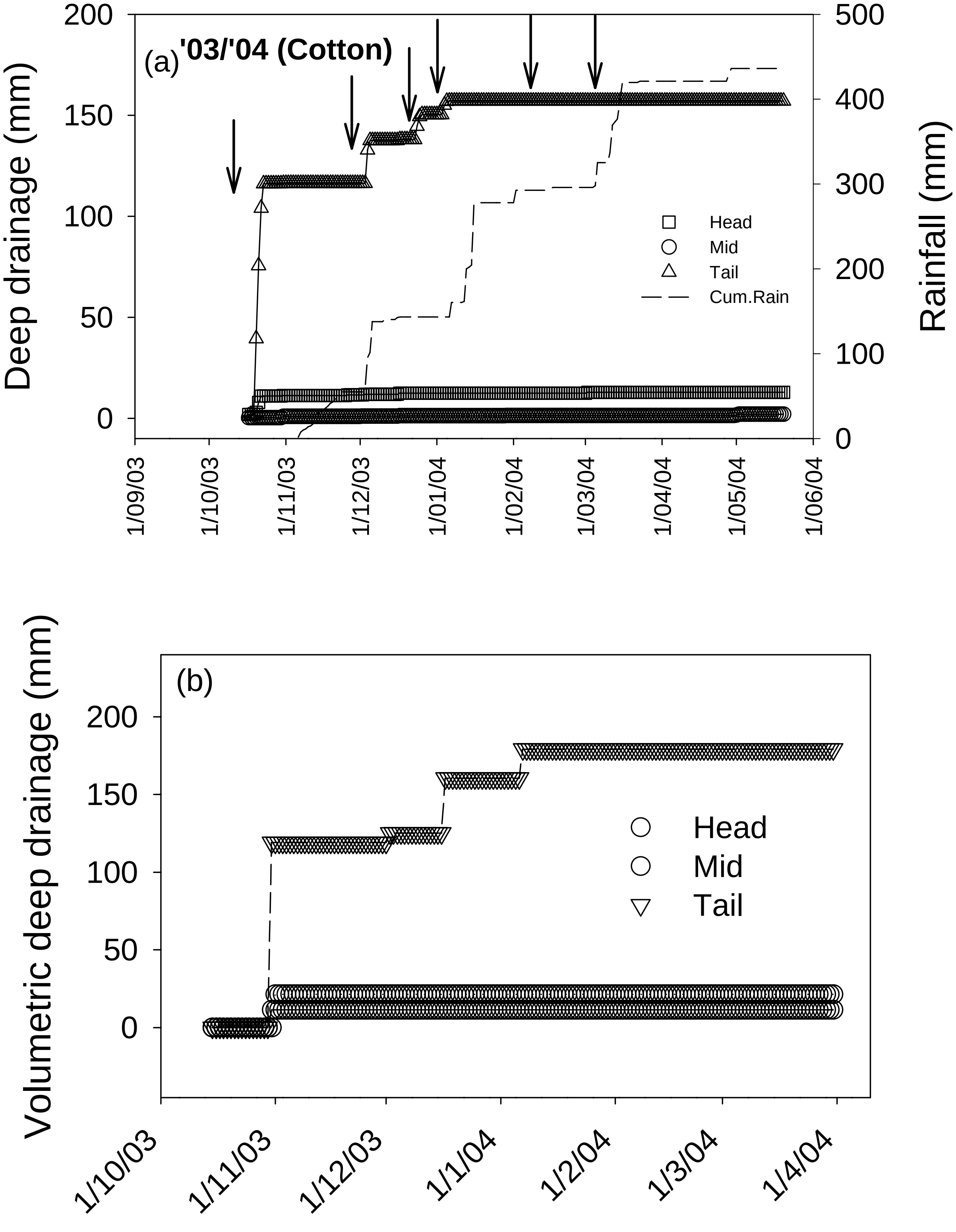

Figure 22 Cumulative deep drainage (logged data) recorded from the Dirranbandi site during ‘03/’04 cotton season. Data from (a) electronic tips amd (b) volume of water colelcted for each of the head mid and tail locations. Arrows show irrigations and the cumulative rainfall is plotted in (a) as a dash line.

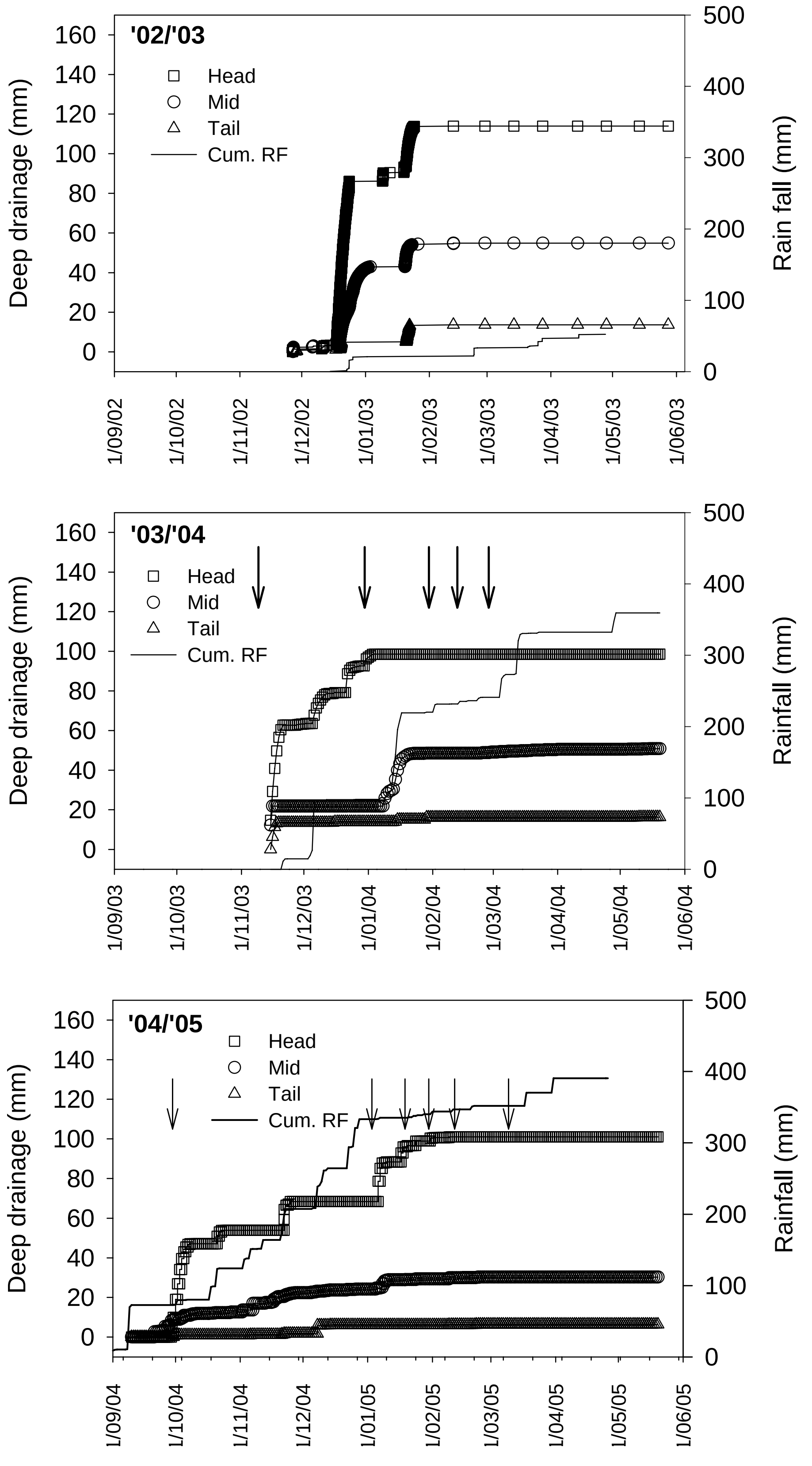

Figure 23 Cumulative deep drainage recorded (as electronic tips) at the Goondiwindi site during the 2002-3, 2003-4 and 2004-5 cropping seasons. The cumulative rainfall is also plotted as fine line. Vertical arrows indicate number and time of irrigation event. Notes: there was no pre-irrigation for the 2003-4 season as the crop (Sorghum) was planted "dry" and wetted-up. Also, no records were kept of irrigations (number or timing) in the 2002-3 season.

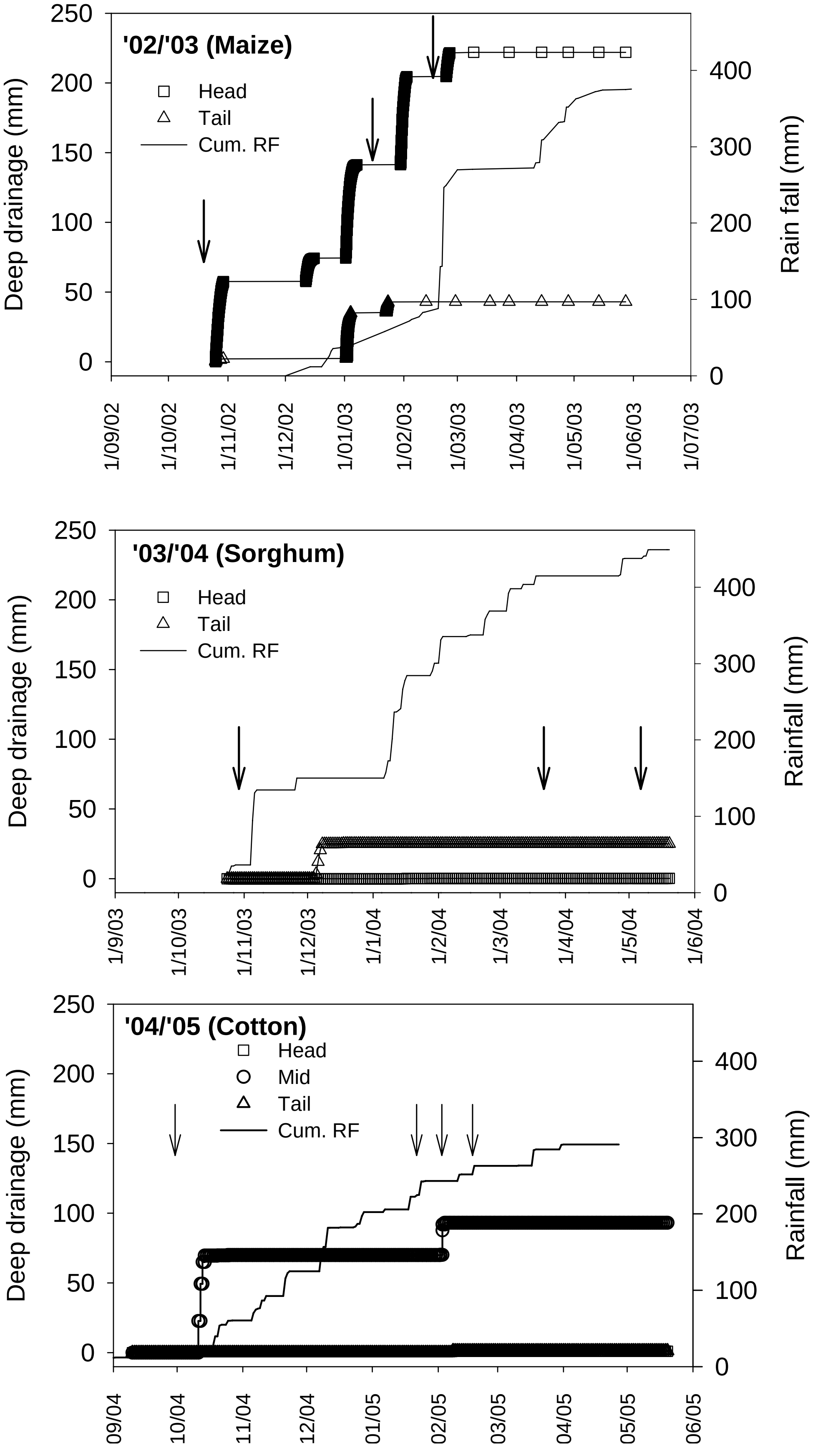

Figure 24 Cumulative deep drainage recorded (electronic tips) from the Macalister site during the 2002-3, 2003-4 and 2004-05 cropping seasons. The cumulative rainfall is also plotted as a fine line. Vertical arrows indicate number and time of irrigation event.Note; DD during 2005-6 & 2006-7 were relatively low and ranged from 4 to maximum of 31 mm.

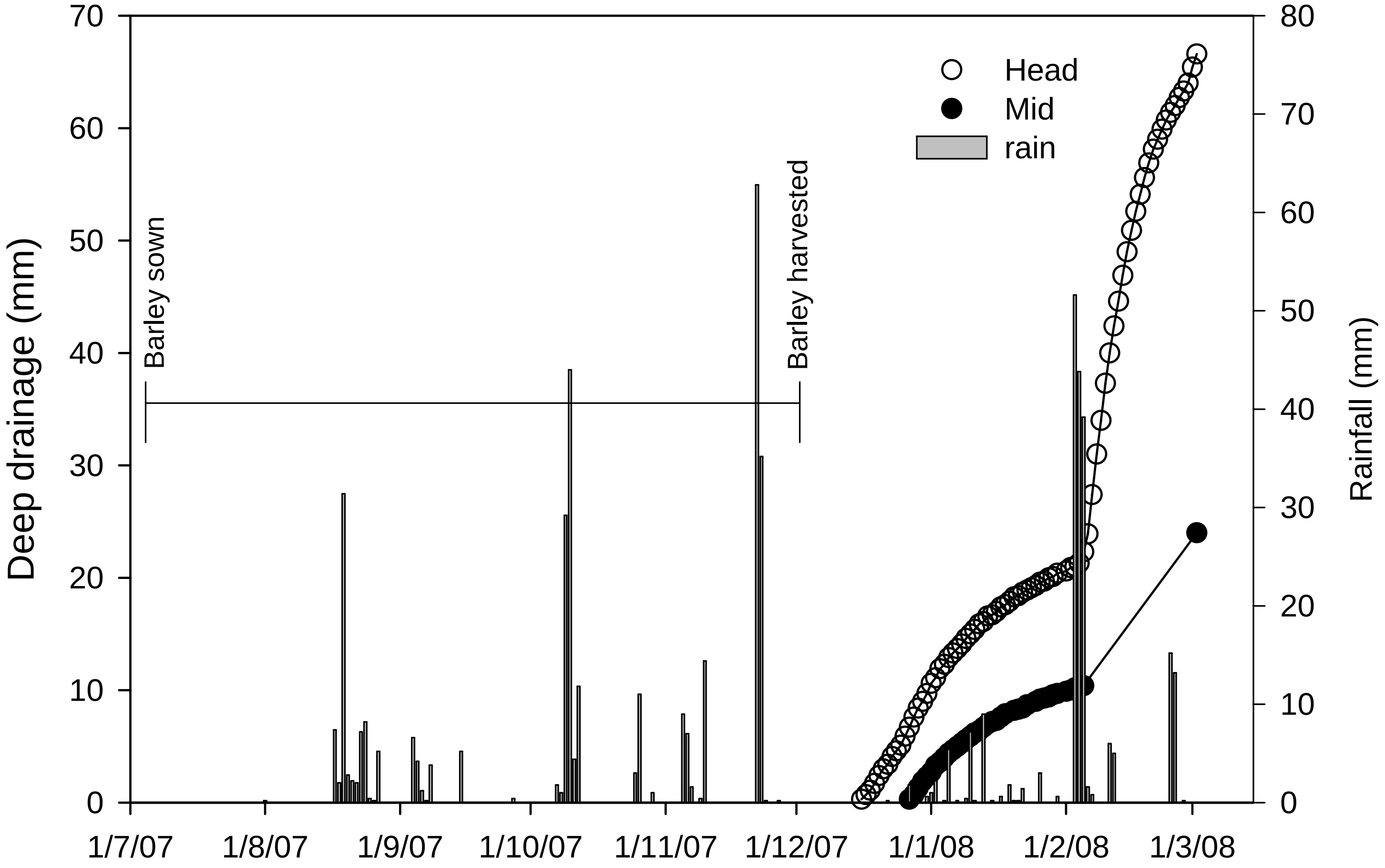

Figure 25 The measured precipitation at the Macalister site during the rainfed barley and post barley season (vertical bars) plotted with the measured DD (from the tipping bucket device)\ as a cumulative curve. There was no DD recorded at the tail location.

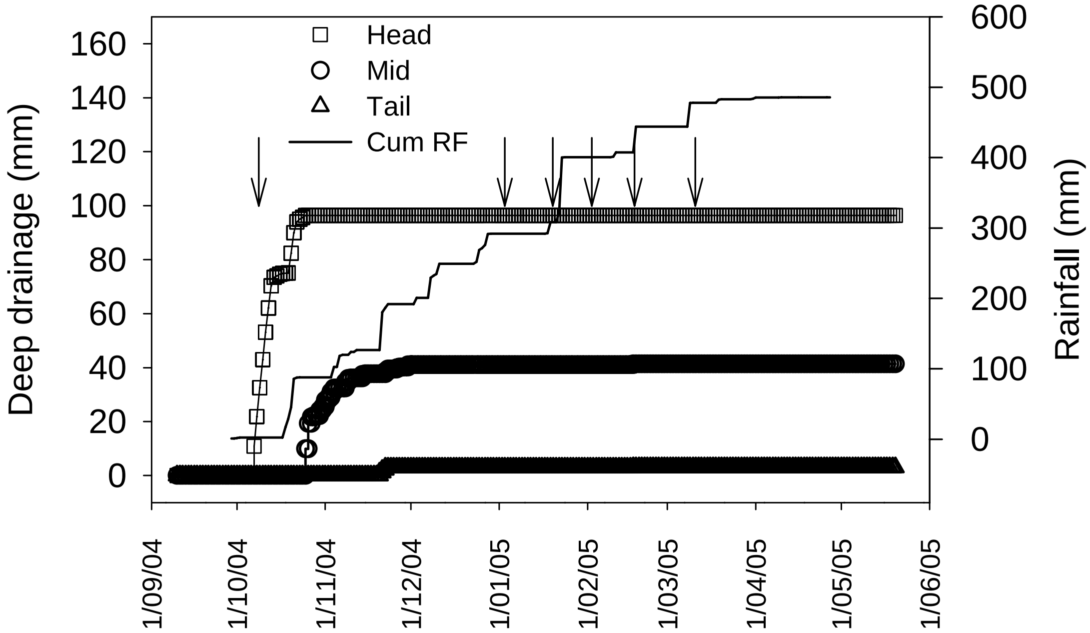

Figure 26 Cumulative deep drainage recorded (electronic tips) from the Pampas site during the 2004-5 cotton season. The actual volumes of water collected for each of the head, mid and tail locations were 71, 106 and 62 mm, respectively. Arrows show irrigations. The cumulative rainfall is plotted as a dashed line.

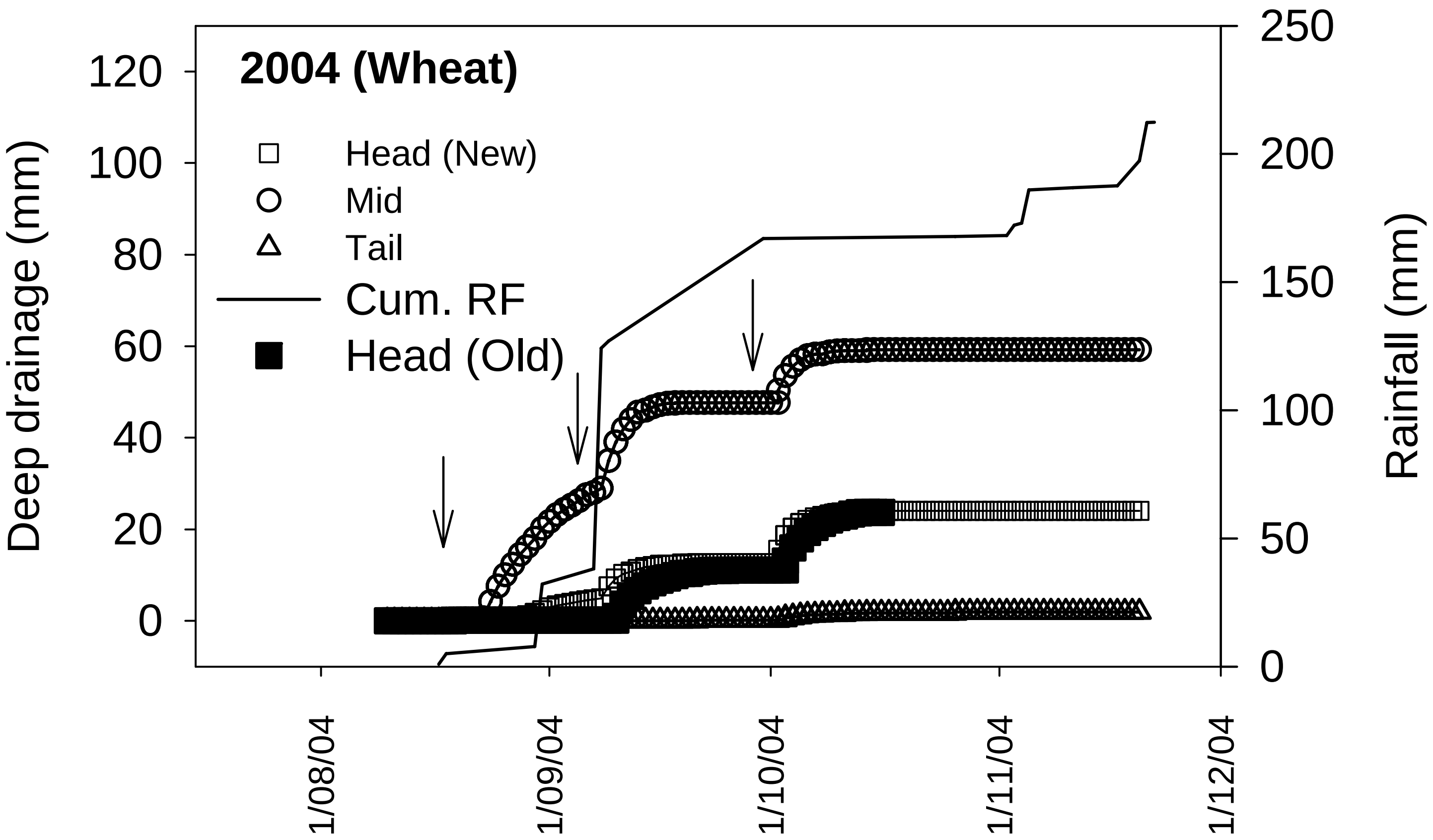

Figure 27 Cumulative deep drainage (logged data) recorded from the St George (N) site during 2004 irrigated wheat season.

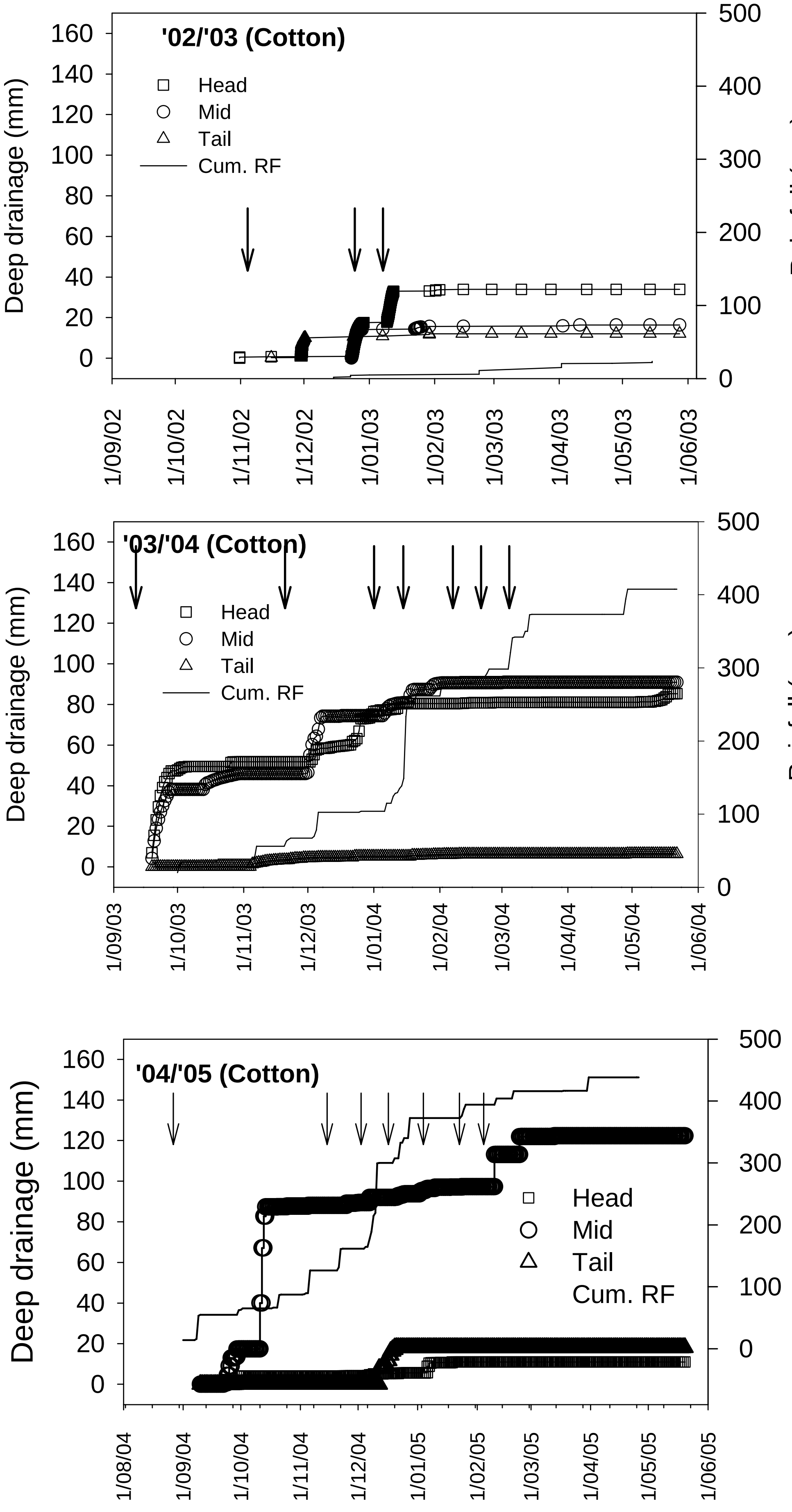

Figure 28 Cumulative deep drainage recorded (as electronic tips) at the St George (S) site during the 2002-3, 2003-4 and 2004-5 cropping seasons. The cumulative rainfall is also plotted as fine line. Vertical arrows indicate number and time of irrigation event. Notes: no records were kept of irrigations (number or timing) in the 2002-3 season

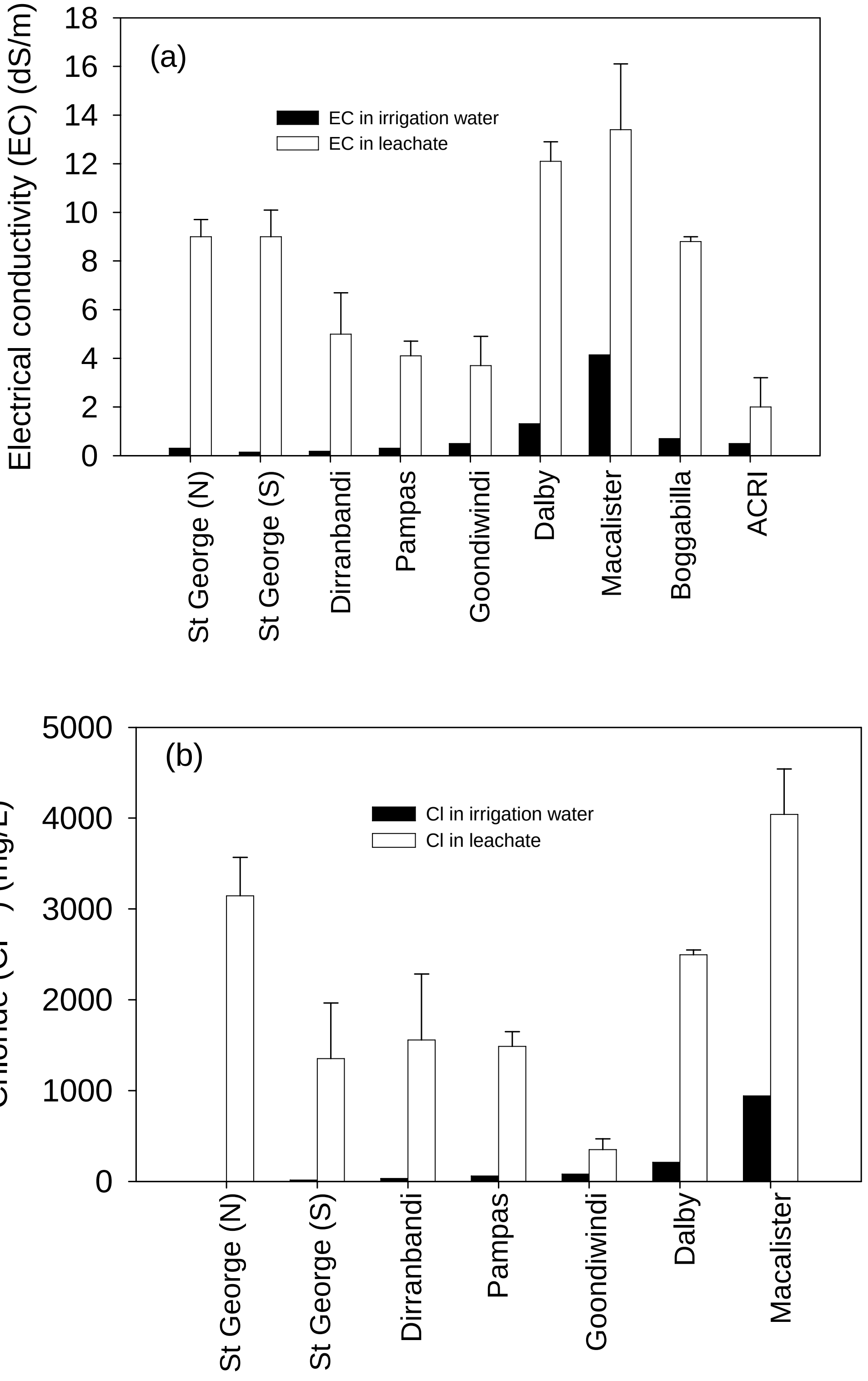

Figure 29 (a) Chloride concentration and (b) electrical conductivity (EC) levels in irrigation waters and in leachates collected at 1.5m depth in seven lysimeter sites.

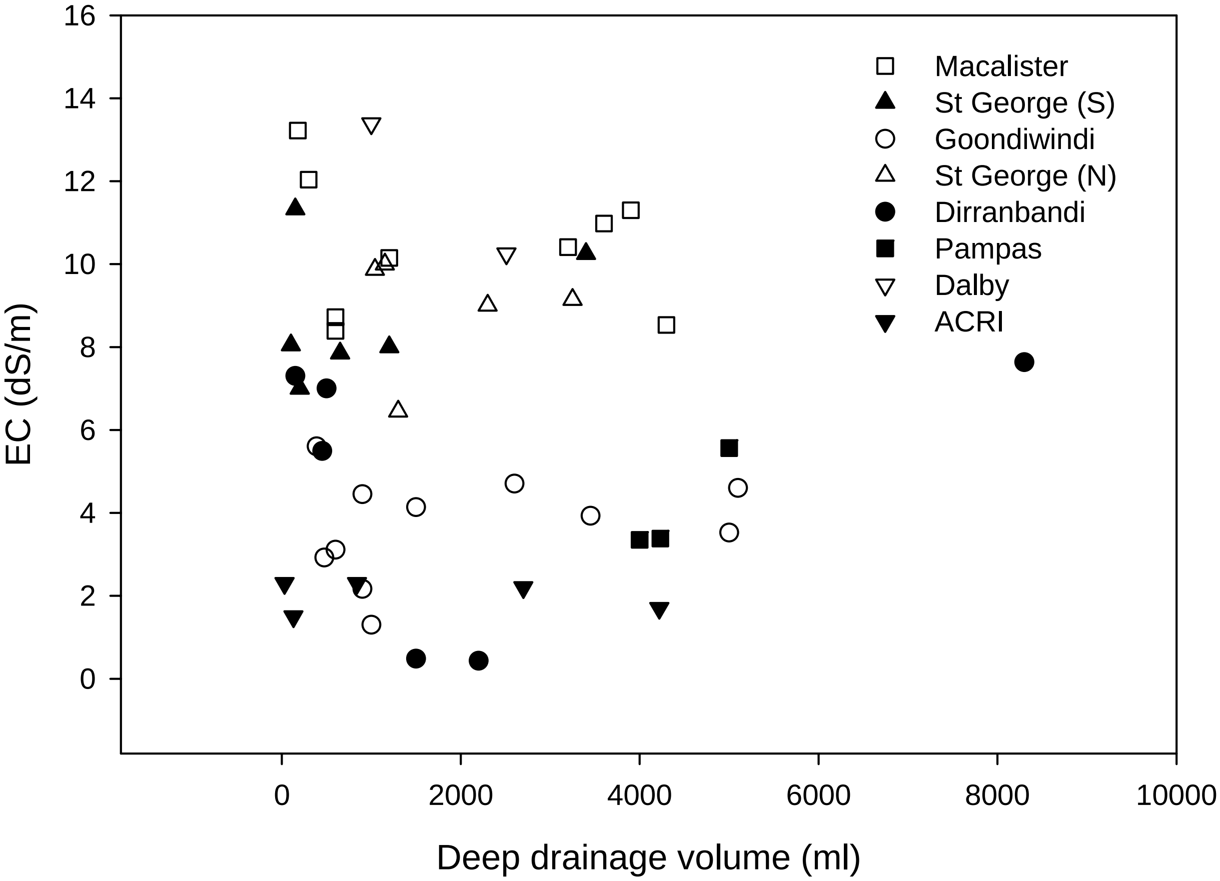

Figure 30 Deep drainage data (leachate volume) plotted against the electrical conductivity values of the (same) leachate water.

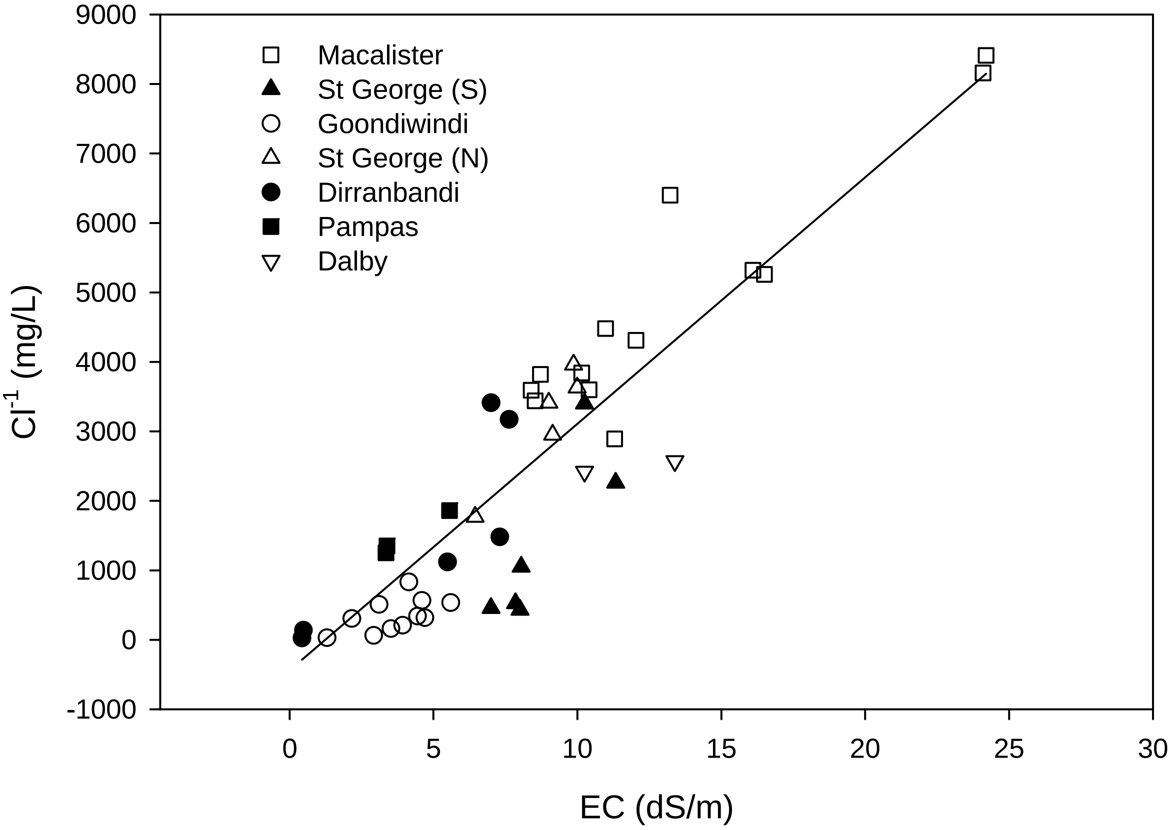

Figure 31 The relationship between electrical conductivity (EC) and chloride (Cl^{-1}) concentration in leachate (DD water samples). Y = -440 + 355x (R^2 = 0.78)

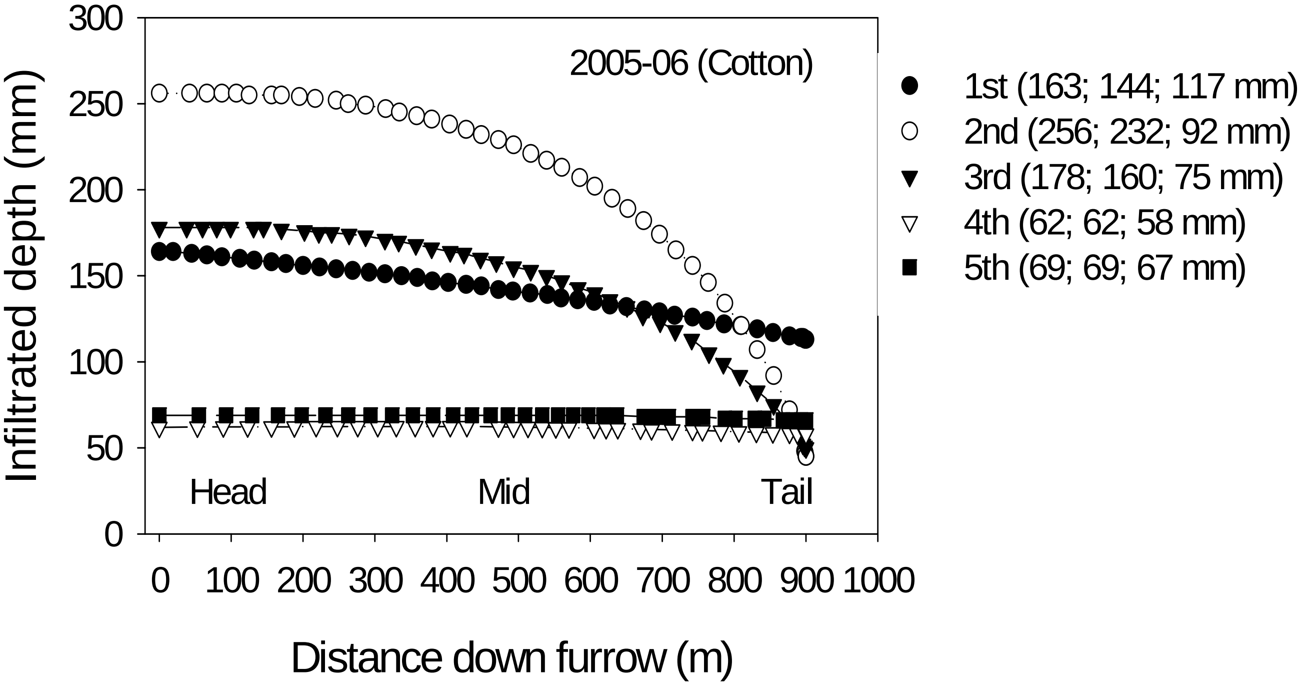

Figure 32 Infiltration uniformity simulated from SIRMOD down the furrow on the Boggabilla (furrow) site for 5 irrigation events in the 2005-6 cotton season. The amounts of water infiltrated at each of the head, mid and tail locations for each irrigation, as calculated through inverse modelling, are given in the legend.

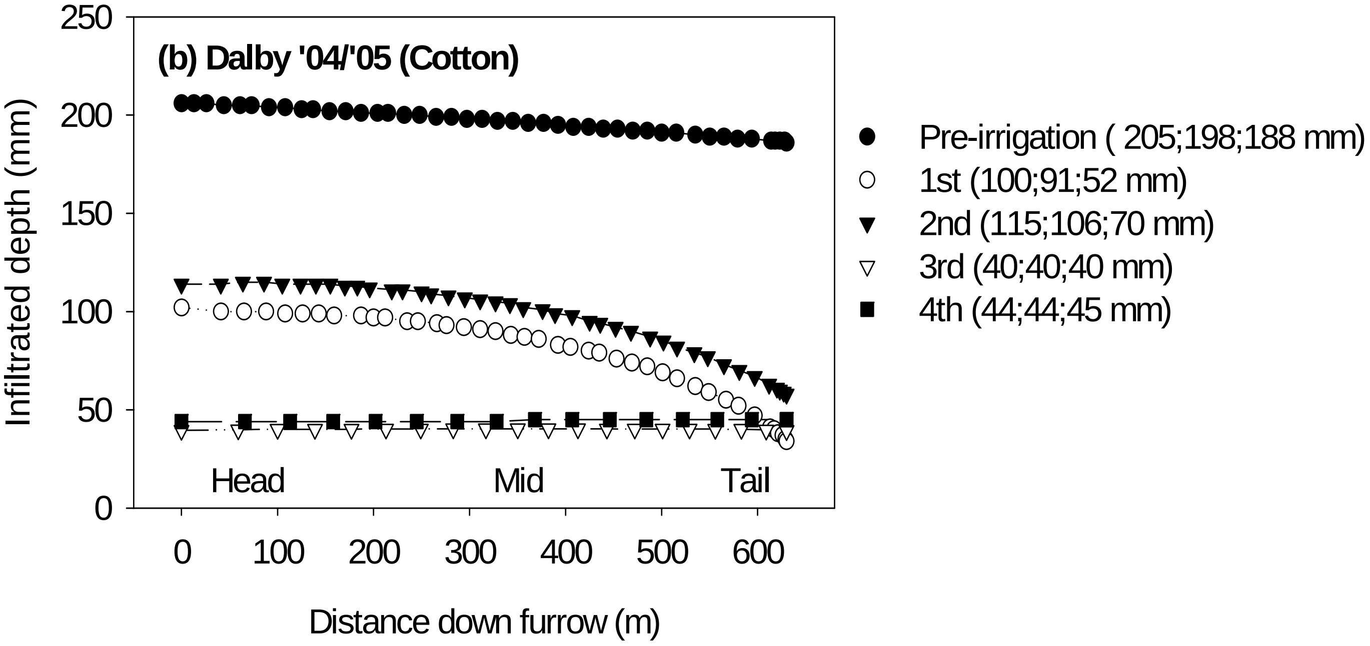

Figure 33 Infiltration uniformity simulated from SIRMOD down the furrow on the Dalby site for 5 irrigation events in the 2004-5 cotton season. The modelled amounts of water infiltrated at each head, mid and tail locations for each irrigation are given in the legend.

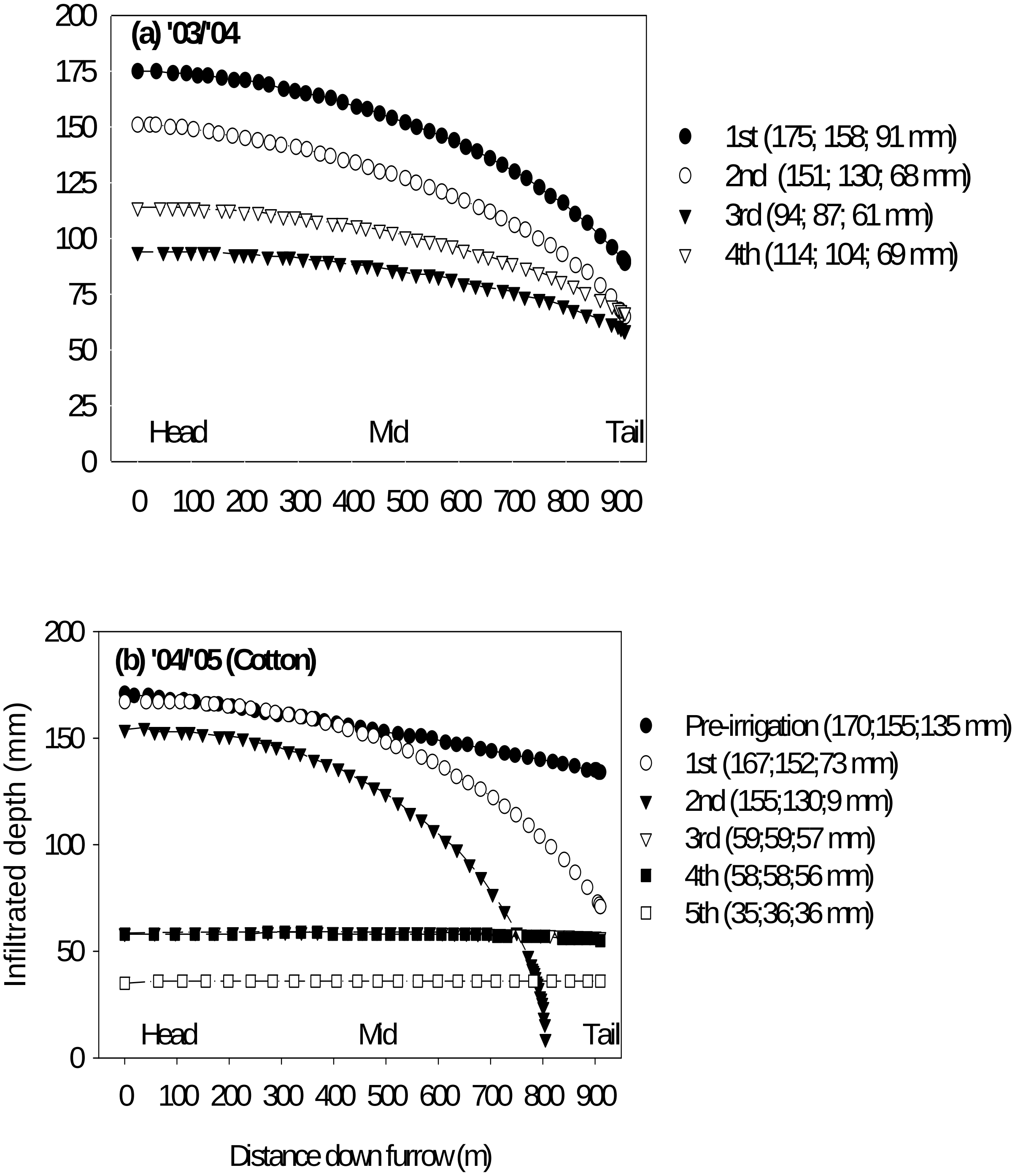

Figure 34 Infiltration uniformity simulated from SIRMOD down the furrow (910 m) on the Goondiwindi site for 4 and 6 irrigation events in the (a) 2003-4 and (b) 2004-5 sorghum and cotton season, respectively. The modelled amounts of water infiltrated at each head, mid and tail locations are also shown in the legend.

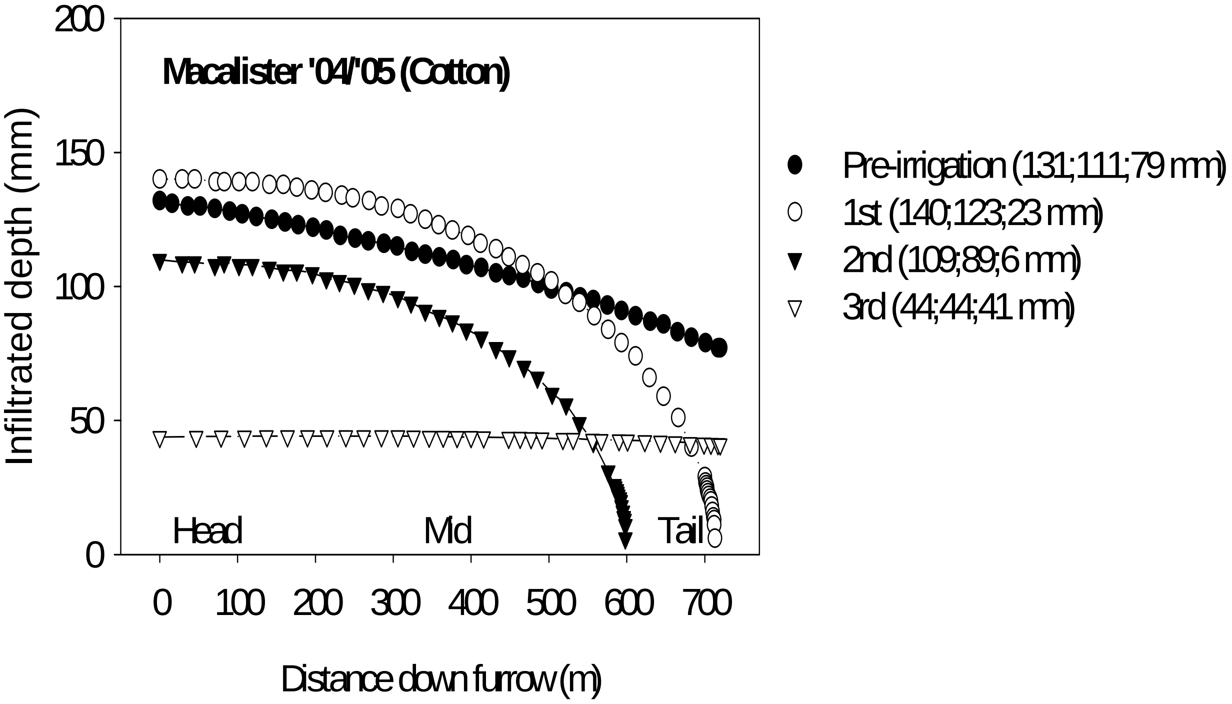

Figure 35 Infiltration uniformity simulated from SIRMOD down the furrow on the Macalister site for 4 irrigation events (as shown in Figure 8) in the 2004-5 cotton season. The modelled amounts of water infiltrated at each head, mid and tail locations are also shown in the legend.

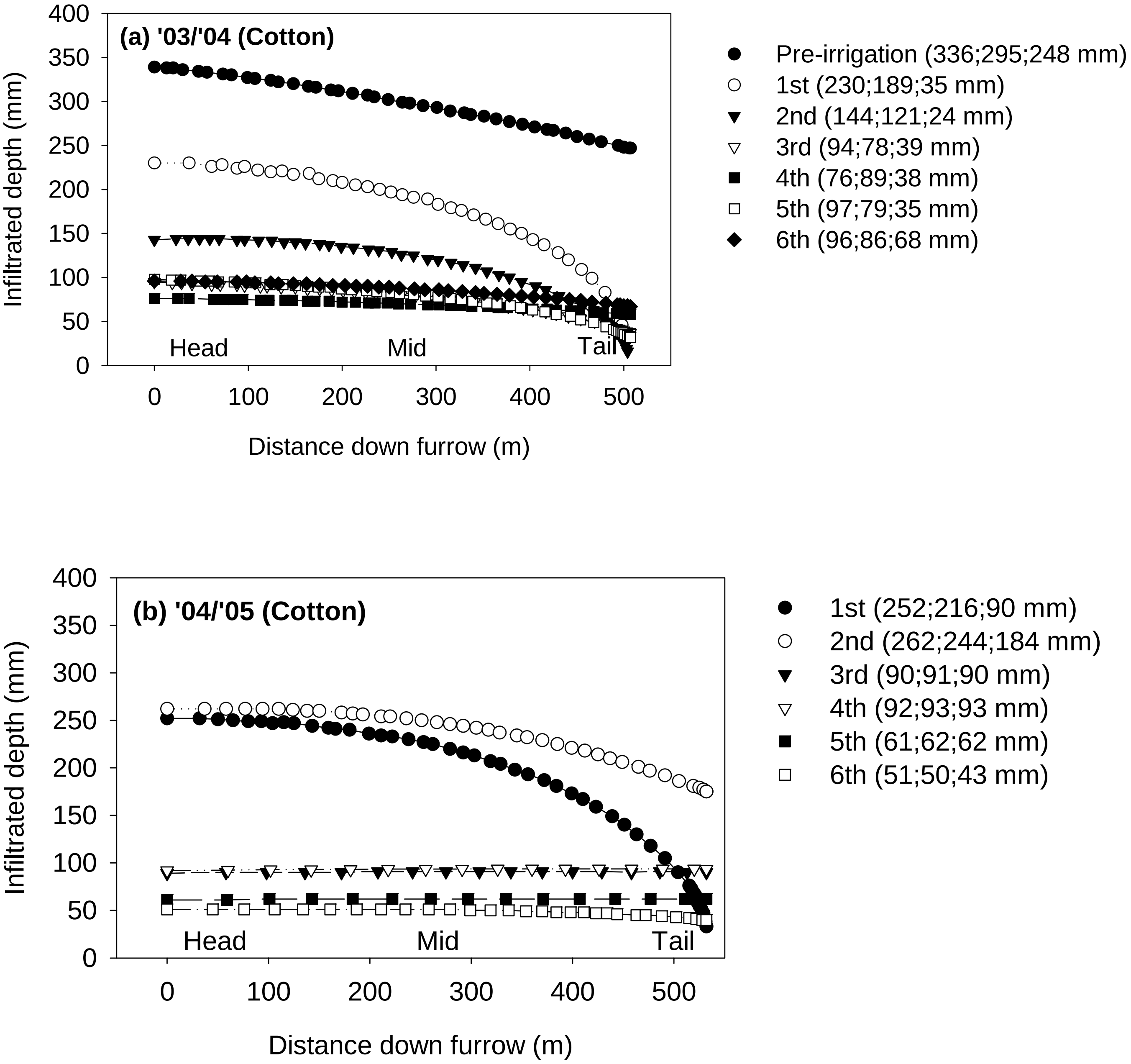

Figure 36 Infiltration uniformity simulated from SIRMOD down the furrow (530 m) on the St George (S) site for 7 and 6 irrigation events in the (a) 2003-4 and (b) 2004-5 cotton seasons. The modelled amounts of water infiltrated at each head, mid and tail locations are also shown in the legend. Note; no data available for pre-irrigation during 2004-05 season.

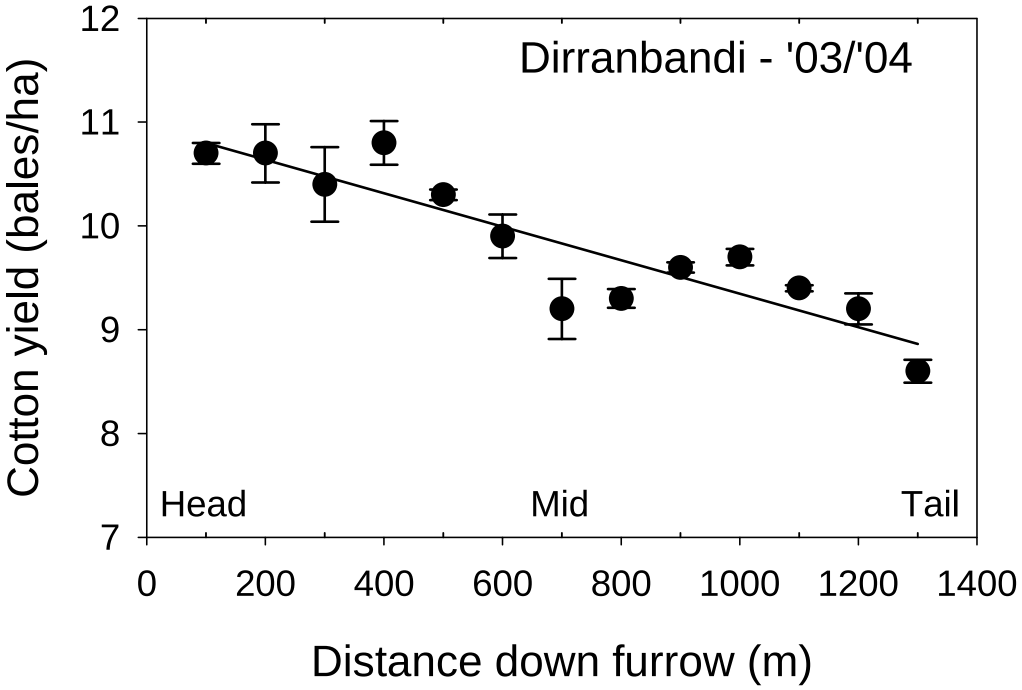

Figure 37 Cotton yield (bales per ha) collected using yield monitors on cotton pickers from the lysimeter site during the 2003-04 seasons. Data are the average of four passes over the lysimeter locations for the duration of 1 minute travel as the picker advanced down the field between head and tail ditches. (The vertical bar at each data point indicates the standard deviations of the average yield).

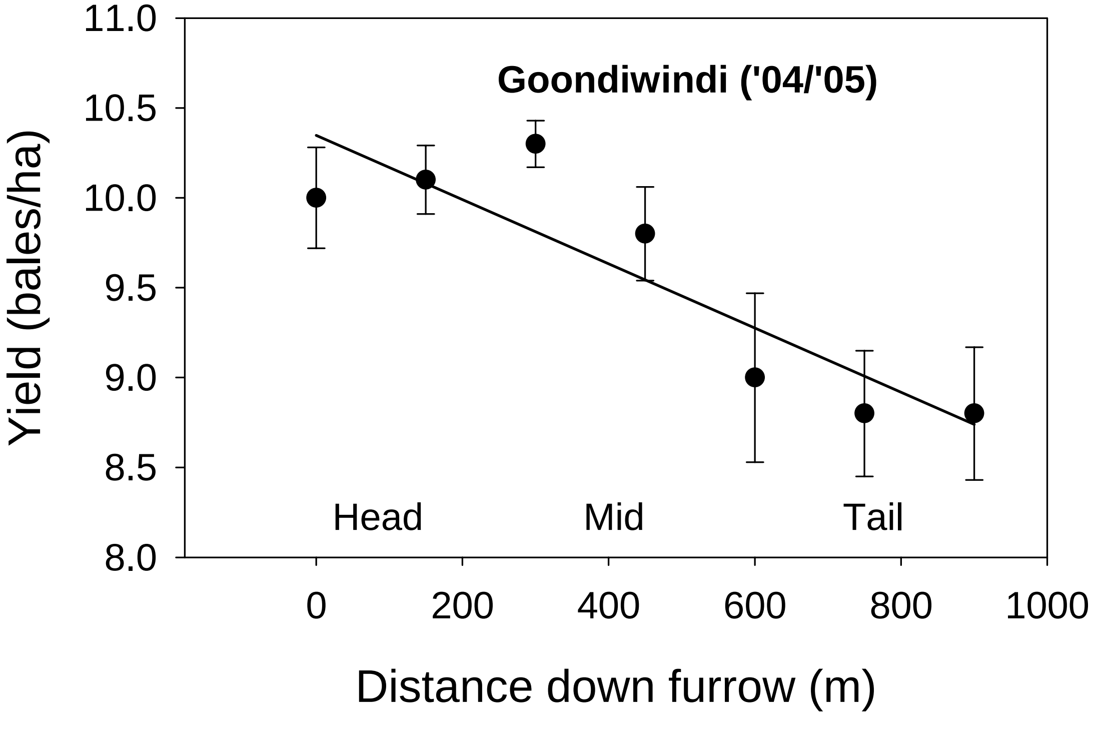

Figure 38 Lint yield (bales per ha) (data collected using yield monitors on cotton picker) from Goondiwindi site during 2004-5 season. Vertical bar at each data point shows the standard deviations (±SD) of mean yield.

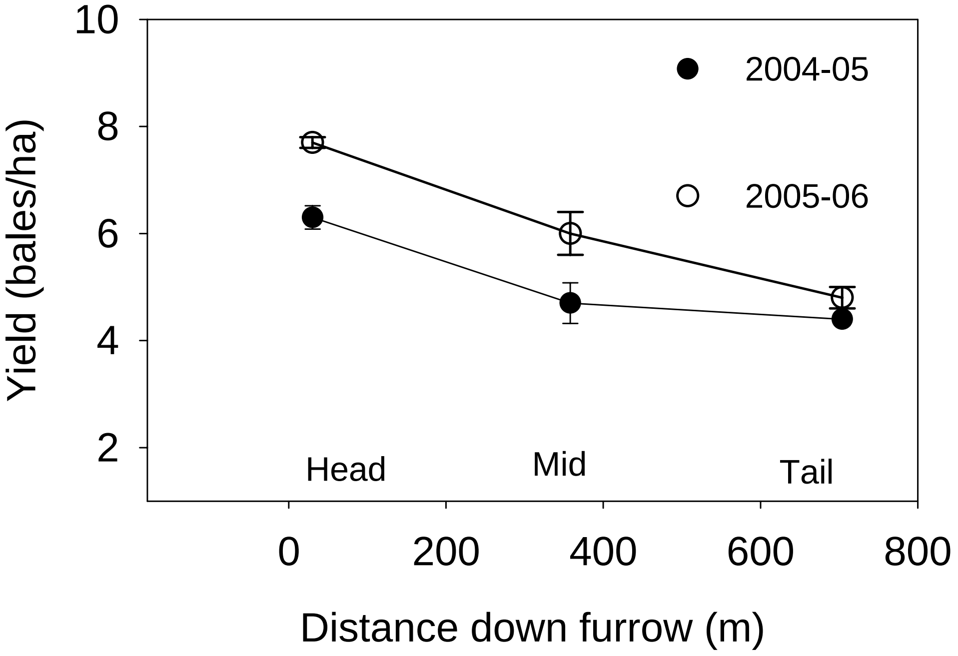

Figure 39 Yield of hand-picked cotton at each of the head, mid and tail lysimeter sites, for the Macalister site in the 2004-5 and 2005-06 seasons. The standard error (variability about the average value) is given as a small bar through the data points.

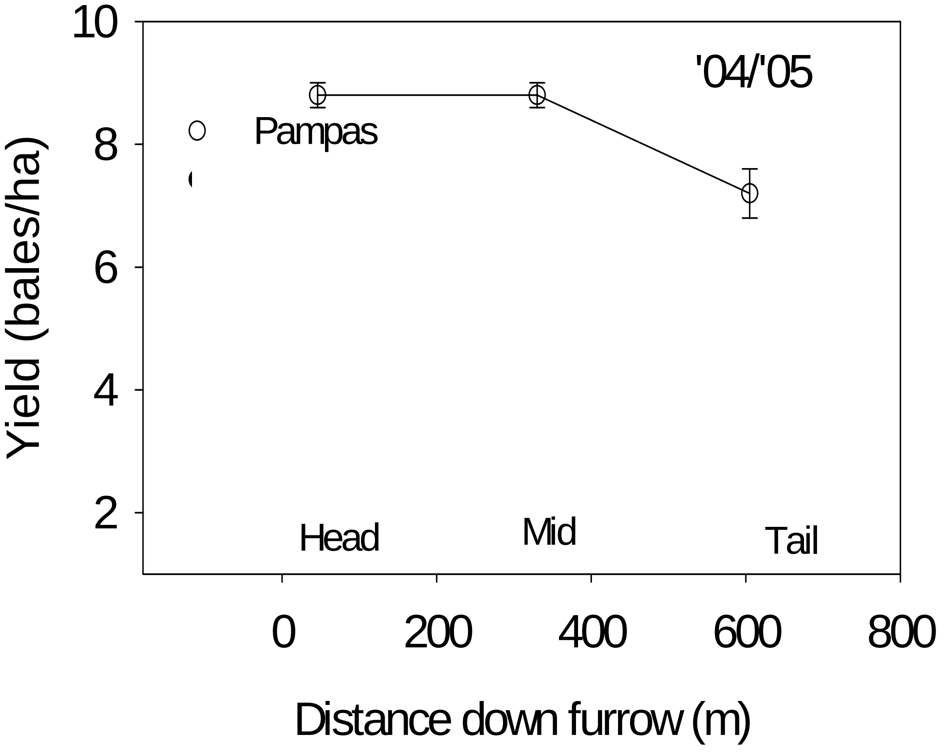

Figure 40 Yield of hand-picked cotton at each of the head, mid and tail lysimeter sites, for the Pampas site in the 2004-5 season. The standard error (variability about the average value) is given as a small bar through the data points.

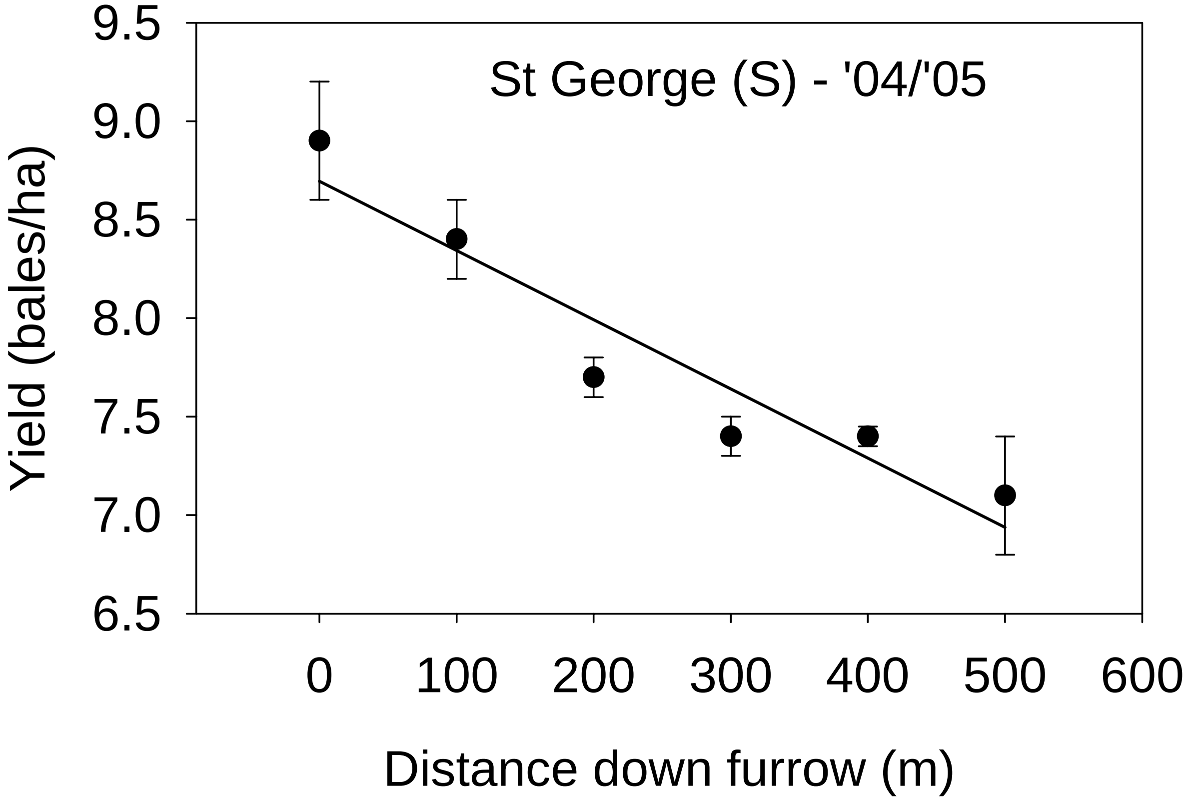

Figure 41 Lint yield (bales per ha) (data collected using yield monitors on cotton picker) from St George site during 2004-5 season. Vertical bar at each data point shows the standard deviations (±SD) of mean yield.

Table 1 Geographic location, latitude and longitude of head, mid and tail lysimeters, Australian Soil Classification (ASC) and Great Soil Group (GSG), furrow length and irrigating spacing of the ten experimental sites.

Site	Location	Latitude /Longitude of Head, Mid, Tail lysimeters	ASC * at site	GSG ** at site	Furrow length (m)	Field area (ha)	Irrigation spacing (m)
ACRI	Head Mid Tail	30° 11’53.7 S/149° 36’35.2 E 30° 11’53.0 S/149° 36’30.6 E 30° 11’52.6 S/149° 36’24.5 E	Self-mulching, black, Vertosol	Grey clay	195	8.2	1
Boggabilla (furrow)	Head Mid Tail	28° 42’11.1 S/150° 21’04.1 E 28° 42’09.3 S/150° 20’49.2 E 28° 42’07.1 S/150° 20’35.0 E	Epipedal, black, Vertosol	Grey clay	900	60	2
Boggabilla (lateral)	Head Mid Tail	28° 42’14.8 S/150° 21’04.0 E 28° 42’12.8 S/150° 20’48.5 E 28° 42’11.3 S/150° 20’34.4 E	Epipedal, black, Vertosol	Grey clay	900	85	n/a (spray)
Dalby	Head Mid Tail	27° 14’46.1 S/151° 09’06.4 E 27° 14’32.4 S/151° 09’07.7 E 27° 14’29.1 S/151° 09’09.2 E	Self-mulching, black, Vertosol	Grey clay	630	75	2
Dirranbandi	Head Mid Tail	28° 38’52.0 S/148° 03’34.0 E 28° 38’44.8 S/148° 03’23.0 E 28° 38’38.6 S/148° 03’13.9 E	Epipedal, grey, Vertosol	Grey clay	1290	200	2
Goondiwindi	Head Mid Tail	28° 36’14.6 S/149° 57’29.6 E 28° 36’12.6 S/149° 57’14.8 E 28° 36’10.6 S/149° 56’58.5 E	Epipedal, black, Vertosol	Grey clay	910	145	2
Macalister	Head Mid Tail	27° 01’12.1 S/151° 07’43.8 E 27° 01’17.4 S/151° 07’31.9 E 27° 01’22.0 S/151° 07’21.9 E	Haplic, self-mulching, grey, Vertosol	Grey clay	720	102	3
Pampas	Head Mid Tail	27° 41’43.6 S/151° 20’07.6 E 27° 41’36.3 S/151° 20’01.8 E 27° 41’29.0 S/151° 19’55.4 E	Haplic, self-mulching, black, Vertosol	Black earth	660	52.4	1
St George (N)	Head Mid Tail	27° 54’35.9 S/148° 37’37.5 E 27° 54’34.2 S/148° 37’40.7 E 27° 54’35.9 S/148° 37’32.3 E	Epipedal, brown, Vertosol	Brown clay	570	88	1
St George (S)	Head Mid Tail	28°09’45.9S/148° 41’25.5E 28°09’45.8S/148° 41’15.7E 28°09’47.9S/148° 41’09.1E	Epipedal, brown, Vertosol	Brown clay	532	95	1

* Australian soil classification (Isbell)
** Great Soil Group

Table 2.a Boggabilla (Lateral)

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	7.7	8.6	8.1	0.10	0.20	0.15	37	27	30
0.10-0.20	7.9	9.3	8.2	0.09	0.30	0.11	23	43	50
0.50-0.60	8.9	9.3	9.0	0.27	0.81	0.34	137	880	248
0.80-0.90	8.9	8.9	9.1	0.53	1.17	0.64	479	1510	710
1.20-1.30	8.6	*	8.5	0.60	*	0.81	700	*	1150
1.40-1.50	8.7	*	8.3	0.59	*	0.91	689	*	1290

	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC(meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	17.1	12.8	22.4	14.9	12.4	15.0	1.62	3.13	1.31	1.10	0.72	1.31	37	32	43
0.10-0.20	18.8	11.3	18.2	16.4	14.5	13.1	2.02	4.44	1.60	0.67	0.42	1.08	37	30	38
0.50-0.60	16.5	7.3	13.2	17.3	13.8	15.3	4.59	7.26	4.71	0.60	0.33	0.53	39	28	37
0.80-0.90	14.5	7.7	10.2	17.3	14.4	15.6	5.76	7.56	6.64	0.59	0.41	0.39	36	28	34
1.20-1.30	11.5	*	9.3	14.1	*	14.9	4.80	*	6.83	0.44	*	0.42	32	*	33
1.40-1.50	10.8	*	9.5	12.9	*	15.2	4.37	*	6.86	0.34	*	0.45	31	*	30

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	8	22	*	15	16	*	21	18	*	56	48	*
0.10-0.20	6	17	6	9	14	16	25	19	25	57	50	54
0.50-0.60	4	14	4	10	16	15	25	22	26	60	49	55
0.80-0.90	5	*	5	11	*	15	25	*	26	58	*	52
1.20-1.30	7	*	2	16	*	20	24	*	29	54	*	50
1.40-1.50	10	*	2	16	*	21	22	*	30	51	*	49

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	1.57	1.04	1.79				37.3	34.1	39.0	25.6	25.1	30.1
0.10-0.20	0.94	0.78	1.18				34.9	36.6	38.3	25.0	24.5	22.8
0.50-0.60	0.84	0.43	1.01				44.1	37.4	42.1	29.4	23.8	23.3
0.80-0.90	0.44	0.32	0.59				41.4	37.4	41.3	29.0	27.6	23.3
1.20-1.30	0.32	*	0.64				36.2	*	40.6	25.5	*	22.7
1.40-1.50	0.32	*	0.43				33.6	*	41.3	23.4	*	22.8

Table 2.a Boggabilla (Furrow)

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	8.0	8.6	7.9	0.09	0.18	0.08	15	94	41
0.10-0.20	8.0	8.9	8.3	0.12	0.21	0.09	10	68	35
0.50-0.60	9.3	9.2	8.9	0.37	0.43	0.24	143	269	111
0.80-0.90	9.3	8.8	8.9	0.59	0.54	0.37	532	552	292
1.20-1.30	8.9	8.3	8.9	0.75	0.73	0.70	873	930	635
1.40-1.50	8.5	8.2	8.5	0.88	0.77	0.75	1210	915	789

	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC(meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	16.3	21.0	19.0	11.8	13.5	13.4	1.18	1.84	0.84	0.77	0.68	1.42	31	41	37
0.10-0.20	15.6	19.8	20.8	11.0	13.9	16.3	0.82	3.02	1.88	0.99	1.63	1.13	30	34	38
0.50-0.60	12.6	14.2	15.8	15.8	16.7	18.3	5.63	6.69	4.51	0.26	0.46	0.67	34	38	42
0.80-0.90	9.41	12.4	12.0	15.4	15.8	18.2	7.23	7.15	5.87	0.29	0.46	0.65	34	40	42
1.20-1.30	7.85	13.0	11.3	14.0	15.9	17.2	6.64	7.32	5.85	0.50	0.61	0.52	27	38	38
1.40-1.50	7.56	12.6	11.8	13.4	15.4	18.3	6.23	7.04	6.20	0.36	0.54	0.65	28	37	35

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	16	*	11	17	*	11	20	*	21	46	*	57
0.10-0.20	17	10	7	15	8	10	20	25	25	46	58	59
0.50-0.60	16	8	*	18	8	*	20	26	*	50	57	*
0.80-0.90	12	5	2	16	7	7	20	30	26	50	58	65
1.20-1.30	12	*	4	26	*	8	23	*	24	43	*	61
1.40-1.50	13	5	3	18	8	8	25	30	23	43	57	63

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	1.24	1.52	1.96				29.8	35.6	39.3	19.9	22.1	24.3
0.10-0.20	1.17	1.06	1.11				28.4	35.8	37.5	18.2	22.1	23.3
0.50-0.60	0.80	0.67	0.77				39.3	43.3	43.8	22.4	24.3	31.4
0.80-0.90	0.60	0.46	0.84				42.9	43.1	48.7	23.2	24.9	32.4
1.20-1.30	0.36	0.33	0.43				37.8	38.9	39.5	20.6	25.0	27.8
1.40-1.50	0.35	0.33	0.38				36.8	34.0	39.7	20.1	21.2	28.2

Table 2.b Dalby

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	8.6	8.6	8.3	0.25	0.22	0.24	119	113	129
0.2-0.3	8.2	8.5	8.2	0.53	0.42	0.35	362	301	238
0.5-0.6	8.0	7.9	8.3	0.80	0.76	0.73	906	726	581
0.8-0.9	8.4	7.8	8.6	0.98	0.89	0.90	917	903	928
1.2-1.3	8.3	8.3	8.5	0.91	0.95	0.89	770	961	981
1.5-1.6	8.1	8.1	8.2	0.86	0.89	0.90	834	928	878
1.7-1.8	8.4	8.5	8.4	0.93	0.94	0.89	923	821	810

	Ca (meq/100g)			Mg (meq/100g)			Na meq/100g)			K (meq/100g)			CEC (meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	19.0	17.2	14.8	16.6	15.9	14.0	4.44	4.50	3.20	0.99	0.69	0.88	45	40	40
0.2-0.3	18.6	15.8	12.8	18.9	17.7	15.8	5.91	5.41	4.07	0.56	0.53	0.37	46	41	34
0.5-0.6	18.5	15.8	12.7	20.1	20.0	18.9	5.54	5.13	4.71	0.63	0.46	0.40	46	45	39
0.8-0.9	17.9	15.1	12.9	19.7	20.0	20.7	4.43	4.24	4.89	4.46	0.56	0.50	46	44	41
1.2-1.3	18.2	15.6	13.8	23.8	21.2	21.3	4.74	4.37	4.85	0.97	0.71	0.60	52	46	42
1.5-1.6	18.2	15.7	14.4	24.3	21.3	22.6	4.90	4.40	5.09	0.85	0.85	0.66	53	49	44
1.7-1.8	18.4	16.5	14.0	24.8	22.4	21.1	5.22	4.54	4.85	0.85	0.73	0.64	50	43	43

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	11	15	20	15	14	15	16	15	14	59	55	50
0.2-0.3	10	13	19	13	11	14	15	13	13	62	61	53
0.5-0.6	6	10	14	12	11	11	18	14	16	65	64	58
0.8-0.9	7	11	15	14	11	11	17	15	14	65	61	60
1.2-1.3	5	9	14	11	11	11	13	13	14	70	65	60
1.5-1.6	5	9	13	11	11	11	14	12	13	70	65	65
1.7-1.8	7	10	12	11	11	11	12	13	6	69	66	68

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	1.02	1.10	1.48	2.24	2.41	3.27	52	48	46	25	24	22
0.2-0.3	1.00	1.02	0.91	2.21	2.24	2.00	50	51	48	26	26	23
0.5-0.6	1.13	1.02	0.88	2.48	2.24	1.93	53	52	50	27	27	25
0.8-0.9	0.94	0.85	0.69	2.07	1.87	1.52	55	52	52	28	26	25
1.2-1.3	0.49	0.55	0.46	1.08	1.22	1.01	57	53	46	30	27	26
1.5-1.6	0.40	0.54	0.49	0.87	1.18	1.08	58	55	50	30	28	27
1.7-1.8	0.40	0.55	0.62	0.87	1.22	1.35	58	54	51	31	28	26

Table 2.c Dirranbandi

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	7.3	6.7	7.0	0.05	0.04	0.04	60	40	40
0.20-0.30	8.2	7.7	8.1	0.04	0.03	0.04	42	60	76
0.50-0.60	8.6	8.2	8.3	0.04	0.02	0.04	200	90	306
0.80-0.90	8.4	8.6	7.9	0.06	0.03	0.08	568	250	695
1.20-1.30	7.6	8.6	7.8	0.17	0.06	0.10	872	503	687
1.50-1.60	7.8	8.5	7.8	0.11	0.07	0.09	956	614	843
1.70-1.80	7.9	8.5	7.7	0.10	0.07	0.09	1170	673	906

	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC(meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	21.0	19.0	21.0	9.5	10.0	12.0	1.40	1.20	1.20	1.20	0.89	1.10	33	36	39
0.20-0.30	19.0	19.0	23.0	8.9	11.0	13.0	2.40	2.20	2.40	0.96	0.53	0.83	31	35	40
0.50-0.60	14.0	17.0	20.0	8.4	11.0	13.0	4.90	2.80	3.50	0.51	0.46	0.86	28	32	37
0.80-0.90	14.0	14.0	19.0	10.0	10.0	13.0	5.60	2.80	3.70	0.59	0.50	0.89	30	27	37
1.20-1.30	14.0	13.0	18.0	8.7	11.0	12.0	4.10	3.00	3.80	0.52	0.58	0.76	23	26	34
1.50-1.60	11.0	13.0	17.0	8.7	12.0	12.0	4.00	3.10	3.60	0.49	0.60	0.74	24	27	33
1.70-1.80	11.0	13.0	*	9.7	12.0	*	4.80	3.30	*	0.53	0.60	*	27	28	*

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	8	8	8	27	28	18	13	11	10	52	56	61
0.20-0.30	10	7	7	29	28	18	12	10	13	50	54	61
0.50-0.60	12	8	7	30	30	21	10	11	14	48	53	58
0.80-0.90	10	10	7	30	32	22	14	12	14	49	46	59
1.20-1.30	12	11	7	28	31	23	16	11	13	44	46	57
1.50-1.60	12	11	8	29	29	22	16	11	14	43	47	56
1.70-1.80	11	11	*	27	28	*	16	14	*	46	50	50

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	0.53	0.51	0.68							20	21	24
0.20-0.30	0.48	0.46	0.62							20	20	24
0.50-0.60	0.40	0.43	0.46							19	20	23
0.80-0.90	0.35	0.32	0.45							20	18	23
1.20-1.30	0.23	0.24	0.35							17	18	21
1.50-1.60	0.21	0.23	0.35							16	18	21
1.70-1.80	0.20	0.20	0.29							18	18	21

Table 2.d Goondiwindi

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	8.5	8.3	8.0	0.27	0.27	0.21	126	93	127
0.2-0.3	8.8	8.6	8.0	0.39	0.29	0.22	121	99	98
0.5-0.6	8.4	8.4	8.7	1.24	1.15	0.29	199	175	134
0.8-0.9	7.8	7.7	8.5	2.35	1.74	0.34	202	190	222
1.2-1.3	7.1	6.4	8.6	1.39	0.77	0.29	271	293	259
1.5-1.6	6.1	5.4	8.3	0.58	0.69	0.24	310	356	235
1.7-1.8	5.5	5.2	8.8	0.62	0.73	0.31	378	458	255

	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC(meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	19.6	18.5	19.6	11.3	9.5	9.3	2.41	1.58	1.05	2.01	0.60	0.73	34	31	34
0.2-0.3	16.6	17.2	19.1	12.6	11.8	10.6	4.28	3.56	1.85	0.80	0.40	0.41	34	33	35
0.5-0.6	15.0	15.8	15.4	11.6	11.1	10.6	5.47	5.29	2.81	0.46	0.41	0.37	32	32	31
0.8-0.9	14.8	12.8	12.8	13.1	11.3	9.7	5.69	5.82	2.84	0.96	0.51	0.41	30	29	28
1.2-1.3	11.2	9.6	11.3	10.9	9.1	7.7	5.60	5.76	2.45	0.75	0.48	0.53	30	28	23
1.5-1.6	9.5	9.2	10.0	8.8	7.9	6.8	4.93	5.14	2.15	0.42	0.50	0.58	29	37	19
1.7-1.8	9.7	9.5	10.5	8.6	8.5	7.3	5.24	5.34	2.33	0.43	0.51	0.51	28	28	20

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	16	12	16	12	15	17	15	15	14	56	57	52
0.2-0.3	16	9	15	12	14	15	16	15	13	58	60	55
0.5-0.6	16	9	16	11	14	16	14	16	13	58	62	53
0.8-0.9	15	7	17	14	18	19	14	16	13	58	60	49
1.2-1.3	13	7	19	13	18	20	15	15	11	57	59	47
1.5-1.6	15	6	22	14	19	22	14	17	12	56	56	41
1.7-1.8	12	5	20	14	20	19	17	17	12	57	57	46

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	1.05	1.05	1.11	2.31	2.31	2.45	32	35	33	19	19	19
0.2-0.3	0.97	0.99	0.87	2.14	2.18	1.91	35	40	34	21	21	19
0.5-0.6	0.71	0.73	0.73	1.57	1.60	1.60	31	34	35	19	21	19
0.8-0.9	0.65	0.54	0.65	1.43	1.20	1.43	30	33	33	19	20	18
1.2-1.3	0.62	0.54	0.51	1.37	1.20	1.13	33	37	32	19	21	17
1.5-1.6	0.54	0.59	0.50	1.20	1.30	1.10	34	36	27	20	21	14
1.7-1.8	0.56	0.58	0.51	1.23	1.26	1.13	35	36	29	21	21	15

Table 2.e Macalister

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	8.5	8.5	8.3	0.97	1.12	1.02	614	795	440
0.2-0.3	8.4	8.3	8.3	1.46	1.30	1.26	1561	1505	1289
0.5-0.6	8.2	8.4	8.4	1.83	1.47	1.35	2050	1625	1536
0.8-0.9	8.3	8.5	8.5	1.67	1.49	1.29	2128	1758	1256
1.2-1.3	8.5	8.6	8.7	1.55	1.53	1.27	1896	1904	1434
1.5-1.6	8.5	8.7	8.7	1.52	1.40	1.30	1663	1512	1198
1.7-1.8	8.5	8.7	8.7	1.51	1.40	1.38	1532	1398	1293

	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC (meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	34.4	34.7	37.5	20.7	21.1	19.8	14.0	12.3	10.6	1.61	1.89	1.72	72	69	78
0.2-0.3	31.4	26.4	35.8	21.6	28.6	21.6	13.3	12.8	14.3	1.25	1.25	0.78	72	76	79
0.5-0.6	26.3	28.5	27.3	27.4	27.6	26.3	13.4	11.8	10.3	1.01	1.26	1.03	69	76	78
0.8-0.9	18.0	29.0	25.6	31.9	28.7	33.3	13.6	11.7	13.5	1.05	1.27	1.46	72	78	77
1.2-1.3	16.5	14.4	19.0	35.8	34.1	31.7	16.0	14.1	15.0	1.57	1.13	1.68	74	78	76
1.4-1.5	16.1	12.1	18.0	34.4	36.1	31.4	17.2	15.7	15.7	1.79	1.47	1.68	68	69	72

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	3	2	3	11	9	9	14	13	13	73	73	72
0.2-0.3	2	3	3	8	9	9	12	11	12	78	76	76
0.5-0.6	1	3	2	7	8	9	14	11	11	77	76	75
0.8-0.9	2	2	3	7	8	9	14	9	10	77	79	76
1.2-1.3	2	1	3	7	7	8	11	9	13	79	80	76
1.5-1.6	2	2	2	6	7	7	12	10	11	78	79	79
1.7-1.8	2	2	2	7	6	7	12	10	11	79	79	78

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	1.42	1.59	1.54	3.12	3.49	3.39	61	63	62	43	41	39
0.2-0.3	1.17	1.24	1.10	2.58	2.72	2.41	68	64	64	41	40	40
0.5-0.6	1.16	1.00	1.07	2.55	2.21	2.35	64	66	64	41	40	42
0.8-0.9	1.19	1.07	1.07	2.62	2.35	2.35	67	65	75	42	42	42
1.2-1.3	1.04	1.10	0.91	2.28	2.41	2.01	66	70	79	42	45	41
1.5-1.6	0.85	0.73	0.81	1.87	1.60	1.77	67	70	77	43	43	44
1.7-1.8	0.74	0.64	0.73	1.63	1.40	1.60	67	68	75	42	42	43

Table 2.f Pampas

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	8.2	7.4	7.6	0.12	0.10	0.10	39	59	46
0.2-0.3	8.7	8.3	8.2	0.15	0.12	0.10	63	47	44
0.5-0.6	8.9	8.5	8.6	0.30	0.23	0.18	160	130	61
0.8-0.9	8.8	8.7	8.8	0.38	0.25	0.22	310	172	92
1.2-1.3	8.6	8.6	8.8	0.43	0.24	0.28	462	188	145
1.5-1.6	8.6	8.6	8.7	0.45	0.24	0.28	475	200	199
1.7-1.8	8.3	8.5	8.5	0.44	0.24	0.29	482	234	246

	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC (meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	34.2	32.1	31.0	25.0	23.1	23.0	1.91	1.20	1.56	1.14	1.51	1.48	63	65	65
0.2-0.3	30.3	32.8	32.5	24.5	25.1	25.3	3.16	2.42	2.65	0.77	0.96	1.15	64	65	73
0.5-0.6	29.6	29.2	29.7	29.8	24.8	28.5	5.23	3.65	4.43	0.96	0.81	0.85	69	66	69
0.8-0.9	25.3	27.8	28.5	29.0	26.1	29.0	5.53	4.40	5.17	1.01	1.04	1.11	65	62	69
1.2-1.3	24.2	25.8	26.0	26.8	24.3	27.9	5.20	4.25	5.34	0.93	0.81	0.99	53	58	64
1.5-1.6	23.5	25.4	26.5	25.3	22.6	27.2	4.77	4.02	5.44	0.68	0.60	0.84	53	52	65
1.7-1.8	23.1	27.9	24.6	24.5	25.9	26.0	4.49	4.26	5.16	0.64	0.66	0.79	50	59	54

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	2	2	2	3	3	2	19	19	17	74	74	77
0.2-0.3	2	2	1	3	4	2	19	16	15	74	74	80
0.5-0.6	1	1	1	3	3	2	19	18	14	73	77	81
0.8-0.9	1	1	1	5	3	2	21	18	15	73	77	80
1.2-1.3	1	1	1	4	10	2	26	28	21	67	61	75
1.5-1.6	1	1	1	13	11	3	34	35	24	51	51	68
1.7-1.8	1	1	<1	17	9	3	32	22	27	51	65	65

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.0-0.1	1.19	1.24	1.22	2.62	2.72	2.69	64.1	65.1	na	34	35	35
0.2-0.3	1.10	1.11	1.11	2.41	2.45	2.45	65.7	67.0		35	36	37
0.5-0.6	0.94	1.05	1.05	2.07	2.31	2.31	67.4	66.6		36	36	37
0.8-0.9	0.80	0.97	0.94	1.76	2.14	2.07	66.5	66.8		35	35	37
1.2-1.3	0.52	0.63	0.66	1.15	1.39	1.45	58.7	57.0		32	31	35
1.5-1.6	0.44	0.51	0.54	0.977	1.11	1.18	51.0	51.4		28	29	34
1.7-1.8	0.48	0.51	0.52	1.04	1.11	1.15	51.0	73.3		28	32	33

Table 2.g St George (North)

	pH			EC (dS/m)			Cl (mg/kg)								
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail						
0.00-0.10	8.4	8.7	8.4	0.23	0.18	0.21	56	32	46						
0.20-0.30	8.8	9.2	8.5	0.37	0.37	0.39	38	53	86						
0.50-0.60	7.6	8.8	8.0	2.80	0.96	0.94	143	287	407						
0.80-0.90	7.0	7.7	7.6	3.20	2.80	2.14	317	630	727						
1.20-1.30	4.7	6.8	7.0	2.62	1.77	2.49	570	1210	969						
1.50-1.60	4.7	6.0	6.5	1.06	2.33	1.89	904	1732	1341						
1.70-1.80	4.6	5.4	6.1	1.10	3.07	1.77	979	1748	1749						
	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC(meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	20.8	19.6	24.0	5.5	6.9	5.4	0.61	1.08	0.57	1.36	1.98	1.65	29	32	33
0.20-0.30	18.7	14.4	21.3	7.8	10.7	6.2	2.63	4.69	2.04	0.67	1.14	1.32	30	31	34
0.50-0.60	16.9	12.0	20.3	8.5	10.1	6.9	5.84	8.28	3.94	0.57	1.18	1.11	29	32	33
0.80-0.90	12.4	10.8	17.5	8.3	10.4	8.0	7.94	<0.09	5.65	0.57	1.26	1.16	29	31	31
1.20-1.30	10.3	8.7	14.0	6.7	9.6	8.6	7.50	<0.09	6.72	0.59	1.06	1.10	29	30	31
1.50-1.60	9.6	9.0	12.2	5.8	9.5	8.2	6.81	<0.09	7.30	1.98	1.03	1.10	30	31	32
1.70-1.80	9.0	7.6	11.2	5.8	8.0	7.8	6.48	8.66	7.30	0.42	0.83	1.02	31	29	32
	Coarse (%)			Fine (%)			Silt (%)			Clay (%)					
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail			
0.00-0.10	4	5	5	33	24	28	16	13	14	47	56	53			
0.20-0.30	5	5	4	33	21	23	16	15	12	47	60	60			
0.50-0.60	5	3	4	32	19	24	14	15	12	50	61	61			
0.80-0.90	4	4	3	31	20	23	13	14	13	52	61	61			
1.20-1.30	3	3	3	29	25	23	14	15	12	53	58	62			
1.50-1.60	2	3	2	29	24	23	14	13	12	54	61	63			
1.70-1.80	2	3	2	32	21	23	14	13	13	53	61	62			
	OC (%)			OM (%)			FC (%)			PWP (%)					
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail			
0.00-0.10	0.93	0.81	0.80	2.04	1.77	1.76	29	42	40	18	21	20			
0.20-0.30	0.74	0.68	0.80	1.63	1.50	1.76	32	46	44	20	24	22			
0.50-0.60	0.61	0.68	0.57	1.33	1.50	1.25	31	52	45	20	25	23			
0.80-0.90	0.54	0.54	0.52	1.20	1.20	1.15	31	45	47	21	24	24			
1.20-1.30	0.54	0.48	0.40	1.20	1.04	0.87	33	50	46	21	25	24			
1.50-1.60	0.59	0.38	0.41	1.30	0.84	0.91	44	47	48	22	24	24			
1.70-1.80	0.61	0.40	0.40	1.33	0.87	0.87	42	45	52	22	24	25			

Table 2.h St George (South)

	pH			EC (dS/m)			Cl (mg/kg)		
Depth (m)	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	8.6	8.3	8.4	0.28	0.37	0.20	119	80	56
0.20-0.30	8.7	8.5	8.5	0.30	0.34	0.25	131	96	72
0.50-0.60	9.1	8.7	8.9	0.52	0.63	0.41	272	69	103
0.80-0.90	8.0	8.1	8.2	2.87	2.62	1.90	391	101	124
1.20-1.30	7.4	8.0	7.9	2.94	1.96	2.66	600	212	296
1.50-1.60	5.6	6.6	8.1	0.86	0.48	1.71	676	202	397
1.70-1.80	5.3	5.7	8.7	0.85	0.51	0.72	726	255	316

	Ca (meq/100g)			Mg (meq/100g)			Na (meq/100g)			K (meq/100g)			CEC(meq/100g)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	21.6	21.3	21.0	6.4	5.4	6.2	1.05	0.42	0.64	0.90	0.83	0.86	30	29	30
0.20-0.30	19.2	20.0	20.3	7.9	5.9	7.0	2.11	0.72	1.24	0.43	0.47	0.52	29	29	31
0.50-0.60	16.2	16.0	18.0	9.3	7.8	9.5	5.81	2.44	3.71	0.36	0.26	0.39	32	26	31
0.80-0.90	14.5	13.8	14.2	9.4	7.4	8.6	5.98	3.45	4.08	0.44	0.30	0.38	31	24	28
1.20-1.30	14.1	12.8	12.4	9.8	8.3	8.4	6.22	4.29	4.39	0.64	0.48	0.51	29	24	25
1.50-1.60	10.7	9.9	11.1	7.2	7.4	7.4	5.43	4.81	3.60	0.45	0.32	0.50	29	24	23
1.70-1.80	9.9	9.1	9.8	6.3	6.8	6.7	4.87	4.89	3.14	1.29	0.30	0.49	28	25	20

	Coarse (%)			Fine (%)			Silt (%)			Clay (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	17	20	19	31	31	26	12	12	11	40	37	43
0.20-0.30	18	24	19	31	27	25	11	11	11	41	36	45
0.50-0.60	16	24	20	30	26	23	12	12	10	42	39	46
0.80-0.90	17	23	21	28	26	24	12	12	10	43	39	43
1.20-1.30	13	22	21	28	28	27	13	11	10	46	40	41
1.50-1.60	13	22	20	30	29	28	13	12	10	45	39	40
1.70-1.80	13	18	24	30	30	32	12	12	10	45	40	32

	OC (%)			OM (%)			FC (%)			PWP (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.00-0.10	0.93	1.11	0.97	2.04	2.45	2.14	32	33	36	17	15	16
0.20-0.30	0.81	0.88	0.77	1.77	1.94	1.70	33	31	36	18	14	17
0.50-0.60	0.70	0.68	0.65	1.53	1.50	1.43	37	29	35	20	14	18
0.80-0.90	0.53	0.59	0.51	1.16	1.30	1.13	33	29	33	19	15	16
1.20-1.30	0.45	0.48	0.39	0.99	1.06	0.86	34	31	31	19	17	16
1.50-1.60	0.42	0.44	0.44	0.93	0.96	0.96	37	33	29	20	18	15
1.70-1.80	0.42	0.48	0.51	0.93	1.06	1.13	35	35	27	19	19	13

Table 3 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 (the irrigated depth).

Site	Crop	Irrigated depth (mm)	Season	DD Head		DD Mid		DD Tail	
				Vol.	*LF*	**Vol.**	*LF*	**Vol.**	*LF*
ACRI[1]	Fallow*	*(824)*	05/06	**200**	*24*	**96**	*12*	**61**	*7*
	Cotton	800	06/07	**310**	*39*	**112**	*14*	**65**	*8*
	Fallow	-	07/08	**0**	-	**0**	-	**0**	-
Boggabilla									
(a) furrow	Cotton	628	05/06	**105**	*17*	**87**	*14*	**92**	*15*
	Fallow	-	06/07	**0**	-	**0**	-	**0**	-
	Cotton	450	07/08	**19**	*4*	**40**	*9*	**1**	*0*
(b) lateral move	Cotton	270	05/06	**31**	*11*	**0**	*0*	**0**	*0*
	Cotton	230	06/07	**0**	*0*	**0**	*0*	**0**	*0*
	Cotton	150	07/08	**0**	*0*	**0**	*0*	**0**	*0*
Dalby	Cotton	465	04/05	**39**	*8*	**95**	*20*	**34**	*7*
	Soybean	400	05/06	**0**	-	**0**	-	**0**	-
	Sorghum***	100+rainfed	06/07	**0**	-	**17**	**	**0**	-
	Cotton****	100+rainfed	07/08	**0**	-	**0**	-	**0**	-
Dirranbandi	Cotton	926	03/04	**11**	*1*	**21**	*2*	**176**	*19*
	Cotton	600	05/06	**0**	-	**1**	*0*	**6**	*1*
	Fallow	-	06/07	**0**	-	**0**	-	**0**	-
	Fallow	-	07/08	**0**	-	**0**	-	**0**	-
Goondiwindi	Maize	**	02/03	**187**	**	**196**	**	**24**	**
	Sorghum	462	03/04	**235**	*51*	**101**	*22*	**21**	*5*
	Cotton	563	04/05	**104**	*18*	**23**	*4*	**19**	*3*
	Sunflower	420	05/06	**0**	-	**1**	*0*	**11**	*3*
	Fallow	-	06/07	**0**	-	**0**	-	**0**	-
	Fallow	-	07/08	**0**	-	**0**	-	**0**	-
Macalister	Maize	**	02/03	**175**	**	**nf***	-	**51**	**
	Sorghum	720	03/04	**5**	*0*	**nf***	-	**33**	*6*
	Cotton	335	04/05	**41**	*12*	**101**	*30*	**0**	-
	Cotton	540	05/06	**12**	*2*	**10**	*2*	**0**	-
	Cotton	420	06/07	**31**	*7*	**26**	*6*	**0**	-
	Fallow	*(542)**	07/08	**31**	*6*	**26**	*5*	**0**	-
Pampas	Cotton	963	04/05	**71**	*7*	**106**	*11*	**62**	*6*
	Sorghum	rainfed	05/06	**0**	-	**0**	-	**0**	-
	Fallow	-	06/07	**0**	-	**0**	-	**0**	-
	Sorghum	rainfed	07/08	**0**	-	**0**	-	**0**	-
St George (S)	Cotton	**	02/03	**14**	**	**68**	**	**37**	**
	Cotton	800	03/04	**104**	*13*	**91**	*12*	**18**	*2*

	Cotton	734	04/05	**40**	*5*	**92**	*12*	**50**	*7*
	Field pea	493	05/06	**5**	*1*	**37**	*7*	**33**	*7*
	Cotton	700	06/07	**0**	**	**33**	**	**0**	**
	Fallow	*(532)**	07/08	**14**	*3*	**1**	*0*	**13**	*2*
St George	Wheat	**	2004	**24**	**	**55**	**	**1.6**	**
(N)	Cotton	693	05/06	**27**	*4*	**22**	*3*	**0**	*0*

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

Notes:
#1 lysimeters were installed at different sites in different years.
#2 ACRI [1] The ACRI DD data are given here for completeness but the full presentation of these data with analysis is presented in Appendix 4

Table 4 Planting, harvest and fallow period dates during the course of the DD experiment at the Dalby site.

Planting date	Harvest date	Crop	In crop rainfall (mm)	Irrigation water applied ML/ha (no. of irrigations)
13/10/ 04	26/4/05	Cotton	248	4.6 (5)
09/12/05	28/2/06	Soybean	324	4.0 (4)
18/10/06	20/2/07	Sorghum	163	1.0 (1)

Table 5 Planting, harvest and fallow period dates during the course of the DD experiment at the Dirranbandi site

Planting date	Harvest date	Crop	In crop /fallow rainfall (mm)	Irrigation water applied ML/ha (no. of irrigations)
15/10/ 03	10/4/04	Cotton	461	9.5 (9)
12/6/04	30/10/04	Wheat	107	2.8 (3)
-	-	Fallow	238	-
10/10/ 05	23/3/06	Cotton	209	9 (11)
-	-	Fallow	110 (to 15/1/07)	-

Table 6 Planting, harvest and fallow period dates during the course of the DD experiment at the Goondiwindi site.

Planting date	Harvest date	Crop	In crop /fallow rainfall (mm)	Irrigation water applied ML/ha (no. of irrigations)
10/02	2/03	Maize	240*	
21/10/03	16/02/04	Sorghum	379	4.6 (4)
10/10/04	25/04/05	Cotton	321	5.6 (6)
14/09/05	10/01/06	Sunflower	256	4.2 (4)
2006	2007	Fallow	382	0 (no irrigation)
2007	2008	Fallow	187	0 (no irrigation)

* An estimate – derived from SILO for the period 1/10/02 to 28/2/03; Goondiwindi Post Office data.

Table 7 Planting, harvest and fallow period dates during the course of the DD experiment at the Macalister site.

Cropping season	Crop	In crop rainfall (mm)*	Irrigation water applied ML/ha (no. of irrigations)
2002/2003	Maize	289**	na
2003/2004	Sorghum	295	na
2004/2005	Cotton	305	3.4 (4)
2005/2006	Cotton	108	5.4 (4)
2006/2007	Cotton	68	4.2
2007/2008	Barley^	322***	0

* Note: the long term rainfall average for Dalby (PO), from October- March is 449 mm
** data from SILO for the Macalister PO weather station (BOM no. 041065); 1st October 2002 to 31 March 2003
*** data from SILO for the Macalister PO weather station (BOM no. 041065); 1st October 2007 to 25 March 2008
^ Barley planted 4/7/07 harvested 1/12/2007

Table 8 Planting, harvest and fallow period dates during the course of the DD experiment at the Pampas site.

Planting date	Harvest date	Crop	In crop / fallow rainfall (mm)	Irrigation water applied ML/ha (no. of irrigations)
15/10/ 04	5/5/05	Cotton	483	9.5 (6)
15/10/05	15/4/06	Sorghum	405	
15/10/06	15/3/07	Fallow	209	-

Table 9 Planting, harvest and fallow period dates during the course of the DD experiment; St George (S) site.

Planting date	Harvest date	Crop	In crop /fallow rainfall (mm)	Irrigation water applied ML/ha (no. of irrigations)
15/9/02	2/3/03	Cotton		na
29/9/03	23/3/04	Cotton	374	800 (7)
5/10/04	26/4/05	Cotton	376	734 (7)
11/9/05	28/2/06	Pea	323	493 (4)
17/10/06	29/4/07	Cotton	219	700 (6)
2007	2008	Fallow	532	

Table 10 Macalister irrigation bore water analysis report

Component	Units	Bore at mid	Bore at head
EC_w	dS/m	3.8	4.5
SAR	meq/L	14.9	16.2
Calcium	mg/L *	52.6	56.2
Magnesium	mg/L	64.8	71.7
Sodium	mg/L	683	775
Potassium	mg/L	4	5
Chloride	mg/L	998	1220

* mg/L is equivalent to ppm

Table 11 Dalby - Deep drainage estimated from the water balance model (R, rainfall; I, amount of irrigation water that infiltrated the soil profile; ET, crop evapotranspiration; DD, deep-drainage; LF, leaching fraction) for the 2004-5 cotton season.

	R (mm)	I (mm)	ET (mm)	DD (mm)	LF (%)
Head	248	503	1180	**0**	**0**
Mid	248	479	1180	**0**	**0**
Tail	248	394	1180	**0**	**0**

Table 12 Goondiwindi - Deep drainage estimated from the water balance model (R, rainfall; I, amount of irrigation water that infiltrated the soil profile; ET, crop evapotranspiration; DD, deep-drainage; LF, leaching fraction) for the 2003-4 sorghum and 2004-5 cotton seasons.

		R (mm)	I (mm)	ET (mm)	DD (mm)	LF (%)
2003-4	Head	379	534	843	**70**	**13**
	Mid	379	479	843	**15**	**3**
	Tail	379	289	843	**0**	**0**
2004-5	Head	390	643	1340	**0**	**0**
	Mid	390	592	1340	**0**	**0**
	Tail	390	365	1340	**0**	**0**

Table 13 Macalister- Deep drainage estimated from the water balance model (R, rainfall; I, amount of irrigation water that infiltrated the soil profile; ET, crop evapotranspiration; DD, deep-drainage; LF, leaching fraction) for the 2004-5 cotton season.

	R (mm)	I (mm)	ET (mm)	DD (mm)	LF (%)
Head	305	425	1402	**0**	**0**
Mid	305	368	1402	**0**	**0**
Tail	305	150	1402	**0**	**0**

Table 14 St George (S) -Deep drainage estimated from the water balance model (R, rainfall; I, amount of irrigation water that infiltrated the soil profile; ET, crop evapotranspiration; DD, deep-drainage; LF, leaching fraction) for the 2003-4 and 2004-5 cotton seasons.

		R (mm)	I (mm)	ET (mm)	DD (mm)	LF (%)
2003-4	Head	386	873	1255	**203**	**19**
	Mid	386	790	1255	**50**	**5**
	Tail	386	558	1255	**0**	**0**
2004-5	Head	379	534	843	**70**	**13**
	Mid	379	479	843	**15**	**3**
	Tail	379	289	843	**0**	**0**

Table 15 Boggabilla - Deep drainage estimated from the model SaLF :

Input parameters:

Soil physico-chemical parameters									
Depth (m)	**Clay (%)**			**CEC (meq/100g)**			**ADMC (%)**		
	Head	**Mid**	**Tail**	**Head**	**Mid**	**Tail**	**Head**	**Mid**	**Tail**
0.1	46	*	57	31	41	37	7.3	8.9	8.7
0.3	46	58	59	30	34	38	7.4	9.1	9.3
0.6	50	57	*	34	38	42	8.1	8.9	9.7
0.9	50	58	65	34	40	42	8.4	9.4	9.9
Exchangeable sodium (ESP – Na as a % of the total exchangeable cations) at 0.9m depth; 21.3, 17.9 and 14.0 for H, M & T respectively; EC in irrigation water = 0.7 dS/m									

Irrigation and in-season rainfall (mm)		
Crop/season	irrigation (I)	in-season rainfall (RF)
Cotton/ 2005-6	628	330
Fallow/ 2006-7	0	217
Cotton/ 2007-8	450	350

Output						
	Deep drainage (mm)			***Leaching fraction (% of I + RF)***		
Crop/season	**Head**	**Mid**	**Tail**	***Head***	***Mid***	***Tail***
Cotton/ ’05 – ‘06	9	16	14	*1*	*2*	*1*
Fallow/ ’06 – ‘07	0	0	0	-	-	-
Cotton/ ’07 – ‘08	6	10	9	*1*	*1*	*1*
Note: 100mm = 1 ML						

Table 16 Dalby - Deep drainage estimated from the model SaLF

Input parameters:

Soil physico-chemical parameters									
Depth (m)	**Clay (%)**			**CEC (meq/100g)**			**ADMC (%)**		
	Head	**Mid**	**Tail**	**Head**	**Mid**	**Tail**	**Head**	**Mid**	**Tail**
0.1	59	55	50	45	40	40	6.4	6.4	5.0
0.3	62	61	53	46	41	34	6.6	6.5	5.8
0.6	65	64	58	46	45	39	7.3	7.0	6.8
0.9	65	61	60	46	44	41	7.6	7.1	6.3
Exchangeable sodium (meq/100g) at 0.9m depth; 0.10; 0.10 & 0.12 for H, M & T respectively									

Irrigation water applied and in-season rainfall (mm)		
Crop / season	Irrigation (I)	In-season rainfall (RF)
Cotton/ ‘04-‘05	460	248
Soybean / ‘05/’06	400	324
Sorghum / ‘06/’07	100	163

Output						
	Deep drainage (mm)			***Leaching fraction (% of I + RF)***		
Crop / season	**Head**	**Mid**	**Tail**	***Head***	***Mid***	***Tail***
Cotton/ ‘04-‘05	169	175	522	*24*	*25*	*74*
Soybean / ‘05/’06	162	168	490	*22*	*23*	*68*
Sorghum / ‘06/’07	19	18	136	*7*	*7*	*52*
Note: 100mm = 1 ML						

Table 17 Dirranbandi - Deep-drainage estimated from SaLF

Input parameters

Soil physio-chemical parameters									
Depth (m)	Clay (%)			CEC (meq/100g)			ADMC (%)		
	Head	Mid	Tail	Head	Mid	Tail	Head	Mid	Tail
0.1	52	56	61	33	36	39	3.8	4.2	4.9
0.3	50	54	61	31	35	40	3.8	4.1	5.0
0.6	48	53	58	28	32	37	3.3	4.0	4.7
0.9	49	46	59	30	27	37	3.7	4.6	4.3
Exchangeable sodium (ESP) at 0.9m depth; 19; 10 & 10 for H, M & T respectively; EC of irrigation water = 0.18 dS/m									

Irrigation and effective rainfall (mm)		
Crop/season	Irrigation	RF
Cotton/ '03-'04	950	460
Wheat/ '04	280	107
Cotton/ '05-'06	900	209

Output

	Deep-drainage (mm)			**Leaching fraction (%)**		
Crop/season	**Head**	**Mid**	**Tail**	**Head**	**Mid**	**Tail**
Cotton/ '03-'04	9	14	17	1	1	1
Wheat/ '04	1	2	1	0	0	0
Cotton/ '05-'06	6	10	12	1	1	1
Note: 100mm = 1 Meg						

Table 18 Goondiwindi-Deep drainage estimated from the model SaLF

Input parameters:

Soil physico-chemical parameters									
Depth (m)	**Clay (%)**			**CEC (meq/100g)**			**ADMC (%)**		
	Head	**Mid**	**Tail**	**Head**	**Mid**	**Tail**	**Head**	**Mid**	**Tail**
0.1	56	57	52	34	31	34	4.7	5.3	5.0
0.3	58	60	55	34	33	35	4.9	5.3	5.0
0.6	58	62	53	30	29	28	4.5	5.1	4.8
0.9	58	60	49	30	28	23	4.3	5.2	5.0
Exchangeable sodium (ESP – Na as a % of the total exchangeable cations) at 0.9m depth; 10.1; 20.1 & 19.0 for H, M & T respectively; EC in irrigation water = 0.5 dS/m									

Irrigation and in-season rainfall (mm)		
Crop/season	Irrigation (I)	RF
Sorghum/ '03-'04	460	379
Cotton/ '04-'05	560	321
Sunflower/ '05-06	420	256

Output

	Deep drainage (mm)	***Leaching fraction (% of I + RF)***

Crop/season	**Head**	**Mid**	**Tail**	***Head***	***Mid***	***Tail***
Sorghum/ ‘03-‘04	8	3	4	*1*	*0*	*0*
Cotton/ ‘04-‘05	9	4	5	*1*	*0*	*1*
Sunflower/‘05-‘06	5	2	3	*1*	*0*	*0*
Note: 100mm = 1 ML						

Table 19 Macalister - Deep drainage estimated from the model SaLF
Input parameters:

Soil physico-chemical parameters									
Depth (m)	**Clay (%)**			**CEC (meq/100g)**			**ADMC (%)**		
	Head	**Mid**	**Tail**	**Head**	**Mid**	**Tail**	**Head**	**Mid**	**Tail**
0.1	73	73	72	72	69	78	8.3	7.5	8.7
0.3	78	76	76	72	76	79	8.0	7.5	8.5
0.6	77	76	75	69	76	78	8.3	7.9	8.8
0.9	77	79	76	72	78	77	8.4	8.0	8.3
Exchangeable sodium (ESP – Na as a % of the total exchangeable cations) at 0.9m depth; 18.9, 15.03 and 18.19 for H, M & T respectively; EC in irrigation water = 4.15 dS/m									

Irrigation and in-season rainfall (mm)		
Crop/season	irrigation (I)	in-season rainfall (RF)
Cotton 2004-5	340	305
Cotton/ 2005-6	270	108
Cotton/ 2006-7	420	68
Barley/ 2007-8	0	322

Output

	Deep drainage (mm)			***Leaching fraction (% of I + RF)***		
Crop/season	**Head**	**Mid**	**Tail**	***Head***	***Mid***	***Tail***
Cotton ’04 – ‘05	92	118	100	*14*	*17*	*15*
Cotton/ ’05 – ‘06	38	48	41	*10*	*13*	*11*
Cotton/ ’06 – ‘07	65	83	71	*13*	*17*	*15*
Barley/ ’07 – ‘08	1.5	1.9	1.6	*0*	*0*	*0*
Note: 100mm = 1 ML						

Table 20 Pampas - Deep drainage estimated from the model SaLF

Input parameters:

Soil physico-chemical parameters									
Depth (m)	**Clay (%)**			**CEC (meq/100g)**			**ADMC (%)**		
	Head	**Mid**	**Tail**	**Head**	**Mid**	**Tail**	**Head**	**Mid**	**Tail**
0.1	74	74	77	63	65	65	9.2	9.3	9.1
0.3	74	74	80	64	65	73	10.3	9.1	9.7
0.6	73	77	81	69	66	69	9.5	9.6	9.7
0.9	73	77	80	65	62	69	9.2	8.9	9.3
Exchangeable sodium percentage at 0.9m depth; 8.5; 7.1 & 7.5 for H, M & T respectively; Irrigation water EC = 0.31 dS/m									

Irrigation and in-season rainfall (mm)		
Crop/season	Irrigation (I)	RF
Cotton/ ‘04-‘05	950	483

Output						
	Deep drainage (mm)			***Leaching fraction (% of I + RF)***		
Crop/season	**Head**	**Mid**	**Tail**	***Head***	***Mid***	***Tail***
Cotton/ ‘04-‘05	91	72	185	*6*	*5*	*13*
Note: 100mm = 1 ML						

Table 21. St George (S) -Deep drainage estimated from the model SaLF

Input parameters:

Soil physico-chemical parameters									
Depth (m)	**Clay (%)**			**CEC (meq/100g)**			**ADMC (%)**		
	Head	**Mid**	**Tail**	**Head**	**Mid**	**Tail**	**Head**	**Mid**	**Tail**
0.1	40	37	43	30	29	30	4.6	4.1	4.2
0.3	41	36	45	29	29	31	4.6	3.9	4.4
0.6	42	39	46	32	26	31	4.6	3.7	4.4
0.9	43	39	43	31	24	28	4.8	3.7	4.2
Exchangeable sodium (ESP – Na as a % of the total exchangeable cations) at 0.9m depth; 14.6; 14.4 & 19.3 for H, M & T respectively; EC in irrigation water = 0.14 dS/m									

Irrigation and in-season rainfall (mm)		
Crop/season	Irrigation (I)	RF
Cotton/ ‘03-‘04	800	374
Cotton/ ‘04-‘05	734	376
Field pea/ ’05-06	493	323
Cotton/ ’06-07	700	219

Output						
	Deep drainage (mm)			***Leaching fraction (% of I + RF)***		
Crop/season	**Head**	**Mid**	**Tail**	***Head***	***Mid***	***Tail***
Cotton/ ‘03-‘04	7	5	4	*1*	*0*	*0*
Cotton/ ‘04-‘05	6	4	4	*1*	*0*	*0*
Field pea/ ’05-06	3	2	2	*0*	*0*	*0*

Cotton/‘06-‘07	4	3	3	*0*	*0*	*0*
Note: 100mm = 1 ML						

Appendix 1

Field photographs and cross-sectional diagram of drainage lysimeter installation: hole excavation, lysimeter plumbing, equipment building and field-layout.

Fig. 1 The proline barrel used to extract intact soil cores of 30 cm diameter (in 2 pieces, encased in plastic “liners”) to 150 cm depth. The deeper of the two cores is split in the middle; the lower part becoming the lysimeter.

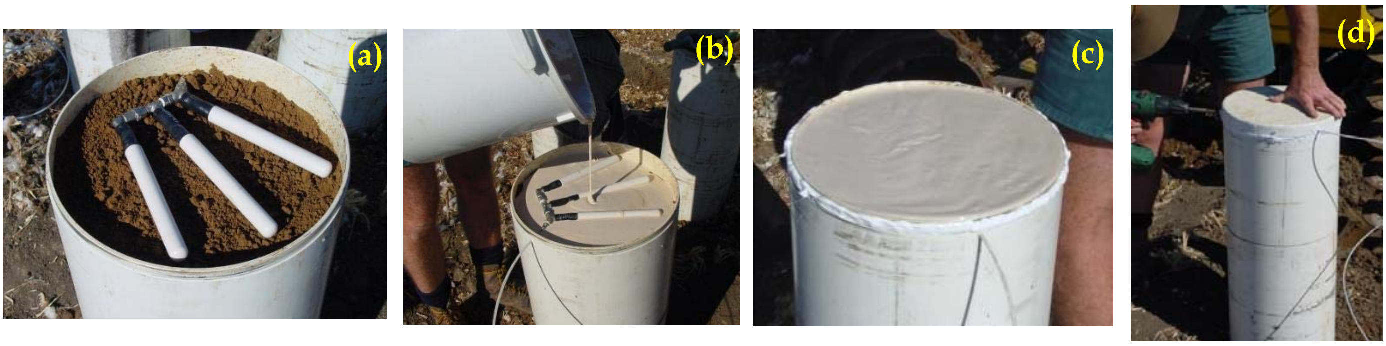

Fig. 2 Working on the base of the lower core (ie at 150 cm depth), 50 mm of soil is excavated and (a) three ceramic “candles” (plumbed together and connected through the plastic side wall with 5 mm (o.d.) plastic tubing) are placed on this surface. The candles are then (b) and (c) immersed in a mix of silica flour and water (to give good contact), and the whole lysimeter apparatus (d) sealed with a plastic cap (siliconed and screwed in place) to give an air-tight seal.

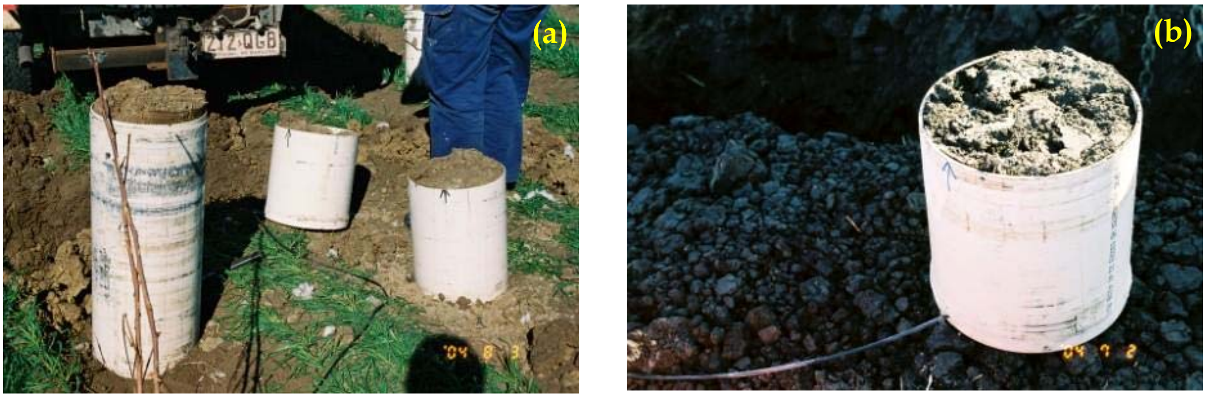

Fig. 3 (a) The three parts of the extracted soil cores. The longer core contains the 0 – 75 cm layer, the two smaller cores contain the 75-105 (right) and the 105-150 cm (center) layer; that becomes the lysimeter. (b) The lysimeter, after plumbing the ceramic candles, silica flour and sealing the base, ready to be lowered back down the hole

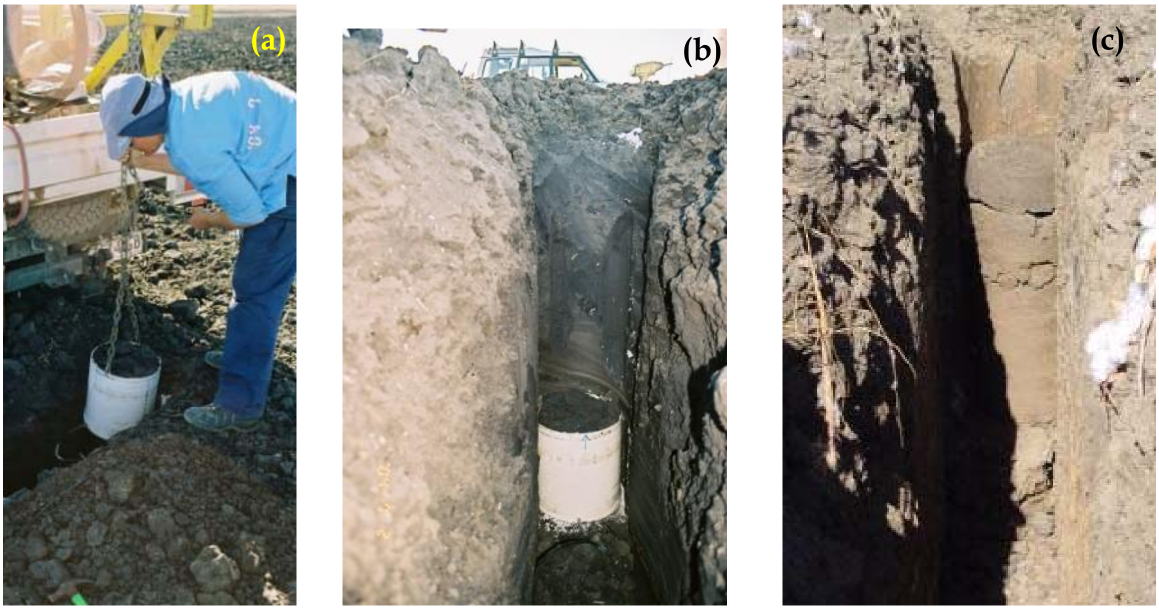

Fig. 4 (a) Lowering the lysimeter back down the hole. (b) The lysimeter in place with plumbed drainage line extending back to the edge of the field (towards the camera). (c), the intact soil cores placed in original order on top of the lysimeter, before the hole and access trench is in

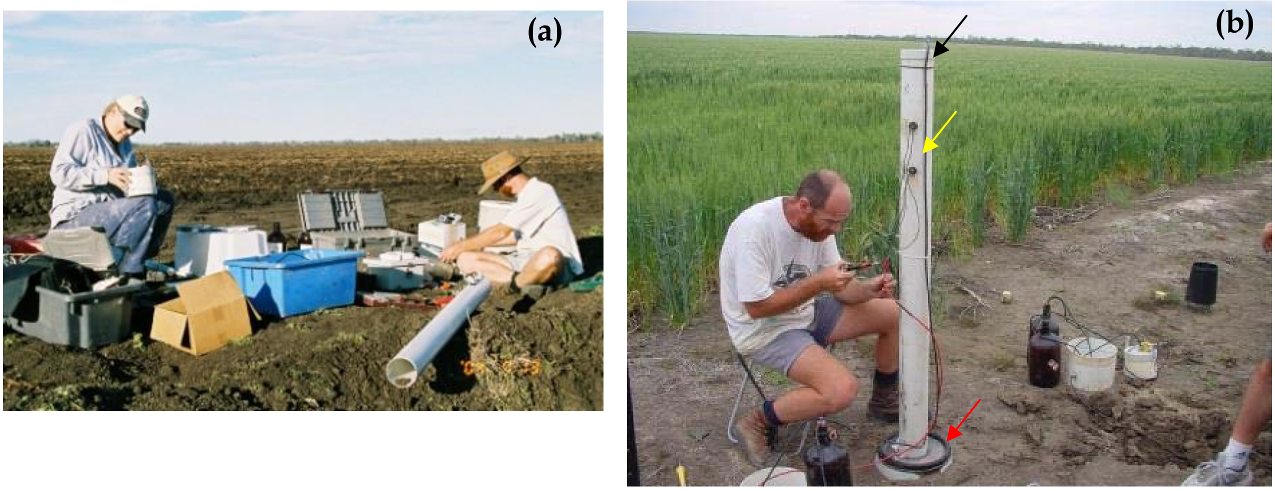

Fig. 5 (a) Building the lysimeter-related apparatus in the field. (b) Plumbing the vacuum tower that supplies the vacuum to the lysimeter. Arrowed are the water reservoir (red), reed switches (yellow) and vacuum supply line (black). The electrical pump (Fig. 6) draws the water up past the lower reed switch, to the upper switch that triggers the pump “off” – creating a vacuum as the water drops back down the column. Passing the lower reed switch, the pump is switched back “on” to again raise the water in the tower.

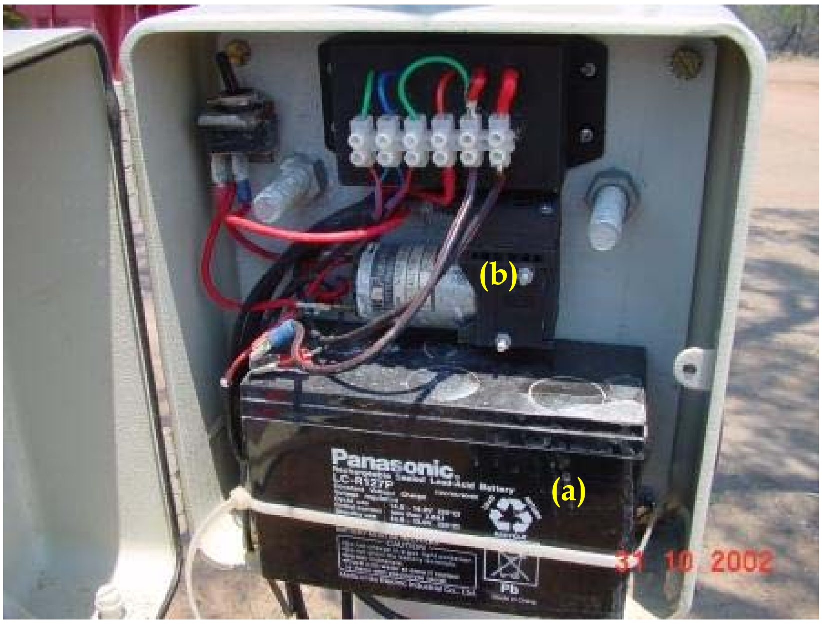

Fig. 6 The apparatus inside the environmental box, commonly mounted on the water tower. Visible are the the (a) battery, and (b) pump to drive the vacuum.

Fig. 7 Trenches to carry the vacuum line (a) along the edge of the field to link each of the three lysimeters, located at the head ditch, mid-field and tail ditch locations, and (b) from each lysimeter out to the edge of the field.

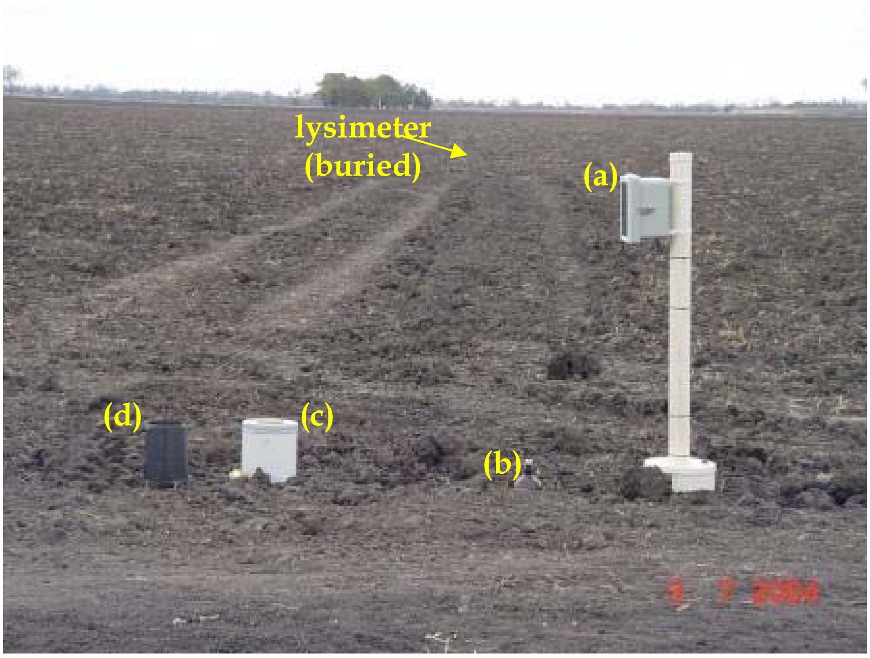

Fig. 8 The vacuum tower and pump apparatus are commonly located at the mid-field location on the edge of the field. The (a) solar panel (that charges the battery) on the face of the environmental box, is visible. Also visible are (b) the water trap that acts a filter for the air intake on the pump, (c) the water sample collection chamber (2/3 rds buried), and (d) a pluviometer, as installed at all sites.

Fig. 9 (a) The contents of the sample trap laid out on the soil surface: two water collection bottles and (arrowed) the tipping bucket device for electronic recording of quantity and time of deep drainage water (from the lysimeter). The (b) tipping bucket apparatus, located in side the PVC container in (a). (c) All the apparatus re-assembled, showing the tipping bucket device on a “swing” device to maintain it level (levelling bubble, arrowed; red), and the electronic data logger (arrowed): a TinyTag ®

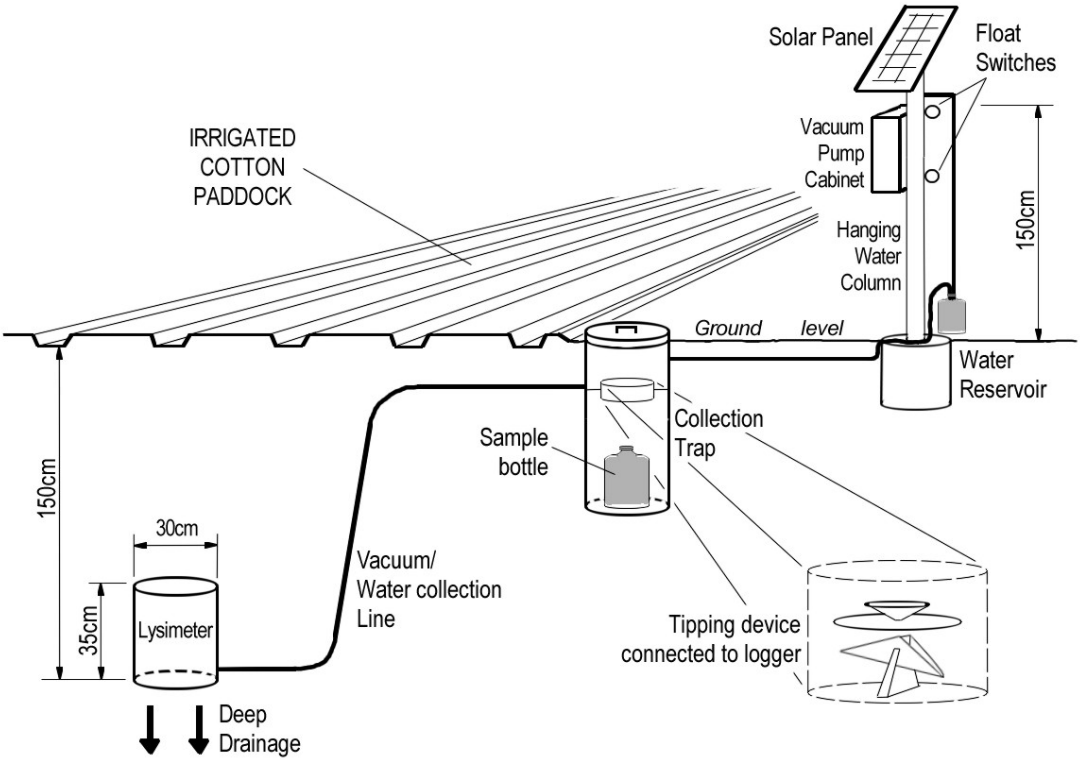

Figure 10. Diagrammatic representation of the lysimeter apparatus set-up at each of the lysimeter sites. The lysimeters are buried at 150 cm from the soil surface, and at different lysimeter sites are located either 2, 6 or 50 metres rectangularly into the field from the lysimeter trap, at each the head, mid and tail locations.

Appendix 2

The soil profile descriptions for lysimeter sites (Dalby, Dirranbandi, Goondiwindi, St George (S) and (N))
- as described by Andrew Biggs, NRW, Toowoomba

-

Macalister mid location

Project: SWRES **Site:** 34 **Observation:** 1

Soil Name: Mb? - No Code Description Found.

Location: GDA 94	**ZONE** 56	314246mE	7009916mN	**Lat:** -27.02049	**Long:** 151.12762
Location: AGD 84	**ZONE** 56	314139mE	7009728mN	**Lat:** -27.02216	**Long:** 151.12652
Location: AGD 66	**ZONE** 56	314140mE	7009730mN	**Lat:** -27.02215	**Long:** 151.12653

Described By: A (Andrew) Biggs (BIGA) **Date:** 31/OCT/01

Landscape:

Geology: No record
Landform Pattern: alluvial plain
Runoff: No record
Microrelief: Zero or none
Drainage: Imperfectly drained
Depth to Water No record
Rock OutCrops: No record
Surface Coarse Fragments: No coarse fragments 0%
Surface Condition: Periodic cracking, Self-mulching
Disturbances: Cultivation - Rainfed

Substrate Lithology: No record
Element: plain
Permeability: Slowly permeable
Microrelief Component: No record
Slope: 1 %

Classifications:

ASC: HAPLIC, SELF-MULCHING, GREY, Vertosol
GSG: Grey clay **PPF:** Ug5.24

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1p	0 to .1	Brownish grey (10YR41) moist; heavy clay; subangular blocky strong 5-10mm structure; firm dry; clear to
B21k	.1 to .8	Brownish grey (10YR41) moist; heavy clay; lenticular moderate 10-20mm structure; lenticular strong 5-10mm structure; few 2-10% fine <2mm calcareous concretions; very firm moderately moist; clear to
B22k	.8 to 1.5	Brownish grey (10YR41) moist; heavy clay; lenticular moderate 10-20mm largest peds structure; lenticular strong 5-10mm next size peds structure; few 2-10% fine <2mm calcareous concretions; very firm moderately moist; gradual to
B23	1.5 to 1.8	Greyish yellow-brown (10YR42) moist; medium heavy clay; lenticular moderate 10-20mm largest peds structure; subangular blocky moderate 2-5mm structure; very few <2% fine <2mm calcareous concretions; very firm moderately moist

Field Tests:

Depth	PH-1
.01	8.5
.1	8.5
.6	8.5
.9	8.5
1.2	8.5
1.5	8

Site Notes:

Site	Ian Gordon/Rae Zischke lysimeter site, Macalister
Site	Project: DNR15 GRDC 'Leaky soils'. Mark Silburn.

Observation Notes:

Soil	affin with Mywybilla
Soil	Chemistry data migrated from file 02-09365.xls from Toowoomba lab. Three pits dug by Jenny Foley to

Dirranbandi head ditch

Project: SWRES **Site:** 193 **Observation:** 1

Soil Name: No record

Location: GDA 94	**ZONE** 55	603398mE	6830421mN	**Lat:** -28.6492	**Long:** 148.05799
Location: AGD 84	**ZONE** 55	603283mE	6830237mN	**Lat:** -28.65086	**Long:** 148.05684
Location: AGD 66	**ZONE** 55	603284mE	6830238mN	**Lat:** -28.65086	**Long:** 148.05685

Described By: A (Andrew) Biggs (BIGA) **Date:** 03/NOV/03

Landscape:

Geology: No record
Landform Pattern: alluvial plain
Runoff: No record
Microrelief: Zero or none
Drainage: Imperfectly drained
Depth to Water No record
Rock OutCrops: No record
Surface Coarse Fragments: No coarse fragments 0%
Surface Condition: Periodic cracking, Surface crust
Disturbances: Cultivation - Irrigated, past or present

Substrate Lithology: No record
Element: plain
Permeability: Slowly permeable
Microrelief Component: No record
Slope: .5 %

Classifications:

ASC: EPIPEDAL, GREY, Vertosol
GSG: Grey clay **PPF:** Ug5.24

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
Ap	0 to .05	Dark grey (10YR41) moist; light medium clay; subangular blocky strong 5-10mm structure; firm dry; slickenside; abrupt to
B21p	.05 to .3	Dark grey (10YR41) moist; medium heavy clay; lenticular weak 2-5mm structure; strong dry; slickenside; clear to
B22	.3 to 1.1	Dark grey (10YR41) moist; medium heavy clay; lenticular moderate 5-10mm largest peds structure; lenticular moderate 2-5mm next size peds structure; very firm moderately moist; slickenside; gradual to
B23	1.1 to 1.5	Grey (10YR51) moist; medium clay; lenticular moderate 5-10mm structure; firm moderately moist; slickenside; clear to
B24	1.5 to 1.8	Brown (10YR53) moist; few 2-10% fine <5mm distinct grey mottles; medium clay; prismatic moderate 10-20mm largest peds structure; lenticular moderate 5-10mm next size peds structure; few 2-10% medium 2-6mm manganiferous laminae; firm dry; slickenside

Field Tests:

Depth	PH-1
.01	9
.3	9
.6	9
.9	9
1.2	9
1.5	9
1.8	9

Site Notes:

Site C rranbandi

Observation Notes:

Location Top end. 5m west of lysimeter tower. Edge of paddock. Surface disturbed.

Dirranbandi mid location

Project: SWRES **Site:** 194 **Observation:** 1

Soil Name: No record

Location:	GDA 94	**ZONE**	55	603116mE	6830639mN	**Lat:** -28.64725		**Long:** 148.05509
Location:	AGD 84	**ZONE**	55	603001mE	6830455mN	**Lat:** -28.64892		**Long:** 148.05393
Location:	AGD 66	**ZONE**	55	603002mE	6830456mN	**Lat:** -28.64891		**Long:** 148.05394

Described By: A (Andrew) Biggs (BIGA) **Date:** 21/OCT/03

Landscape:

Geology: No record

Substrate Lithology: No record

Landform Pattern: alluvial plain

Element: plain

Runoff: No record

Permeability: Slowly permeable

Microrelief: Zero or none

Microrelief Component: No record

Drainage: Imperfectly drained

Slope: .5 %

Depth to Water No record

Rock OutCrops: No record

Surface Coarse Fragments: No coarse fragments 0%

Surface Condition: Periodic cracking, Surface crust

Disturbances: Cultivation - Irrigated, past or present

Classifications:

ASC: EPIPEDAL, GREY, Vertosol

GSG: Grey clay **PPF:** Ug5.24

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
Ap	0 to .1	Dark greyish brown (10YR42) moist; medium heavy clay; subangular blocky strong 5-10mm structure; firm dry; clear to
B21p	.1 to .5	Dark grey (10YR41) moist; medium heavy clay; lenticular moderate 5-10mm structure; strong dry; clear to
B22	.5 to 1.05	Dark grey (10YR41) moist; medium clay; lenticular weak 5-10mm structure; very firm moderately moist; gradual to
B23	1.05 to 1.5	Greyish brown (2.5Y53) moist; medium heavy clay; prismatic weak 10-20mm largest peds structure; lenticular moderate 5-10mm next size peds structure; very firm moderately moist; gradual to
B24	1.5 to 1.8	Greyish brown (2.5Y53) moist; very few <2% medium 5-15mm faint orange mottles; heavy clay; prismatic moderate 10-20mm largest peds structure; lenticular moderate 5-10mm next size peds structure; very few <2% medium 2-6mm manganiferous laminae; very firm moderately moist

Field Tests:

Depth	PH-1
.01	8
.3	8
.6	8
.9	9
1.2	9
1.5	9
1.8	9

Site Notes:

Site	Cubb ıbandi

Observation Notes:

Location	Middle of run

Dirranbandi tail ditch

Project: SWRES **Site:** 195 **Observation:** 1

Soil Name: No record

Location:	GDA 94	**ZONE**	55	602875mE	6830891mN	**Lat:** -28.645	**Long:**	148.0526
Location:	AGD 84	**ZONE**	55	602760mE	6830707mN	**Lat:** -28.64666	**Long:**	148.05145
Location:	AGD 66	**ZONE**	55	602761mE	6830708mN	**Lat:** -28.64666	**Long:**	148.05146

Described By: A (Andrew) Biggs (BIGA) **Date:** 21/OCT/03

Landscape:

Geology: No record
Landform Pattern: alluvial plain
Runoff: No record
Microrelief: Zero or none
Drainage: Imperfectly drained
Depth to Water No record
Rock OutCrops: No record
Surface Coarse Fragments: No coarse fragments 0%
Surface Condition: Periodic cracking, Surface crust
Disturbances: Cultivation - Irrigated, past or present

Substrate Lithology: No record
Element: plain
Permeability: Slowly permeable
Microrelief Component: No record
Slope: .5 %

Classifications:

ASC: EPIPEDAL, GREY, Vertosol
GSG: Grey clay **PPF:** Ug5.24

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
Ap	0 to .1	Dark grey (10YR41) moist; medium clay; subangular blocky strong 5-10mm structure; firm dry; dry when sampled; clear to
B21p	.1 to .5	Dark grey (10YR41) moist; heavy clay; dry when sampled; gradual to
B22	.5 to 1.15	Dark grey (10YR41) moist; heavy clay; lenticular moderate 5-10mm structure; firm moderately moist; moderately moist when sampled; clear to
B23	1.15 to 1.8	Greyish brown (10YR52) moist; few 2-10% fine <5mm faint orange mottles; heavy clay; lenticular moderate 2-5mm structure; few 2-10% fine <2mm manganiferous laminae; firm moderately moist

Field Tests:

Depth	PH-1
.01	8
.3	8.5
.6	8.5
.9	9
1.2	9
1.5	9
1.8	9

Site Notes:

Site	Cu [redacted] anbandi.

Observation Notes:

Location	Bottom end.
Soil	Not as much fine sand as other two sites.

St George (N) head ditch

Project: SWRES **Site:** 196 **Observation:** 1

Soil Name: No record

Location: GDA 94	**ZONE** 55	660475mE	6911736mN	**Lat:** -27.90965	**Long:** 148.63064
Location: AGD 84	**ZONE** 55	660361mE	6911553mN	**Lat:** -27.91132	**Long:** 148.62951
Location: AGD 66	**ZONE** 55	660361mE	6911553mN	**Lat:** -27.91131	**Long:** 148.62952

Described By: A (Andrew) Biggs (BIGA) **Date:** 23/OCT/03

Landscape:

Geology: No record
Landform Pattern: alluvial plain
Runoff: No record
Microrelief: Zero or none
Drainage: Imperfectly drained
Depth to Water No record
Rock OutCrops: No record
Surface Coarse Fragments: No coarse fragments 0%
Surface Condition: Periodic cracking, Surface crust
Disturbances: Cultivation - Irrigated, past or present

Substrate Lithology: No record
Element: plain
Permeability: Slowly permeable
Microrelief Component: No record
Slope: .5 %

Classifications:

ASC: EPIPEDAL, BROWN, Vertosol
GSG: Brown clay **PPF:** Ug5.34
ASC:
GSG: **PPF:**

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1p	0 to .1	Very dark greyish brown (10YR32) moist; light medium clay; granular weak 2-5mm structure; firm moderately moist; moderately moist when sampled; clear to
A12p	.1 to .35	Dark brown (10YR33) moist; light medium clay; lenticular weak 2-5mm structure; firm moist; moist when sampled; clear to
B21	.35 to .7	Brown (10YR43) moist; medium clay; lenticular moderate 5-10mm structure; lenticular moderate 2-5mm structure; very few <2% medium 2-6mm calcareous concretions; few 2-10% fine <2mm calcareous concretions; very firm moist; moist when sampled; clear to
B22	.7 to 1	Brown (7.5YR43) moist; medium clay; lenticular weak 5-10mm structure; few 2-10% medium 2-6mm gypseous crystals; few 2-10% medium 2-6mm gypseous crystals; few 2-10% fine <2mm manganiferous laminae; very firm moderately moist; moderately moist when sampled; clear to
B23	1 to 2.7	Brown (7.5YR53) moist; few 2-10% fine <5mm distinct grey mottles, few 2-10% fine <5mm faint orange mottles; medium clay; prismatic moderate 10-20mm structure; very firm moderately moist; slickenside; moderately moist when sampled; gradual to
B24	2.7 to 3.1	Brown (7.5YR54) moist; few 2-10% medium 5-15mm distinct grey mottles, few 2-10% fine <5mm distinct red mottles; medium heavy clay; prismatic strong 5-10mm structure; lenticular strong 2-5mm structure; very firm moderately moist; moderately moist when sampled

Project: SWRES **Site:** 196 **Observation:** 1

Soil Name: No record

Field Tests:

Depth	PH-1
.01	9
.3	9
.6	9
.9	9
1.2	5.5
1.5	4.5
1.8	4.5
2.1	4.5
2.4	4.5
2.7	4.5

Site Notes:

Site

Observation Notes:

Soil	Was probably originally gilgaied.
Soil	Visible salt? crust on surface in areas just irrigated.

St George (S) Head ditch

Project: SWRES **Site:** 197 **Observation:** 1

Soil Name: No record

Location:	GDA 94	**ZONE**	55	665964mE 6883629mN	**Lat:** -28.1626	**Long:**	148.69036
Location:	AGD 84	**ZONE**	55	665850mE 6883445mN	**Lat:** -28.16427	**Long:**	148.68922
Location:	AGD 66	**ZONE**	55	665850mE 6883446mN	**Lat:** -28.16426	**Long:**	148.68923

Described By: A (Andrew) Biggs (BIGA) **Date:** 23/OCT/03

Landscape:

Geology: No record
Substrate Lithology: No record
Landform Pattern: alluvial plain
Element: plain
Runoff: No record
Permeability: Slowly permeable
Microrelief: Zero or none
Microrelief Component: No record
Drainage: Imperfectly drained
Slope: .5 %
Depth to Water No record
Rock OutCrops: No record
Surface Coarse Fragments: No coarse fragments 0%
Surface Condition: Periodic cracking, Surface crust
Disturbances: Cultivation - Irrigated, past or present

Classifications:

ASC: EPIPEDAL, GREY, Vertosol
GSG: Grey clay
PPF: Ug5.24

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
Ap	0 to .1	Dark grey (10YR41) moist; light clay; subangular blocky moderate 5-10mm structure; clear to
B21	.1 to .5	Dark grey (10YR41) moist; light medium clay; lenticular moderate 5-10mm structure; very few <2% medium 2-6mm calcareous concretions; clear to
B22	.5 to .7	Dark greyish brown (10YR42) moist; light medium clay; lenticular moderate 5-10mm structure; few 2-10% medium 2-6mm calcareous soft segregations; clear to
B23	.7 to .9	Brown (10YR53) moist; light medium clay; lenticular weak 5-10mm structure; few 2-10% medium 2-6mm gypseous crystals; very few <2% medium 2-6mm calcareous soft segregations; clear to
B24	.9 to 1.1	Brown (10YR53) moist; medium heavy clay; lenticular weak 5-10mm structure; very few <2% medium 2-6mm gypseous crystals; clear to
B25	1.1 to 1.2	Greyish brown (10YR52) moist; medium heavy clay; lenticular moderate 5-10mm structure; common 10-20% medium 2-6mm manganiferous laminae; clear to
B26	1.2 to 1.55	Light brownish grey (10YR62) moist; common 10-20% medium 5-15mm distinct brown mottles; medium heavy clay; lenticular moderate 5-10mm structure

Field Tests:

Depth	PH-1
.01	8.5
.3	7.5
.6	7.5
.9	7.5
1.2	6
1.5	5

Site Notes:

Site St.George lysimeter.

Observation Notes:

Location Bill Knight's, top of run, 2m west of tower.

St George (S) mid location

Project: SWRES **Site:** 198 **Observation:** 1

Soil Name: No record

Location: GDA 94	**ZONE** 55	665702mE	6883600mN	**Lat:** -28.1629	**Long:** 148.68769
Location: AGD 84	**ZONE** 55	665588mE	6883416mN	**Lat:** -28.16456	**Long:** 148.68656
Location: AGD 66	**ZONE** 55	665588mE	6883417mN	**Lat:** -28.16456	**Long:** 148.68657

Described By: A (Andrew) Biggs (BIGA) **Date:** 23/OCT/03

Landscape:

Geology: No record

Landform Pattern: alluvial plain

Runoff: No record

Microrelief: Zero or none

Drainage: Imperfectly drained

Depth to Water No record

Rock OutCrops: No record

Surface Coarse Fragments: No coarse fragments 0%

Surface Condition: Periodic cracking, Surface crust

Disturbances: Cultivation - Irrigated, past or present

Substrate Lithology: No record

Element: plain

Permeability: Slowly permeable

Microrelief Component: No record

Slope: .5 %

Classifications:

ASC: EPIPEDAL, BROWN, Vertosol

GSG: Brown clay

PPF: Ug5.34

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1p	0 to .1	Very dark grey (10YR30) moist; light medium clay; subangular blocky moderate 5-10mm structure; clear to
B21p	.1 to .4	Very dark greyish brown (10YR32) moist; medium clay; lenticular weak 5-10mm structure; gradual to
B22	.4 to .8	Brown (10YR43) moist; medium clay; lenticular weak 5-10mm structure; few 2-10% fine <2mm calcareous soft segregations; very few <2% fine <2mm gypseous crystals; gradual to
B23y	.8 to 1.2	Brown (10YR53) moist; few 2-10% fine <5mm faint brown mottles; medium heavy clay; lenticular moderate 5-10mm structure; common 10-20% medium 2-6mm gypseous crystals; clear to
B24y	1.2 to 1.35	Pale brown (10YR63) moist; medium heavy clay; lenticular strong 5-10mm structure; common 10-20% medium 2-6mm manganiferous laminae; common 10-20% medium 2-6mm gypseous crystals; clear to
B25	1.35 to 1.8	Pale brown (10YR63) moist; medium heavy clay; lenticular strong 5-10mm structure

Field Tests:

Depth	PH-1
.01	9
.3	9
.6	9
.9	9
1.2	9
1.5	6.5
1.8	6

Site Notes:

Site St. George lysimeter.

Observation Notes:

Location Bill Knight's, middle of run.

St George (S) tail ditch

Project: SWRES **Site:** 199 **Observation:** 1

Soil Name: No record

Location:	GDA 94	**ZONE**	55	665492mE	6883578mN	**Lat:** -28.16312	**Long:** 148.68556
Location:	AGD 84	**ZONE**	55	665378mE	6883394mN	**Lat:** -28.16479	**Long:** 148.68442
Location:	AGD 66	**ZONE**	55	665378mE	6883395mN	**Lat:** -28.16478	**Long:** 148.68443

Described By: A (Andrew) Biggs (BIGA) **Date:** 23/OCT/03

Landscape:

Geology: No record

Landform Pattern: alluvial plain

Runoff: No record

Microrelief: Zero or none

Drainage: Poorly drained

Depth to Water No record

Rock OutCrops: No record

Surface Coarse Fragments: No coarse fragments 0%

Surface Condition: Periodic cracking, Surface crust

Disturbances: Cultivation - Irrigated, past or present

Substrate Lithology: No record

Element: plain

Permeability: Slowly permeable

Microrelief Component: No record

Slope: .5 %

Classifications:

ASC: EPIPEDAL, GREY, Vertosol

GSG: Grey clay

PPF: Ug5.24

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1p	0 to .1	Very dark grey (10YR31) moist; light medium clay; subangular blocky moderate 5-10mm structure; clear to
B21	.1 to .4	Dark grey (10YR41) moist; light medium clay; lenticular moderate 5-10mm structure; gradual to
B22	.4 to .8	Dark greyish brown (10YR42) moist; dark grey (10YR41) moist; medium clay; lenticular weak 5-10mm structure; very few <2% medium 2-6mm calcareous soft segregations; gradual to
B23	.8 to 1.1	Light brownish grey (10YR62) moist; few 2-10% fine <5mm faint orange mottles; medium clay; lenticular moderate 5-10mm structure; lenticular moderate 2-5mm structure; few 2-10% fine <2mm gypseous crystals; few 2-10% medium 2-6mm calcareous soft segregations; gradual to
B24	1.1 to 1.6	Light grey (10YR72) moist; few 2-10% coarse 15-30mm faint orange mottles; medium clay; lenticular moderate 5-10mm structure; few 2-10% medium 2-6mm calcareous soft segregations

Field Tests:

Depth	PH-1
.01	8.5
.3	8.5
.6	8.5
.9	8.5
1.2	8.5
1.5	8.5

Site Notes:

Site orge lysimeter.

Observation Note

Location t) end.

Soil Different to other ones - blacker.
Is a LS33 area behind sheds.

Goondiwindi head ditch location

Project: SWRES **Site:** 200 **Observation:** 1

Soil Name: Ud - Undabri(1)

Location:	GDA 94	**ZONE**	55	789299mE	6832298mN	**Lat:**	-28.60409	**Long:**	149.95829
Location:	AGD 84	**ZONE**	55	789185mE	6832114mN	**Lat:**	-28.60577	**Long:**	149.95718
Location:	AGD 66	**ZONE**	55	789185mE	6832115mN	**Lat:**	-28.60576	**Long:**	149.95718

Described By: A (Andrew) Biggs (BIGA) **Date:** 23/OCT/03

Landscape:

Geology: No record

Substrate Lithology: No record

Landform Pattern: alluvial plain

Element: plain

Runoff: No record

Permeability: Slowly permeable

Microrelief: Zero or none

Microrelief Component: No record

Drainage: Imperfectly drained

Slope: .5 %

Depth to Water No record

Rock OutCrops: No record

Surface Coarse Fragments: No coarse fragments 0%

Surface Condition: Periodic cracking, Surface crust

Disturbances: Cultivation - Irrigated, past or present

Classifications:

ASC: EPIPEDAL, BLACK, Vertosol

GSG: Grey clay **PPF:** Ug5.15

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1p	0 to .3	Very dark grey (10YR31) moist; medium heavy clay; subangular blocky moderate 5-10mm structure; gradual to
B21	.3 to .6	Very dark greyish brown (10YR32) moist; medium heavy clay; lenticular weak 5-10mm structure; slickenside; clear to
B22	.6 to 1	Brown (10YR53) moist; medium heavy clay; lenticular weak 5-10mm structure; few 2-10% fine <2mm gypseous crystals; very few <2% medium 2-6mm gypseous crystals; few 2-10% fine <2mm manganiferous laminae; slickenside; clear to
B23	1 to 1.4	Light brownish grey (10YR62) moist; medium heavy clay; lenticular weak 5-10mm structure; common 10-20% fine <2mm manganiferous laminae; slickenside; clear to
B24	1.4 to 1.6	Light brownish grey (10YR62) moist; medium heavy clay; lenticular weak 5-10mm structure; common 10-20% medium 2-6mm manganiferous laminae; very few <2% coarse 6-20mm manganiferous laminae; slickenside

Field Tests:

Depth	PH-1
.01	9
.3	9
.6	9
.9	9
1.2	9
1.5	6.5

Site Notes:

Site	McInty

Observation Notes:

Location	Top end. East of tower.
Vegetation	Was coolibah.

Goondiwindi mid location

Project: SWRES **Site:** 201 **Observation:** 1

Soil Name: Ud - Undabri(1)

Location:	GDA 94	**ZONE**	55	788896mE	6832370mN	**Lat:** -28.60353	**Long:** 149.95416
Location:	AGD 84	**ZONE**	55	788782mE	6832186mN	**Lat:** -28.60521	**Long:** 149.95304
Location:	AGD 66	**ZONE**	55	788782mE	6832187mN	**Lat:** -28.6052	**Long:** 149.95305

Described By: A (Andrew) Biggs (BIGA) **Date:** 23/OCT/03

Landscape:

Geology: No record

Substrate Lithology: No record

Landform Pattern: alluvial plain

Element: plain

Runoff: No record

Permeability: Slowly permeable

Microrelief: Zero or none

Microrelief Component: No record

Drainage: Imperfectly drained

Slope: .5 %

Depth to Water No record

Rock OutCrops: No record

Surface Coarse Fragments: No coarse fragments 0%

Surface Condition: Periodic cracking, Surface crust, Self-mulching

Disturbances: Cultivation - Rainfed

Classifications:

ASC: EPIPEDAL, BLACK, Vertosol

GSG: Grey clay

PPF: Ug5.16

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
Ap	0 to .2	Very dark grey (10YR31) moist; medium heavy clay; subangular blocky moderate 5-10mm structure; clear to
B21	.2 to .65	Very dark grey (10YR31) moist; medium heavy clay; lenticular moderate 5-10mm structure; clear to
B22	.65 to .9	Very dark greyish brown (10YR32) moist; medium heavy clay; lenticular weak 5-10mm structure; few 2-10% fine <2mm gypseous crystals; clear to
B23	.9 to 1.4	Brown (10YR53) moist; medium heavy clay; lenticular strong 5-10mm structure; few 2-10% fine <2mm manganiferous laminae; gradual to
B24	1.4 to 1.9	Pale brown (10YR63) moist; medium heavy clay; prismatic moderate 10-20mm structure; lenticular strong 5-10mm structure

Field Tests:

Depth	PH-1
.01	9
.3	9
.6	9
.9	9
1.2	9
1.5	6
1.8	5

Site Notes:

Site

M

Observation Notes:

Location Middle lysimeter, east of equipment.

Project: SWRES Site: 202 Observation: 1

Soil Name: Ud - Undabri(1)

Location:	GDA 94	**ZONE**	55	788464mE	6832445mN	**Lat:**	-28.60295	**Long:**	149.94972
Location:	AGD 84	**ZONE**	55	788350mE	6832261mN	**Lat:**	-28.60463	**Long:**	149.94861
Location:	AGD 66	**ZONE**	55	788350mE	6832262mN	**Lat:**	-28.60462	**Long:**	149.94861

Described By: A (Andrew) Biggs (BIGA) **Date:** 23/OCT/03

Landscape:

Geology: No record

Landform Pattern: alluvial plain

Runoff: No record

Microrelief: No record

Drainage: Imperfectly drained

Depth to Water No record

Rock OutCrops: No record

Surface Coarse Fragments: No record

Surface Condition: Periodic cracking, Surface crust

Disturbances: Cultivation - Irrigated, past or present

Substrate Lithology: No record

Element: plain

Permeability: Slowly permeable

Microrelief Component: No record

Slope: .5 %

Classifications:

ASC: EPIPEDAL, BLACK, Vertosol

GSG: Grey clay

PPF: Ug5.16

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
Ap	0 to .25	Very dark grey (10YR31) moist; medium heavy clay; subangular blocky moderate 5-10mm structure; clear to
B21	.25 to .8	Very dark grey (10YR31) moist; medium heavy clay; lenticular moderate 5-10mm structure; gradual to
B22	.8 to 1.2	Brown (10YR53) moist; medium heavy clay; lenticular weak 10-20mm structure; very few <2% medium 2-6mm calcareous concretions; gradual to
B23	1.2 to 1.8	Brown (10YR53) moist; medium heavy clay; prismatic strong 20-50mm structure; angular blocky moderate 10-20mm structure; few 2-10% medium 2-6mm manganiferous laminae; gradual to

Field Tests:

Depth	PH-1
.01	8
.3	9
.6	9
.9	9
1.2	9
1.5	9
1.8	9

Site Notes:

Site

Observation Notes:

Location	Bottom lysimeter (west)
Soil	Different to others.

Pampas mid location

Project: SWRES **Site:** 255 **Observation:** 1

Soil Name: No record

Location:	GDA 94	**ZONE**	56	336508mE	6935817mN	**Lat:** -27.69199	**Long:** 151.342
Location:	AGD 84	**ZONE**	56	336401mE	6935629mN	**Lat:** -27.69367	**Long:** 151.3409
Location:	AGD 66	**ZONE**	56	336402mE	6935630mN	**Lat:** -27.69366	**Long:** 151.34091

Described By: A (Andrew) Biggs (BIGA) **Date:** 22/JUN/04

Landscape:

Geology: Qa - Alluvium
Landform Pattern: alluvial plain
Runoff: No record
Microrelief: Zero or none
Drainage: Imperfectly drained
Depth to Water No record
Rock OutCrops: No bedrock exposed
Surface Coarse Fragments: No coarse fragments 0%
Surface Condition: Periodic cracking, Self-mulching
Disturbances: Cultivation - Irrigated, past or present

Substrate Lithology: Alluvium
Element: plain
Permeability: Slowly permeable
Microrelief Component: No record
Slope: .1 %

Classifications:

ASC: HAPLIC, SELF-MULCHING, BLACK, Vertosol
GSG: Black earth **PPF:** Ug5.15

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1	0 to .1	Black (10YR11) moist; angular blocky strong 10-20mm largest peds structure; angular blocky strong 5-10mm next size peds structure; clear to
B21p	.1 to .3	Black (10YR11) moist; lenticular strong 5-10mm largest peds structure; lenticular strong 2-5mm next size peds structure; gradual to
B22	.3 to .9	Black (10YR21) moist; lenticular strong 10-20mm largest peds structure; lenticular strong 2-5mm next size peds structure; very few <2% medium 2-6mm calcareous concretions; gradual to
B23	.9 to 1.3	Brownish black (10YR23) moist; lenticular strong 5-10mm largest peds structure; lenticular strong 2-5mm next size peds structure; very few <2% medium 2-6mm calcareous concretions; gradual to
B24	1.3 to 1.85	Dark brown (10YR33) moist; very few <2% fine <5mm faint orange mottles; lenticular moderate 5-10mm largest peds structure; lenticular strong 2-5mm next size peds structure; very few <2% medium 2-6mm calcareous concretions

Field Tests:

Depth

Site Notes:

Site	Lead
Site	Proposed lysimeter site for Des McGarry

Dalby mid location

Project: SWRES **Site:** 256 **Observation:** 1

Soil Name: No record

Location:	GDA 94	**ZONE**	56	317034mE	6984907mN	**Lat:** -27.24653	**Long:** 151.152
Location:	AGD 84	**ZONE**	56	316927mE	6984719mN	**Lat:** -27.24821	**Long:** 151.1509
Location:	AGD 66	**ZONE**	56	316928mE	6984720mN	**Lat:** -27.2482	**Long:** 151.15091

Described By: A (Andrew) Biggs (BIGA) **Date:** 22/JUN/04

Landscape:

Geology: Qa - Alluvium

Substrate Lithology: Alluvium

Landform Pattern: alluvial plain

Element: plain

Runoff: No record

Permeability: Slowly permeable

Microrelief: Zero or none

Microrelief Component: No record

Drainage: Imperfectly drained

Slope: .5 %

Depth to Water No record

Rock OutCrops: No bedrock exposed

Surface Coarse Fragments: No coarse fragments 0%

Surface Condition: Periodic cracking, Self-mulching

Disturbances: No record

Classifications:

ASC: SELF-MULCHING, BLACK, Vertosol

GSG: Grey clay

PPF: Ug5.16

Vegetation:

Profile Morphology:

Horizon	Depth (m)	Description
A1	0 to .1	Brownish black (10YR31) moist; angular blocky strong 10-20mm structure; clear to
B21	.1 to .35	Brownish black (10YR31) moist; lenticular strong 10-20mm structure; gradual to
B22	.35 to .7	Brownish black (10YR31) moist; lenticular strong 5-10mm structure; gradual to
B23	.7 to 1.05	Brownish grey (10YR41) moist; lenticular moderate 5-10mm structure; very few <2% medium 2-6mm calcareous concretions; gradual to
B24	1.05 to 1.8	Brownish grey (10YR51) moist; very few <2% medium 2-6mm calcareous concretions

Field Tests:

Depth

Site Notes:

Site	C
Site	Proposed lysimeter site for Des McGarry

Observation Notes:

Observation	Some visible sand

Horizon Notes:

Horizon	A1	Darker at southern end

Appendix 3

Irrigation bores – Macalister site; analytical analysis of borewaters

Job No: **07-0362**
Report ID: **07-0362-F-V4**

	Bore-water analysis: 2 bores	**Sample collected**	11 September 2007	11 September 2007
	Macalister	**Sample No**	07-0362-0031	07-0362-0032
	11 September 2007	**Customer's ID**	B-1 Mid-field	B-2 Head-field
		Description	Macalister	Macalister
Method	**Component**	**Units**		
Water: Physicals				
W_PEA_TT	pH @ 25º C		7.8	8.4
W_PEA_TT	Conductivity @ 25º C	µS/cm	3800	4500
* W_CALC	Total dissolved ions	mg/L	2331	2632
W_PEA_TT	Total alkalinity as CaCO3	mg/L	354	321
* W_CALC	Total hardness as CaCO3	mg/L	398	436
* W_CALC	Sodium adsorption ratio		14.9	16.2
* W_CALC	Residual alkalinity	meq/L	<0.1	<0.1
Water: Cations				
W_MD_ICP	Calcium	mg/L	52.6	56.2
W_MD_ICP	Magnesium	mg/L	64.8	71.7
W_MD_ICP	Sodium	mg/L	683	775
W_MD_ICP	Potassium	mg/L	4	5
Water: Anions				
W_PEA_TT	Hydroxide as OH	mg/L	<1	<1
W_PEA_TT	Carbonate as CO3	mg/L	<1	6
W_PEA_TT	Bicarbonate as HCO3	mg/L	432	379
W_FIL_IC	Sulfate as SO4	mg/L	96.3	115
W_MD_ICP	Sulfate	mg/L	85.3	110
W_FIL_IC	Chloride as Cl	mg/L	998	1220
W_FIL_IC	Fluoride as F	mg/L	<0.10	<0.10
W_FIL_IC	Phosphate phosphorus as P	mg/L	<2.5	<2.5
W_FIL_IC	Nitrate nitrogen as N	mg/L	0.4	<0.5
W_FIL_IC	Nitrite nitrogen as N	mg/L	<0.1	<0.1
W_FIL_IC	Bromide as Br	mg/L	4	5.2
* W_IONBAL	Sum Cations	meq/L	37.8	42.5
* W_IONBAL	Sum Anions	meq/L	37.3	43.4
* W_IONBAL	Sum (Cation-Anion)	meq/L	0.417	-0.874
* W_IONBAL	Accept Range		5	5
* W_IONBAL	Ion Balance	%	0.6	-1
Water: Metals				
W_MD_ICP	Aluminium	mg/L	<0.09	<0.09
W_MD_ICP	Boron	mg/L	0.15	0.15
W_MD_ICP	Cobalt	mg/L	<0.03	<0.03
W_MD_ICP	Copper	mg/L	0.01	<0.01
W_MD_ICP	Iron	mg/L	<0.02	<0.02
W_MD_ICP	Manganese	mg/L	0.04	0.153

W_MD_ICP	Molybdenum	mg/L	<0.02	<0.02
W_MD_ICP	Phosphorus	mg/L	<0.13	<0.13
W_MD_ICP	Silicon	mg/L	15.8	18.4
W_MD_ICP	Zinc	mg/L	0.07	<0.01

Name : Julie Ivison
Title : Manager, NRSCC

NATA Accredited Laboratory
Number: 5072

This document is issued in accordance with NATA's accreditation requirements.
Accredited for compliance ISO 17025/IEC
The results of the tests, calibrations and/or measurements included in this document are traceable to Australian/national standards.

Appendix 4

Report on Deep Drainage with barrel lysimeters (NRW, Queensland) at ACRI, Narrabri

T.G. Gunawardena & D. McGarry
NRW, Indooroopilly

Three lysimeters were installed in the same field as the large "CSIRO lysimeter" at the ACRI, Narrabri. Installation of the lysimeters (one at each of the head, mid and tail locations in this field) were made so that they aligned (perpendicularly into the field; 10 meters, and at the same depth; 200cm) as the big lysimeter. Installations were conducted in the period 23–27 May 2005 and the lysimeters were activated to commence recording Deep Drainage (DD) on 27 May 2005.

Early investigations of the DD data from the barrel, constant suction lysimeters seemed to suggest evidence of the effects of soil disturbance on DD quantities as a result of installation procedures.

This Report aims to present all DD data to date and includes a close examination of DD with time to resolve the issue of potential influence of initial installation procedures on early-season DD data.

The lysimeter at the Head location

As evident in Figure 1, a rain period started on 12/6/05 (17 days after activation) and both the head and tail lysimeters started recording DD (i.e. the "first tip" of the tipping bucket device) on 12/7/05 (30 days after the rain started and 46 days since activation). At that time (in the period 27/5/05 to 12/7/05) the total rain received was 202 mm.

By 22/09/05 (120 days after installation and 103 days after the intermittent rain began) the Head lysimeter had recorded a total DD of 128 mm. In that period there was no irrigation, and a total of 269 mm of rain (Fig. 1). Hence, DD in that period was 48% of rainfall.

With continuing, intermittent rain (a further 555 mm) up to the date of the 1st crop irrigation of the 2006-7 cotton season (23/10/06), the head lysimeter recorded only a further 68 mm of DD.; representing DD in that period as 12% of rainfall.

Hence, though the initial DD of 128 mm at the Head location may be accounted for by soil disturbance (during installation), after that time the impact of installation on DD quantity appears vastly reduced.

The cotton crop of the 2006-7 season received 7 ML in eight (8) irrigations and a further 178 mm of rain in the growing season. The large response of the Head lysimeter to the irrigations is evident in Figure 1. In total, there was 310 mm of DD; being 35% of applied waters (irrigation plus rain).

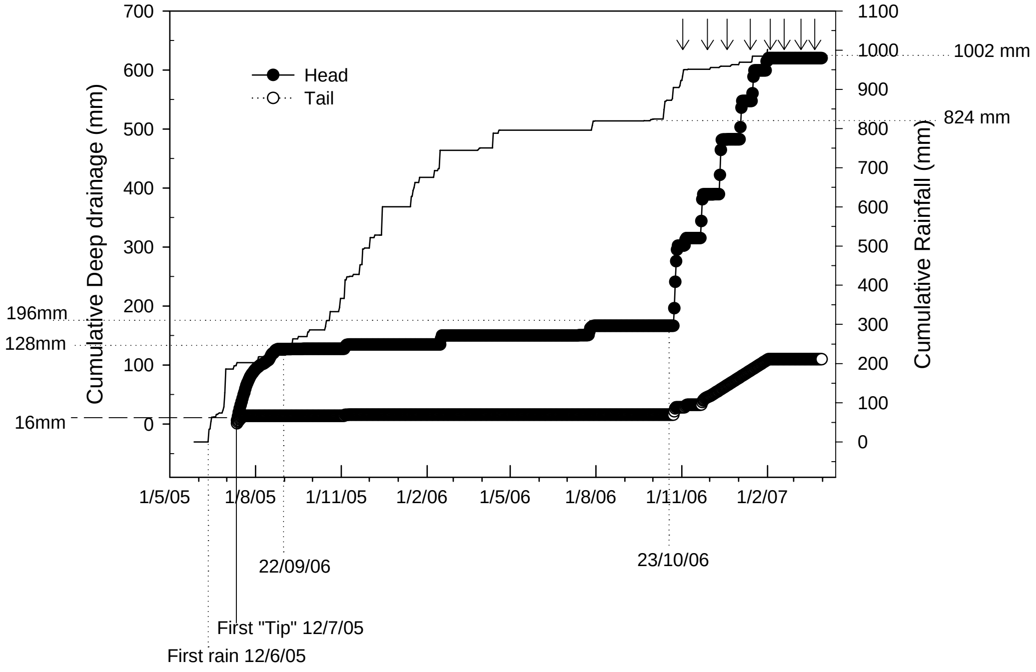

Figure 1. A plot of deep drainage (DD) at each of the head and tail lysimeters at the C1 site on ACRI (Narrabri), as collected *via* the tipping bucket device and logged. DD data is presented as a cumulative line, as too is rainfall for the same period. Irrigation events (arrows), and key rainfall and DD dates are also shown.

The lysimeter at the Mid location

Unfortunately, the tipping bucket device at the mid location was not in operation. DD was measured solely from the volume of waters collected (in the collection bottles at the edge of the site) since installation.

Subsequent to installation and prior to the first irrigation event for the 2006-7 crop, the volumes collected from the mid lysimeter are given in Table 1. Note that these dates cannot be uniquely matched with rain days as the volume collection did not immediately follow rain events. Rain amounts for each collection period are also shown in Table 1. Up to 3/8/05, a total of 88 mm of DD eventuated from 217 mm of rain; so DD was 40% of applied waters. After that date, DD greatly reduced, being only 8.4 mm to 8/9/06, from 602 mm of rain.

The lysimeter at the Tail location

Relative to the total pre-season rainfall of 824 mm, the tail lysimeter recorded DD of only 16 mm (Fig. 1). During the season (7 ML of irrigation and a further 178 mm rain), the tail recorded a further 94 mm of DD (a cumulative total of 110 mm since installation). For the cotton season period, DD was 11% of applied waters.

Table 1. Volumes of water collected from the mid location lysimeter, ACRI site.

Date	DD (mm)	Rain (mm) for each collection period
26/5/05 to 12/7/05	42	202
3/8/05	46	15
31/12/05	5	383
20/2/06	3	144
8/8/06	0.4	75
Total	**96.4**	**819**

Conclusions

Based on the data collected since the time of installation to the end of the 2006-07 season:

- Apart from the period immediately after installation (120 days after installation of which 103 days experienced intermittent rain), there is no evidence of impact of installation technique on subsequent DD data, despite almost 17 ML of water being applied to the site (rain and irrigation) for the period being reported here.
- The trend for diminishing quantities of DD from the head to the mid to the tail locations (310, 112 and 65 mm, respectively) matches well with the same trend found at many of the other DD sites. Causality is seen as “DD opportunity time) with irrigation waters lying longer at the head ditch end than the tail. Causality does not seem to be linked to the particle size analysis at the lysimeter depth (200 cm) at each

of the head, mid and tail locations (Table 2); sand % being greatest at both head and mid, and clay % least at the same two locations.

- An early EM (electro-magnetic) survey of the field showed an anomaly in close proximity to the head lysimeter; perhaps a sand lens or old channel. Perhaps there is a link between this feature and the large DD at this location.
- Prior to the 2006-07 cotton season, stronger evidence of diminishing DD at head since installation (plotted graph) and also at mid location (dates and amounts in table).

So, from the above analysis it appears that the lysimeters were well integrated with the soil matrix when the paddock during all irrigation events.

Table 2. Particle size analysis (%) for four soil fractions – for the soil at 200 cm depth (lysimeter depth) from the three field locations at the ACRI site. Analysis conducted by the Natural Resource Sciences Chemistry Centre, NR&W, Indooroopilly (NATA-approved).

	Coarse sand	Fine sand	Silt	Clay
Head	2	43	16	38
Mid	1	25	24	49
Tail	2	53	14	31

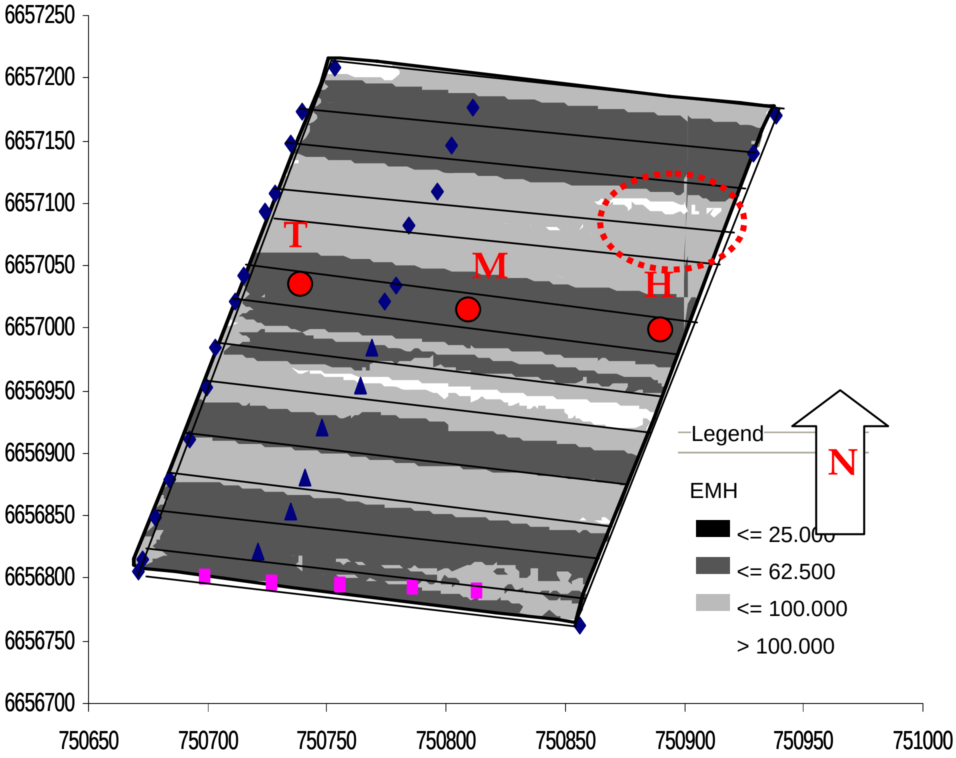

Figure 2. An EM38 survey, conducted of the experimental field in June 2004. The locations of the head, mid and tail barrel lysimeters are notated (H, M, T). Evident is the north-south "anomaly" (circled) close to the head lysimeter, considered to be an old channel or ditch.

Table 3. Deep drainage (volume) collected after each irrigation event (dates given) in the 2006-7 irrigated cotton growing season.

	Irrigated cotton 2006-7 at ACRI								
Sample dates	**24-25/10**	**22/11**	**12/12**	**3/1**	**16/1**	**30/1**	**14/2**	**28/2**	**Total DD (mm)**
Head	88	57	60	44	32	14	13	1.9	**310**
Mid	19	18	39	19	9	4	4	0.4	**112**
Tail	11	17	12	20	4	0.4	0	0.0	**65**

Note: irrigation applications were 1 ML/ha x 8 irrigations = 8 ML total

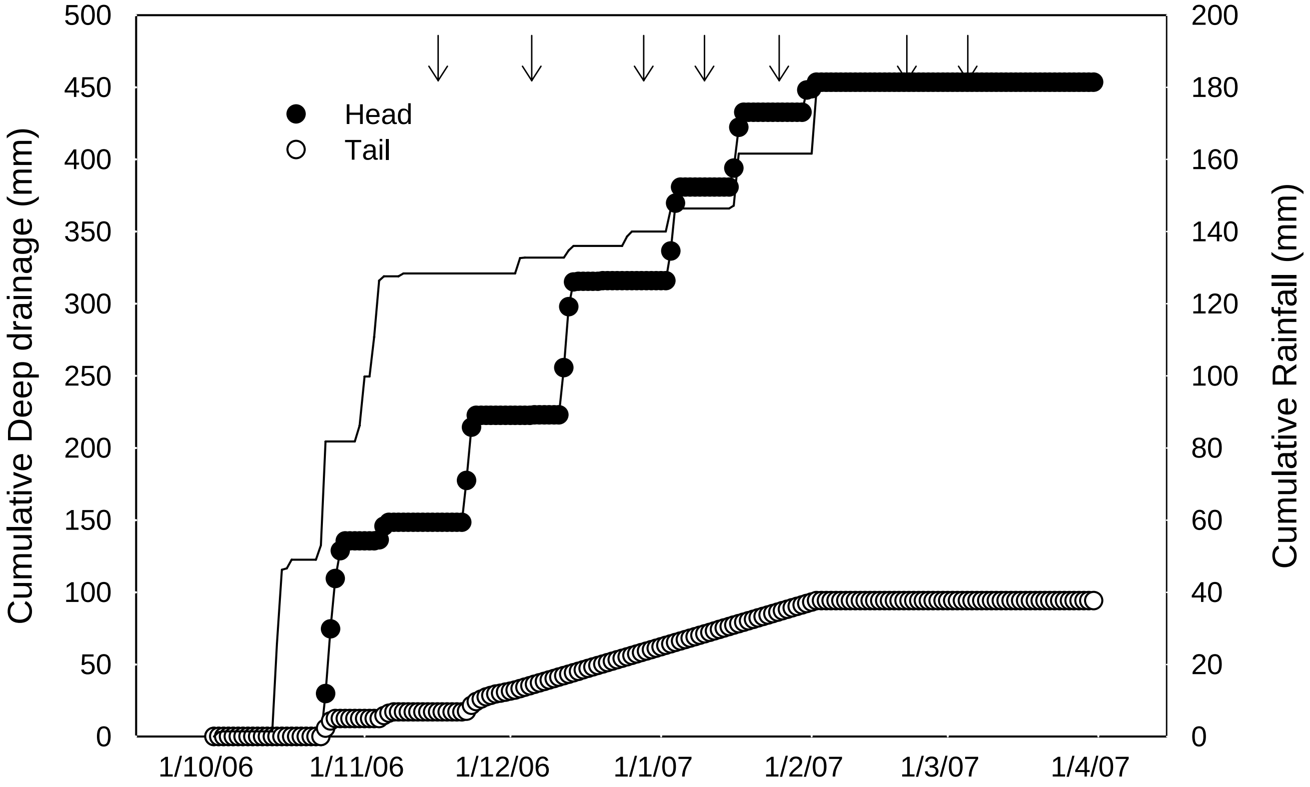

Figure 3 Deep drainage (logged) during the 2006-7 irrigated cotton season. Cumulative rainfall is also shown as a continuous line. Vertical arrows indicate time and number of irrigations.

Appendix 5

Report on inherent soil chemical properties and early season Deep Drainage data - the Maules Creek site, Narrabri

Des McGarry & Thusitha Gunawardena
NR&W, Indooroopilly, Qld

Methods

During installation of the 4 drainage lysimeters at the Maules Creek site (July, 2007), additional cores (150 cm length x 2 cm diameter) were collected for "routine" soil chemical analysis; one core at each of the head, mid and tail lysimeter locations in the "sorghum field" and one core at the "mid-opposite" lysimeter location in the wheat field. The cores were cut into 10 cm lengths and the following sections submitted for chemical analyses to the NRSc Chemistry Centre (NR&W, Indooroopilly): 0-10, 10-20, 30-40, 70-80, 120-130, 140-150 cm. The Excel spreadsheet (attached) presents the analyses conducted and the results, as well as graphs for specific, important attributes (re-produced above, here).

Results

The graphs (Figures 1 to 5, below) show the site (in terms of the four cores sampled) to be most heterogeneous, for almost all the attributes determined. The heterogeneity is both between field locations and within locations (*i.e.* variation with depth).

The soil at all sampled locations is acid to 20 cm (Fig. 1). In particular, the mid-opposite location has a pH of 5.5 on the soil surface. Application of lime should be considered at this site; to neutralise the soil and perhaps aid fertiliser utilisation. Below 30 cm, the soil at all locations becomes alkaline, in particular below 70 cm at the mid and tail and mid-opposite with pH of >8.5 to 150 cm.

The soil surface at all sampled locations has very large values of Organic Carbon, being 1.7 to almost 3 % at all locations. These are very large values for a cultivated and irrigated field – particularly the tail location (Fig. 2). However, considering that the soil is acidic at the same depth, these (acidic) organic fractions may not be conducive to seedling vigour (early plant growth) or soil fauna proliferation. Below

30 cm, all locations have organic carbon values <1; values more common on soil surfaces in the semi-arid regions of Australia (such as Narrabri).

The Ca : Mg ratio (the ratio of the two exchangeable cations) is one calculated value, commonly used to demonstrate soil physical quality; in particular structure strength and resilience (bounce-back potential) to wetting (rain and irrigation). The value of 2 or greater is commonly accepted as an indicator of good (strong /resilient) soil structure, and it can be seen that only the soil surface layers at the head and mid locations have values of approximately 2 (Fig. 3). Surface layers at the tail have a maximum of only 1.5, dropping away rapidly with depth (as does the mid-opposite) to values of 0.9 at 100 cm.

Exchangeable sodium percent (ESP) of the subsoils, ie the sodium exchangeable ion, expressed as a percentage of the total sum of cations (CEC – the cation exchange capacity), is strongly variable between locations. Values of ESP of >6 and >15 for topsoils and subsoils, respectively, are required to class a soil as "sodic", with associated problems of hardsetting, poor structure development, and poor water and plant root penetration that follow. In these terms, all surface layers have very low ESP (<3), so are not sodic, and therefore not prone to sealing and crusting after rain or irrigation (Fig 4). However, deeper soil layers, particularly from 40 cm to 150 cm at the tail location, have values of ESP up to 30%, showing the subsoil to be very strongly sodic – with consequent tightness, low porosity and poor structure soil structure with negative impacts on water and root penetration. The mid-opposite also has values of ESP close to 15 in the 80 – 100 cm; so again is mildly sodic in those layers. Both the head and mid have non sodic subsoils (values always <7), so should have good subsoil structure.

Particle size analysis (sand, silt and clay proportions) also vary strongly between lysimeter sites and with depth at any one site (Fig. 5). The head location has large proportions of sand from 20 cm to 100 cm depths with values peaking at 55% at 40 cm, and correspondingly has the least proportion of clay (down to 30% in the same layers). At the other extreme, the tail location has the least sand content (down to 20 % in the 80 to 110 cm layers) and the largest clay proportion (up to 57% at 80 cm).

Silt content on the immediate soil surface of all locations, apart from the head, are large - around 30%; perhaps showing a propensity for surface sealing with wetting.

Lastly, the question can be asked: " how will these soil inherent properties affect deep drainage responses in this field?" This should be considered in at least two ways – the nature of the soil above the lysimeter (ie down to 120 cm) and the nature of the actual soil at 120-150 cm, that composes the lysimeter. The former will influence the potential of water to move to the lysimeter, and having reached (or not reached) it – the nature of the lower layer will determine the movement of water through the lysimeter (and out to the collection traps).

Generally, the greatest impact on DD will undoubtedly arise from the site's heterogeneity, as evident in almost all the soil properties presented here; both between field locations and with depth at each location. Focussing on some of the main points, the head location is by far the sandiest (and least clayey and silty) location; perhaps leading to large values of DD. Linked to this, perhaps, the head location has low ESP values throughout the soil profile; again perhaps inducing good soil structure and increased DD. The tail location has the largest clay content, with an obvious clay "bulge" at 80 – 120 cm, that in association with very large ESP levels may cause a very dense, tight, non-leaking location – with low DD. Both the mid-opposite and the mid have large sand proportions at the lysimeter depth (visibly obvious while installing the lysimeters), being 55 to 62 % clay, that may cause large DD values – if the waters can percolate down to this level.

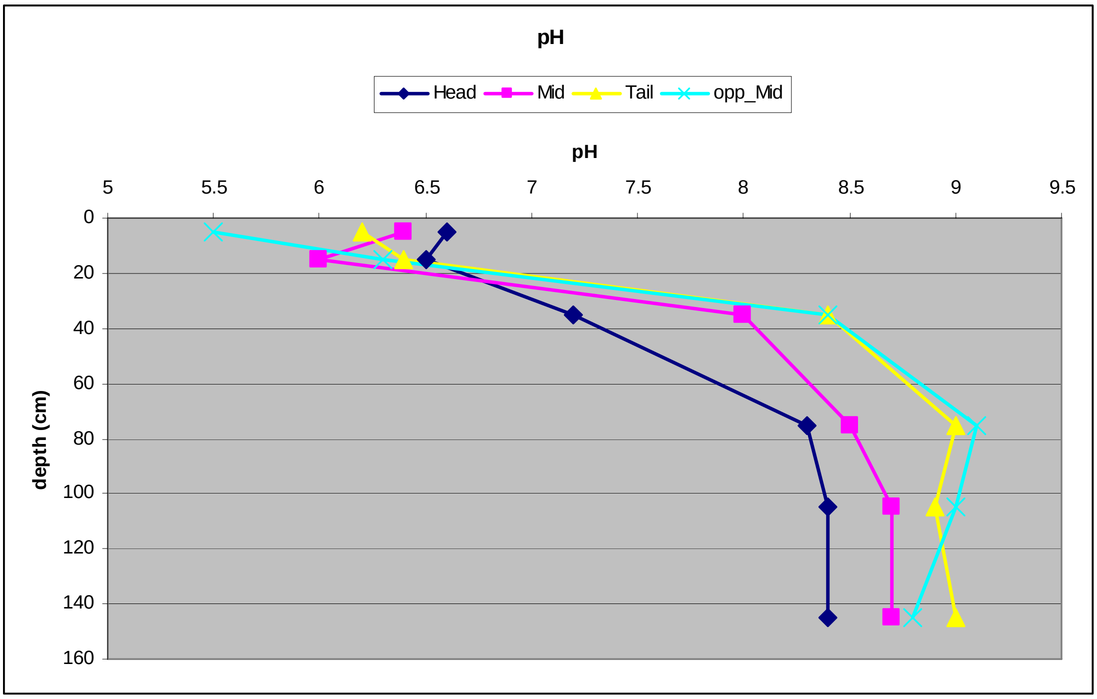

Fig. 1 Soil pH to150 cm depth at each of the four lysimeter locations (head, mid, tail and mid-opposite) at the Maules Creek site.

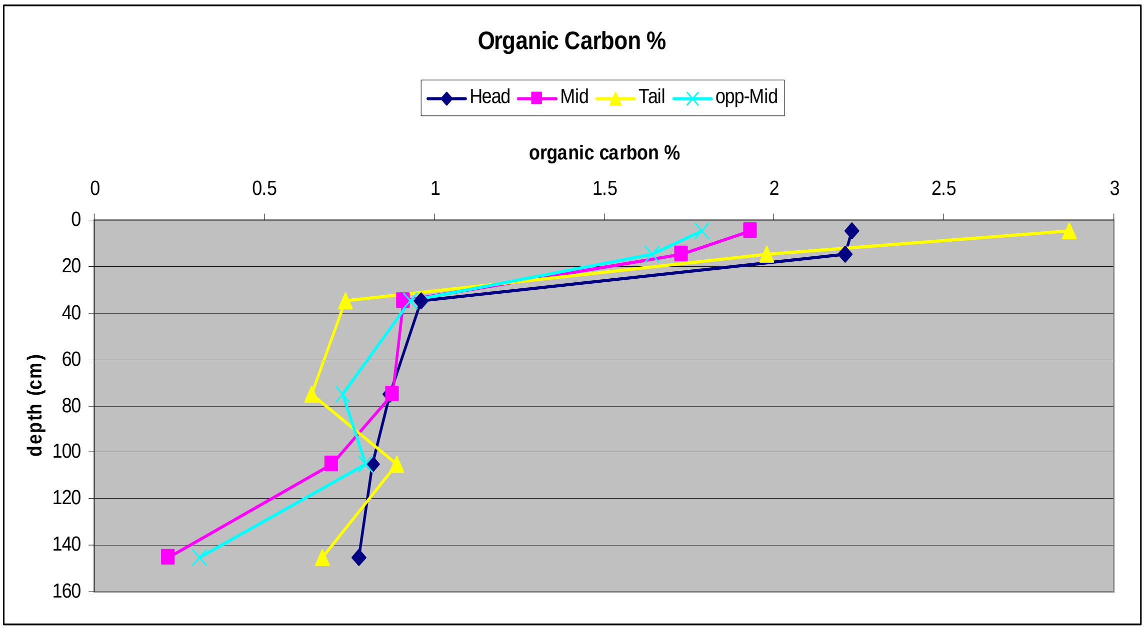

Fig. 2 Soil Organic Carbon to150 cm depth at each of the four lysimeter locations (head, mid, tail and mid-opposite) at the Maules Creek site.

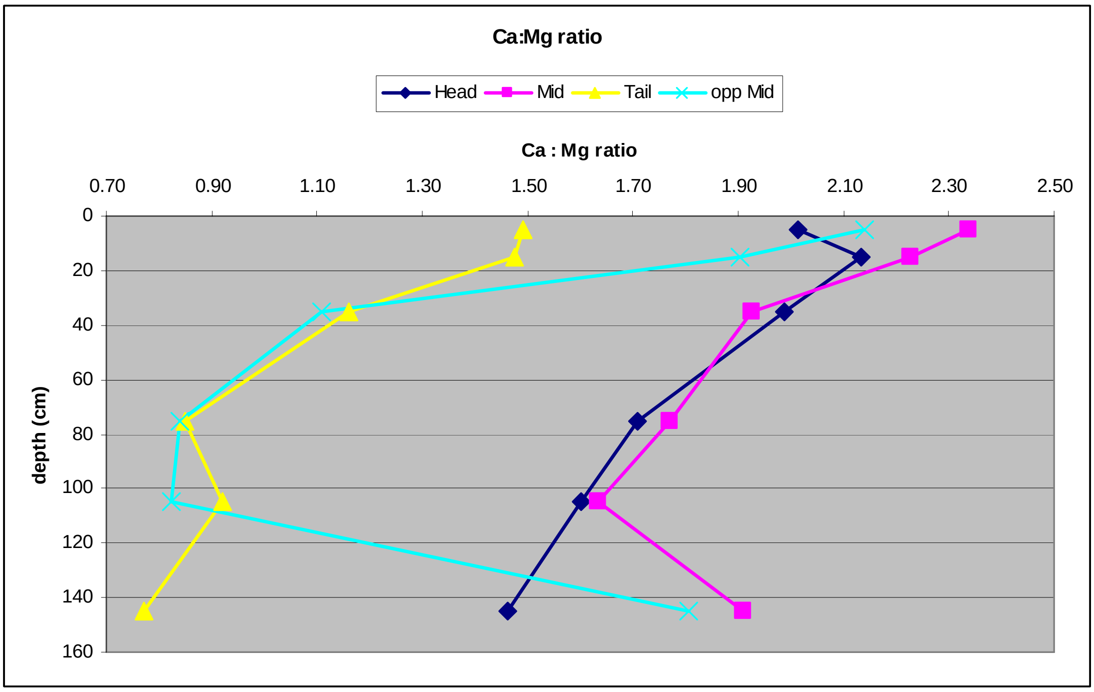

Fig. 3 Ca : Mg ratio (exchangeable cations) to150 cm depth at each of the four lysimeter locations (head, mid, tail and mid-opposite) at the Maules Creek site.

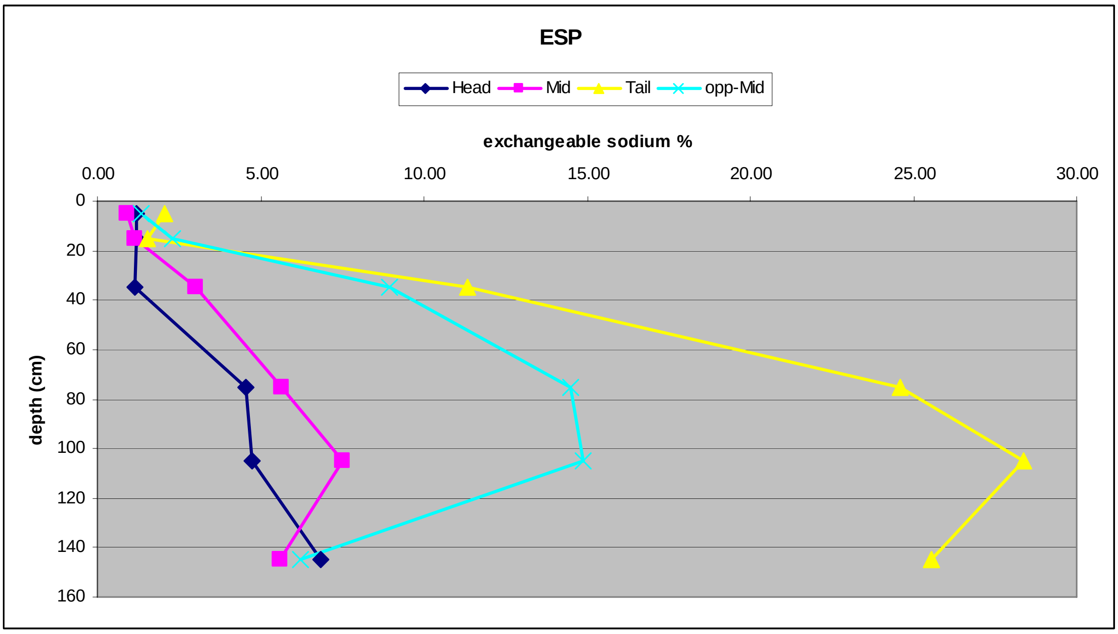

Fig. 4 Exchangeable sodium % (ESP) ie Sodium as a % of the cation exchange capacity (CEC) to150 cm depth at each of the four lysimeter locations (head, mid, tail and mid-opposite) at the Maules Creek site.

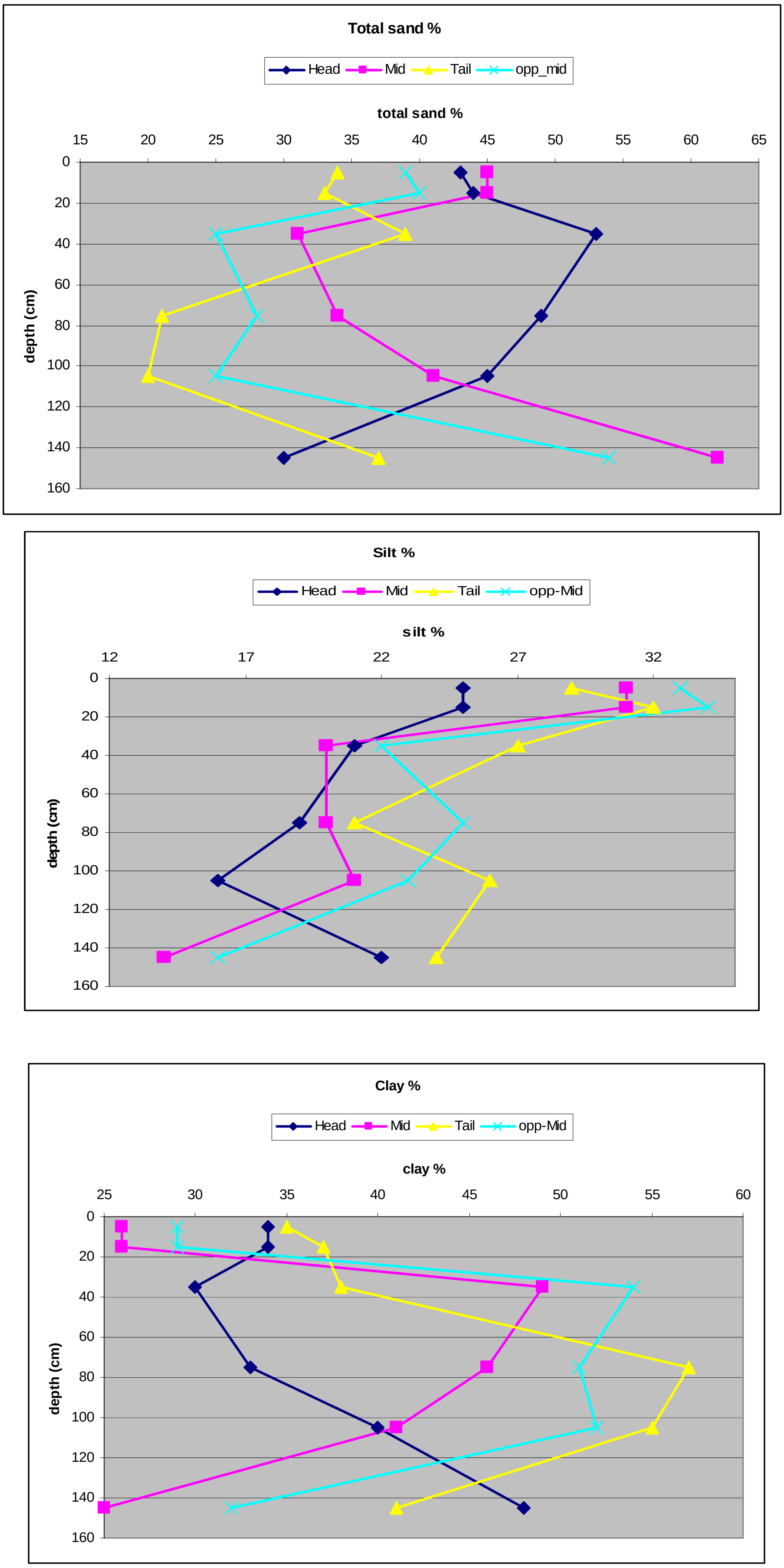

Fig. 5 Particle size analyses – sand, silt and clay (%) to150 cm depth at each of the four lysimeter locations (head, mid, tail and mid-opposite) at the Maules Creek site.

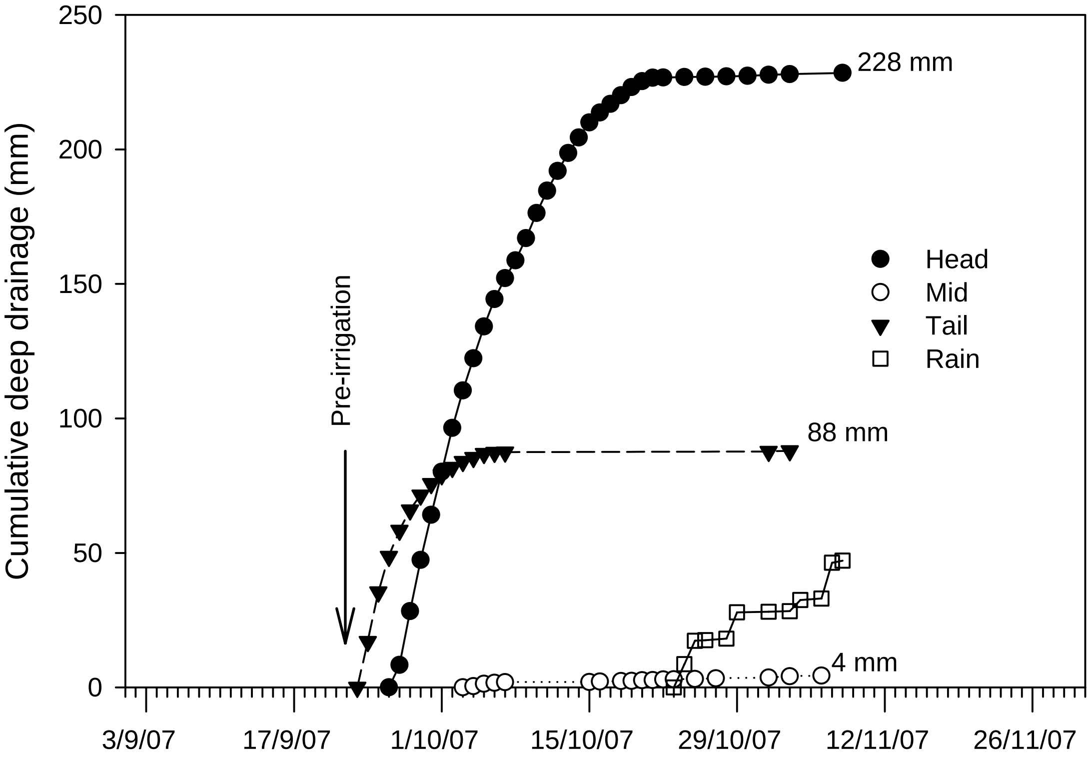

Figure 6 Cumulative deep-drainage logged by tipping bucket after the pre-irrigation on 23/10/07 for sorghum. Rainfall of 24/10/07 to 8/11/07 also shown.

Cumulative deep drainage (DD) recorded (*via* tipping bucket and saved on Tiny Tags) at the head, mid and tail lysimeters was 228, 4 and 88 mm[10], respectively (Figure 6). This was for the period of 23 September to 8 November 2007 (from the pre-irrigation to the last data download). It is evident that the tail lysimeter started recording DD before the head (by approximately 3 days), perhaps due to the proximity of the tail lysimeter to the collection trap. The distance differential is 455 m (the distance between head and tail lysimeters), so the head DD water needs to travel that additional distance, before activating the tipping bucket device.

Rainfall in this data collection period was first recorded on 24/10/07 but the largest falls were on 29/10/07 (9mm) and 7/11/07 (13mm) (Figure 1). In that period – when there was rainfall but no irrigation - DD increased by 1.7 mm (226.7 to 228.4 mm), 2 mm (2 to 4 mm) and 0.5 mm (87.4 to 87.9) at head, mid and tail locations. Total

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[10] Note: 100 mm of DD = 1 ML/ha of DD

rainfall recorded was 47 mm. Generally, it is unusual to gain a lysimeter response from rainfall, but small responses seem to have occurred at the Maules Ck site.

Table 1 Comparison of logged and volumetric DD (mm)

	Head	**Mid**	**Tail**	**Mid-opposite**
Volumetric	182	4	98	129
Logged	228	4	88	165

Table 1 presents DD totals for each of the four lysimeters at Maules Ck for both the logged data (as in Figure 1) and the actual water volumes collected in the collection bottles. Discrepancies in the two figures occur at each field location; the volumetric being less at each of head and mid-opposite (20% and 22% less - head and mid-opposite, respectively). These may be attributed to either measurement errors (with the actual water sample), or else water remains in the bottom of the tipping bucket device – if the device is not perfectly level. The tail location had the opposite response with the volumetric value being 10% greater than the logged value; perhaps attributed to either the tipping bucket device sticking or being unable to monitor peak flows of water.

Monitoring of both expressions of DD will continue throughout the following seasons at all four locations.

Appendix 6

Investigative study of past and current groundwater levels of the monitoring boreholes in the St George (south) irrigation area

Draft #1

- for discussion and comment; towards an Interim Report

Anne Riesz and Des McGarry

Natural Resources and Water, Queensland Government
Toowoomba and Indooroopilly

Australian Government
Cotton Research and Development Corporation

Cotton Catchment Communities CRC

Queensland Murray Darling Committee Inc.

Queensland Government
Natural Resources and Water

Investigative study of past and current groundwater levels of the monitoring boreholes in the St George (south) irrigation area

Anne Riesz[11] **and Des McGarry**[12]

Introduction

The Department of Natural Resources and Water (NR&W) of the Queensland Government is conducting investigations of water level changes with time in the groundwater monitoring bores of the St George (south) irrigation area. The irrigation area lies to the south east of the town of St George on the Balonne River (Figure 1) and was opened to irrigation via the original St George supply channel in the mid 1950's by the Queensland Water Resources Government Department. The initial scheme was devised for the production of fodder for fat lambs, and consisted of

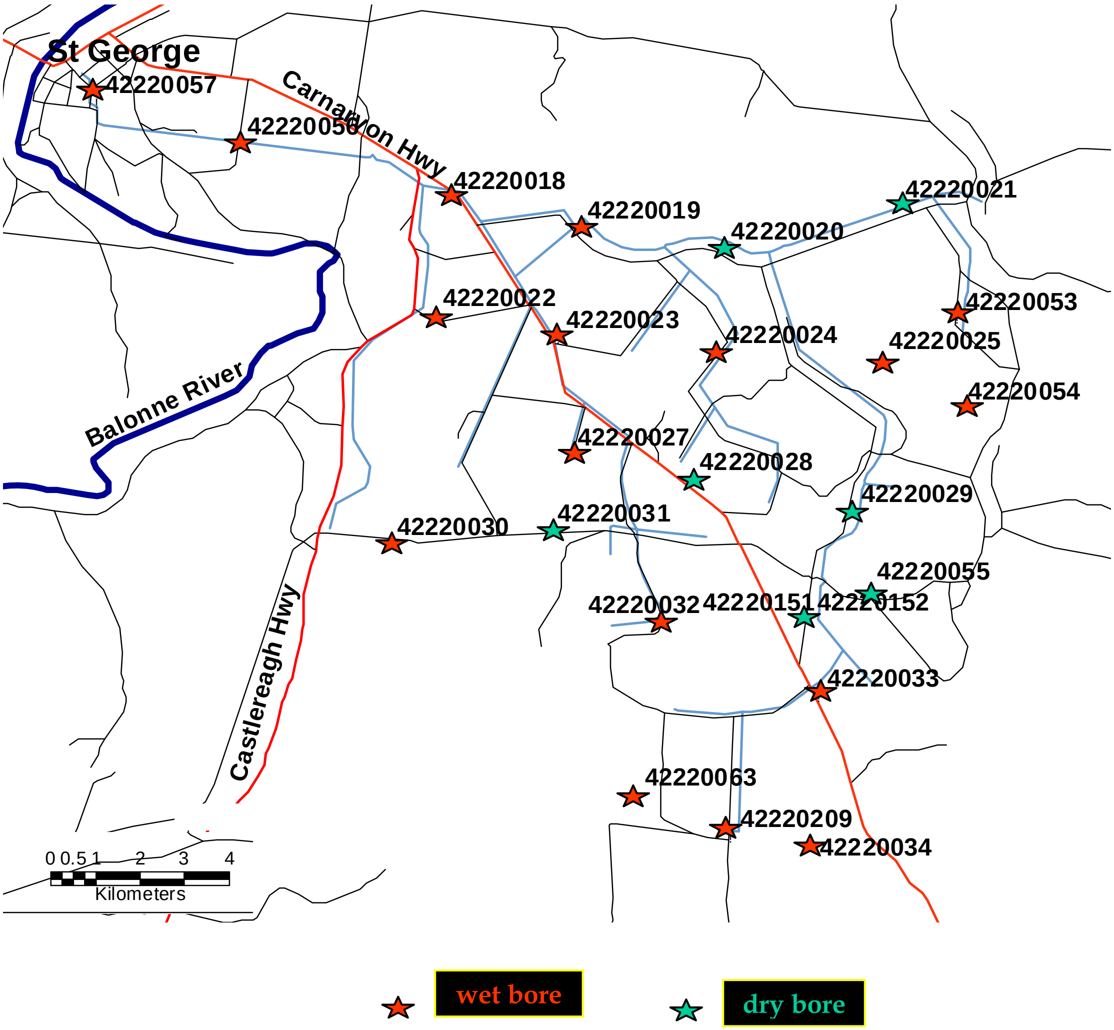

Figure 1. Location of dry and wet monitoring bores in St George Irrigation Area

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[11] NR&W, Groundwater Assessment and Planning, Southwest Region, Toowoomba; anne.riesz@nrw.qld.gov.au

[12] NR&W, Water Cycle Sciences, Indooroopilly

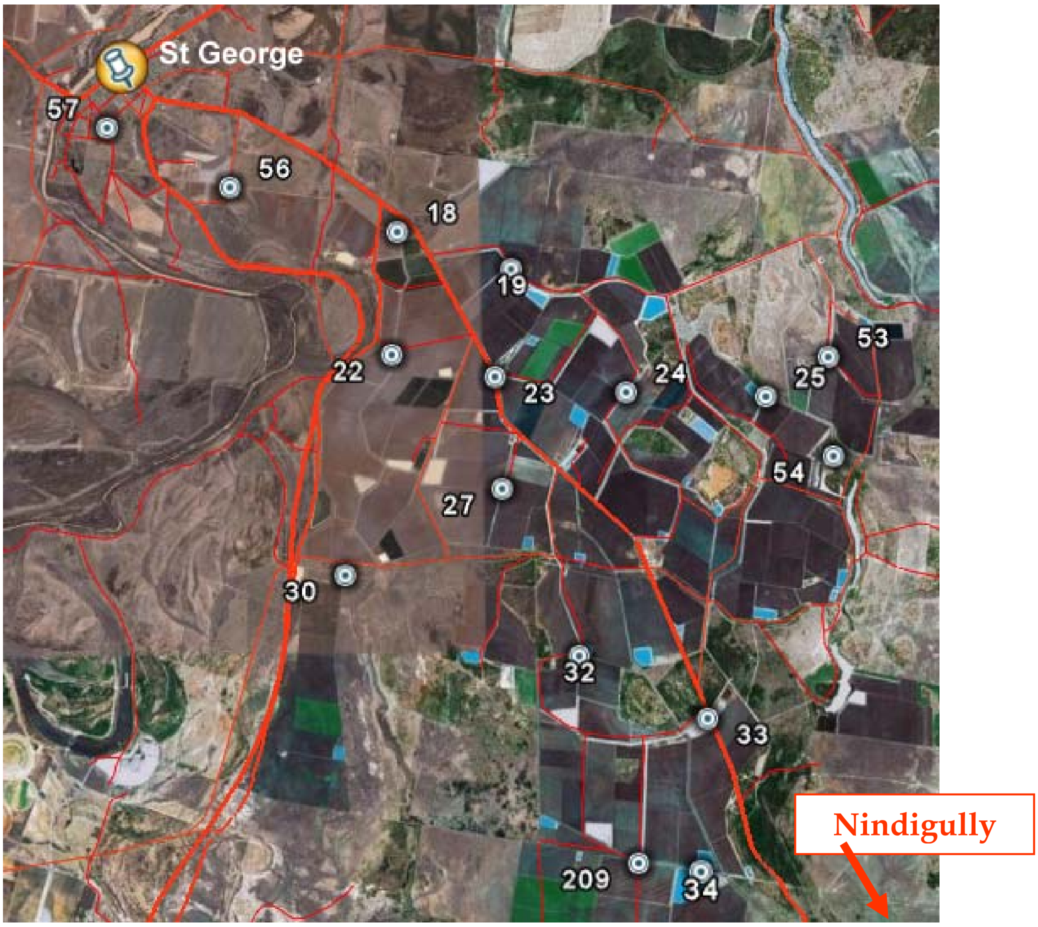


Figure 2. Location of the wet monitoring bores in the St George Irrigation Area

construction of the Jack Taylor Weir in 1953 and subsequent irrigation of approximately 2,700 ha of land via the original St George supply channel (Pullar and Cook, 2001). The next phase of expansion occurred in the early 1970s, with the construction of Beardmore Dam on the Balonne River in 1972, and subsequent construction of the Buckinbah supply channel, and the Buckinbah and Moolabah Weirs on the Thuraggi Watercourse (GHD, 2001). This expansion has enabled a total of 9,470 ha of irrigable land. Cotton is the main crop, although cereals, oilseeds and fodder are also grown in the area (MDBC, 2006).

There are a total of 24 observation boreholes within the irrigation area (Figure 1). Of these, 16 have been found to contain water (Figure 2); hereafter termed the “wet” boreholes. The remainder have (apparently) been dry, since installation. One borehole (42220026) has been destroyed without trace. All boreholes consist of 50 mm diameter PVC pipe, perforated with cut “slots” at a selected depth to monitor groundwater levels, and protected on the surface with a metal sheath (Figure 3).

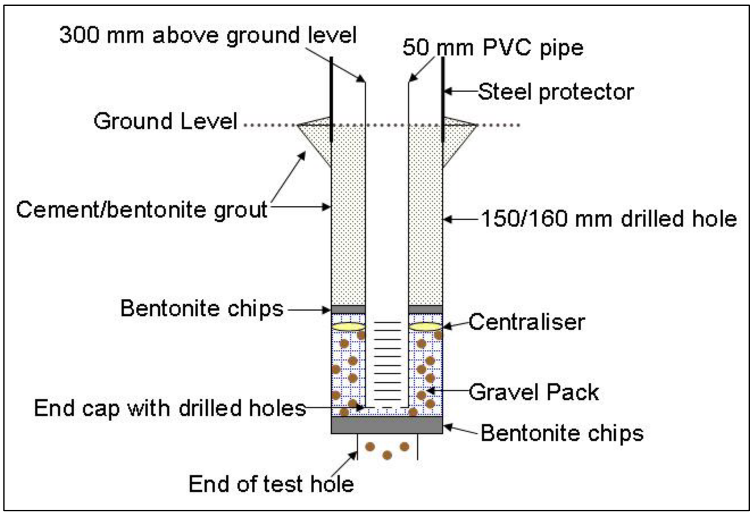
Drillers’ logs and historic water level collection

During the installation of the monitoring boreholes, records were kept ("drillers' logs") of the type and depths of materials being removed, bore construction details such as the depth of slots cut into the PVC pipe. Subsequently, water level records of the boreholes in the investigation area have been monitored from installation by tape measure. All of the data (drillers' logs and water levels) have been entered into DNR&W's "groundwater database". The database was interrogated for this information to facilitate presentation of the data in this report.

Recent field methods

From 19 – 21 June, 2006, DNR&W conducted water quality analysis and bore development *via* air lifting and hand bailing of the sixteen wet monitoring bores in the St George Irrigation area (south). Weirs and channels were also sampled for water quality. Water quality (Electrical Conductivity [EC] and pH) was analysed in the field for water sitting in the bores at arrival on site. In bores that had a sufficient depth of water, samples were taken from the top of the water column, and then the bottom of the water column and analysed separately. Water in each bore was then air lifted or hand bailed. During air lifting and hand bailing, water was removed equivalent or greater to three to four times the volume of water in each bore, allowing for development of the bore as well as enabling accurate sampling of water from the aquifer, rather than stagnant water from the bore. A range of water samples (stagnant water, water after development, weir and dam water) have been submitted for major ion analysis to the NRSc Chemistry Centre (NRW, Indooroopilly).

From 11 - 15 December 2006, the DNR&W conducted down borehole video investigations, using an AUSLOG "Mighty Cam" system[13]. The sixteen "wet" monitoring bores were investigated with colour video footage taken to the end of each borehole. The purpose was to determine the condition of the monitoring boreholes, specifically the integrity of casings and joints, the nature and location of slots, and the general effectiveness of these bores as monitoring bores, particularly with knowledge that many of the bores were drilled more than 30 years ago. Also, veracity of data to be recorded by the new logger systems required close inspection of the boreholes, particularly to determine if the bores are functioning correctly, i.e. that the water level in the bores reflects the water table of the aquifer each bore is monitoring.



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[13] http://www.auslog.com.au/product_files/borehole_video/borehole_video_index.html

Figure 3. Generic diagram of the construction of a monitoring bore. Not all bores are constructed in this manner, as discussed above.

RESULTS

A. Location of monitoring boreholes

The details of each bore are outlined in Table 1. Additionally, Figure 4 presents a visual representation of each borehole in terms of stratigraphy (from borehole logs where available), ground surface elevation, standing water level (December 2006 data), presence / position of slots, and presence of a sump (below the slots).

Installation of the 23 boreholes spanned a 30 year period, from 1972 to 2002 (Table 1). This wide range of ages appears to be reflected in heterogeneity of several aspects of the boreholes including not only physical considerations such as borehole depth and construction (eg slot type and location) but also an apparent change in the philosophy governing borehole location. The bores drilled in the 1970s were placed immediately beside channels (except two: 42220028 and 42220031), specifically to monitor potential leakages from these. Subsequently, on-farm water storages were constructed (from the mid-1990s), so many boreholes are now located along side these (eg 42220034) though leakage from these storages was not a testing hypothesis. More recent bores (eg 42220151, 42220152, and 42220209) were drilled as part of the National Action Plan for Salinity and Water Quality (NAP) initiative[14]. These bores tend to be deeper, have more detailed logs of stratigraphy, and utilise tools like down-hole geophysics to aid interpretation of results. The various ages of bores is also reflected in the nature and placement of slots and sumps in the boreholes. Slots occur in all the boreholes, though these may be vertical, horizontal or angled cuts with varying aperture size and spacing. Video inspection has shown that most bores (all but five) have sumps (where the PVC extends below the slotted section). Video inspection (see below) has also shown that all the sumps have been drilled with holes (approx. 3 mm drill bit), for reasons now unknown.

Table 2 presents field notes of the proximity of the wet and dry monitoring bores to local geographic phenomenon that may have an impact on the presence/absence of water in the bore, the water level (SWL ie metres below surface) of the water, and the dynamics of this level. Recorded were phenomena such as proximity to water carrying channels and on-farm storages, land use around the bore, and the seasonality of water in these channels and storages. Plans are current to intensify this part of the investigation, enrolling the farmer in closest proximity to the bore to keep a diary of water presence in channels and storages, and irrigation events in nearby cotton fields, and to provide historical information regarding development of water holding infrastructure. Appendix 1 lists the farmers closest to each bore.

The majority of monitoring boreholes (14 of 23) are located beside channels, and several of these (5) are also located next to on-farm storages. Two bores are located in natural, treed areas. However, there appears to be minimal correlation between the location of bores to potential supply phenomena and whether a bore is dry or wet, and

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[14] The general aim of the National Action Plan for Salinity and Water Quality was to provide new knowledge and developing methodologies for improved natural resource management in the Murray Darling Basin of southern Queensland, and more specifically to understand the processes and controls on salinity in the region.

the level of water in the bore. For example, both 42220031 and 4222054 are in treed "reserves" / grazing land, some distance from water bodies. However, the former is wet and the latter dry. Of the bores installed in the 1970s (42220018 to 4222034) all but two (42220028 and 42220031) are located besides channels. However, six of these are dry bores.

RN	Easting	Northing	Elevation	Date of Installation	Depth of bore (m)	Presence of Water	SWL* (m) (12/06)	Aquifer
42220018	661916	6893592	197.78	1972	11.30	Wet	- 9.90	Alluvial
42220019	664587	6892891	197.83	1972	12.59	Wet	- 12.39	Alluvial
42220020	667605	6892258	197.80	1972	12.26	Wet?**	- 12.12	Alluvial
42220021	670837	6893159	197.62	1972	12.57	Dry	- 12.57	Alluvial
42220022	661688	6890891	196.35	1972	12.27	Dry	- 12.27	Alluvial
42220023	664129	6890356	196.78	1972	12.48	Wet	- 5.87	Alluvial
42220024	667258	6889976	197.18	1973	12.76	Wet	- 9.23	Alluvial
42220025	670497	6889774	196.01	1973	12.92	Wet	- 6.19	Alluvial
42220027	664310	6887636	196.33	1972	12.20	Wet	- 9.68	Alluvial
42220028	666730	6887038	196.58	1972	12.78	Dry	- 12.78	Alluvial
42220029	669897	6886258	196.02	1972	18.42	Dry	- 18.42	Alluvial
42220030	660500	6885644	194.82	1972	26.26	Wet	- 20.01	GCF***
42220031	663893	6885869	195.20	1972	24.53	Dry	- 24.53	GCF
42220032	665987	6883738	193.75	1972	31.07	Wet	- 17.57	GCF
42220033	669167	6881968	192.99	1972	32.80	Wet	- 31.10	GCF
42220034	668965	6878541	193.28	1972	22.97	Wet		GCF
42220053	672030	6890679	196.97	1989	20.05	Wet	- 19.01	Alluvial
42220054	672048	6888574	196.26	1989	18.20	Wet	- 11.49	Alluvial
42220055	670201	6884441	194.21	1989	16.77	Dry	- 16.77	Alluvial
42220056	657841	6894915	199.58	1990	18.80	Wet	- 11.87	Alluvial
42220057	655035	6895917	199.63	1989	14.56	Wet	- 10.49	Alluvial
42220152	668991	6883753	194.20	2002	15.88	Dry	- 15.88	Alluvial
42220209	667393	6878738	192.52	2002	41.14	Wet	- 31.69	GCF

Table 1. Information for the monitoring bores in the St George Irrigation Area.
*SWL is the standing water level which is the depth from soil surface to the water surface within the monitoring borehole, measured by the principal author during field visits in September 2006.
** Bore 42220020 may have a very small amount of water present – requires re-checking before considering logger installation
*** GCF is the Griman Creek Formation.

RN	Site description – respect to proximity to water bodies	Presence of Water
42220018	beside channel (permanently water filled) no fields nearby	Wet
42220019	beside channel (permanently water filled) close to cotton fields	Wet
42220020	beside channel (seasonally water filled) close to cotton fields	Wet?
42220021	beside channel (seasonally water filled) close to cotton fields	Dry
42220022	beside channel (seasonally water filled) close to cotton fields	Dry
42220023	beside channel (permanently water filled) beside road	Wet
42220024	between 2 channels (one permanently water filled, the other seasonal) close to cotton fields	Wet
42220025	beside channel (permanently water filled) beside road	Wet
42220027	In a channel – on edge; (seasonally water filled) between cotton fields	Wet
42220028	beside highway, distant from supply channel but in middle of cotton fields	Dry
42220029	beside channel (seasonally water filled) and tail ditch of cotton field	Dry
42220030	beside channel (always water filled) and farm storage (seasonally full) on edge of cotton field area	Wet
42220031	In a treed area – hundreds of metres from channels and fields	Dry
42220032	beside channel (seasonally water filled) and farm storages (seasonally full) in middle of cotton fields	Wet
42220033	beside highway and large farm storage (seasonally full) in middle of cotton fields	Wet
42220034	between three farm storages and one channel (all seasonally water filled) in middle of cotton fields	Wet
42220053	beside channel (seasonally water filled) and in middle of cotton fields	Wet
42220054	in a treed area – 200 metres from channels, storages and fields	Wet
42220055	beside channel (permanently water filled)	Dry
42220056	beside channel (permanently water filled) close to drip irrigation field	Wet
42220057	beside channel (permanently water filled) no fields nearby	Wet
42220152	beside channel (permanently water filled) close to cotton fields	Dry
42220209	at southern end of irrigation area, channels nearby (permanently water filled) between cotton fields and edge of irrigated land	Wet

Table 2. Location of the wet and dry monitoring boreholes in respect to water carrying channels, irrigated cotton fields and on-farm storages, and their seasonality in relation to water level changes.

B. Stratigraphy and slot locations

RN	Depth of slots (m)	Stratigraphy at Slots	Presence of Water
42220018	11.60 – 12.22	Sand, fine to medium	Wet
42220019	11.60 – 12.20	N/A	Wet
42220020	11.20 – 12.48	Sand, gravel, fine to v. course	Wet?
42220021	N/A	N/A	Dry
42220022	11.60 – 12.22	N/A	Dry
42220023	11.60 – 12.20	Sand, fine to medium, claybound	Wet
42220024	11.60 – 12.20	Sand and gravel	Wet
42220025	11.58 – 12.20	Sand, fine to v. course	Wet
42220027	11.53 – 12.20	Sand, clayey, fine to course	Wet
42220028	11.72 – 12.32	Sand, clayey, fine to medium	Dry
42220029	17.32 – 17.98	Sand, clayey, fine to v. course	Dry
42220030	25.10 – 25.70	Multicoloured rock	Wet
42220031	22.38 – 24.23	Multicoloured rock	Dry
42220032	29.81 – 30.48	Multicoloured rock	Wet
42220033	29.81 – 30.47	Multicoloured rock	Wet
42220034	20.66 – 21.33	Multicoloured rock	Wet
42220053	18.60 – 19.60	Sand, medium, clay	Wet
42220054	17.00 – 18.00	Sand, medium, clay	Wet
42220055	15.60 – 16.60	Sand, clay	Dry
42220056	17.10 – 18.10	Sand and medium gravel, clay	Wet
42220057	13.10 – 14.10	Gravel and sand, sandy clay	Wet
42220152	13.00 – 16.00	N/A	Dry
42220209	36.00 – 39.00*	Sand, v. fine to medium, clay	Wet

Table 3. Depth of slots and stratigraphy at that depth for each monitoring borehole.
*The bore card for bore 42220209 describes the slots at 42 – 49 m. However recent downhole video investigations showed the slots to be between 36 – 39 m.

Information from the bore logs (where available) in terms of stratigraphy, the location of slots and the stratigraphy at the slots location is included in Table 3 and Figure 4 (Anne's diagram). Generally, records of the early borelogs (1970s) gave simple descriptors of materials removed during drilling. Unfortunately, the original borelogs were destroyed, negating the possibility of trying to gain further information from the drillers' logs. Evident from Table 3 is that the placement of slots and screens is not consistent in terms of either depth or material (at that depth). There seems to have been a rationale with the 1970s bores to drill to and slot at approximately the same depth (11.6 m to 12.2 m), irrespective of what materials occurred at that depth. At this depth, some of the bores tap sands and gravels, and others tap clay rich materials.

The range in water levels, water quality and response of water levels in bores in the alluvial aquifer indicate a system that is heterogeneous, with the probability of a wide range of connectivity between water bearing sand lenses. This level of heterogeneity is common with alluvial depositional environments, such as those under the St George Irrigation Area. The location of the deposition of sediments of the Balonne River has been controlled to the west by the Dirranbandi Trough and associated fault, and the anastomosing[15] channels of the Maranoa Fan (Kernich, *et al* 2003; and Kernich *et al*, 2005; abstract of the latter presented in Appendix 2). The palaeo-Balonne was a braided system, depositing materials over a wide extent, with sand units displaying poor lateral connectivity and good connectivity along the units, resulting in a strongly anisotropic character to groundwater flow through these units (Clarke and Riesz, 2004).

C. Historic bore logs

The bore logs for all wet monitoring bores are presented in Appendix 3. All data are plotted in Figure 5 on a common Y-axis (being SWL – water level in metres below surface). In general, viewing of the logs highlights that data continuity has been variable in terms of logging interval (a range of more than 2 per year to less than 1 per year); the 1970s and the early 2000s tended to be data rich but the 1980s and 1990s were data poor) (Figure 5). These data limitations greatly reduce capacity to comment on groundwater movement in this period.

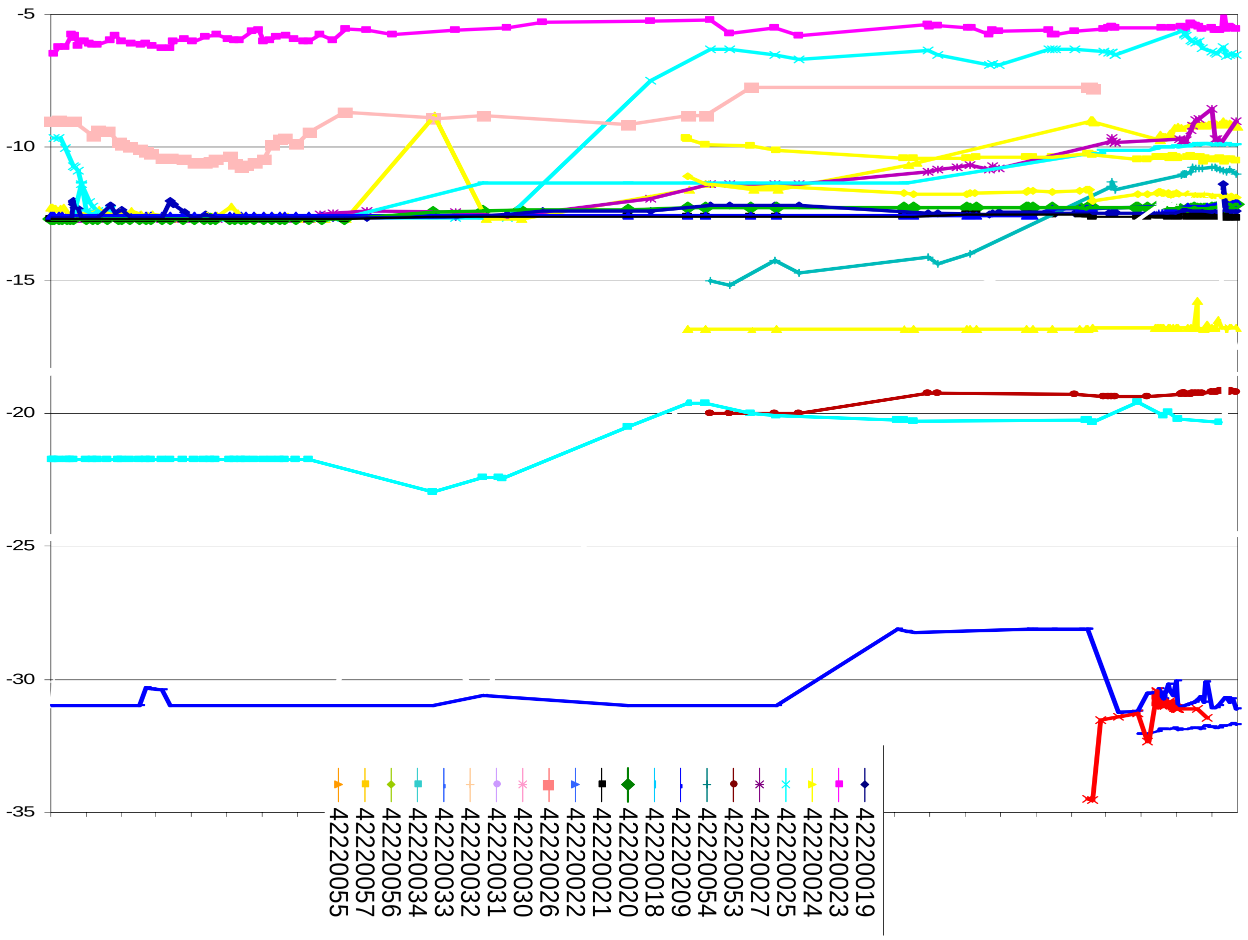

Figure 5. Historic water level borelogs for all St George monitoring boreholes, plotted for SWL ie metres below surface.

Not only are data continuity poor for water levels, but also for EC and pH recording. In addition to poor continuity for this data, the values may be inaccurate due to the

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[15] Anastomosis (or braiding) describes a stream that is overloaded with sediment, so tends to break into smaller channels that wander across the streambed, branching and reconnecting.

sampling of stagnant water in bores that may not represent groundwater if the bores have not been developed by pumping or airlifting.

Several trends can be taken from the historic bore logs. However, it is also apparent that there are few "overall" trends in groundwater response for the whole irrigation area; not surprising considering the heterogeneity of bore depths, slots in terms of depth and material at that depth, and the proximity of local potential contributing phenomena like channels and storages.

- 42220023 is the bore where the water level is closest to the ground surface; the highest level being 5.2 metres (1991) and rarely below 5.5 metres to 2007. Bore 42220025 is second shallowest; 6.2 metres below ground in 1990 and rarely less more than 6 metres to 2007.
- Of the bores installed in 1972, most were inactive until the early or mid 1980s when they suddenly became active, in that water levels rose rapidly. These were 1979 (42220026), 1981 (42220018 and to a lesser extent 42220020), 1983 (42220034), 1985 (42220024, 42220025, 42220027, 42220032) and 1993 (42220033).
- Generally, the groundwater rise in these bores peaked in the 1990s and then has plateaued, for example: 1990 (42220025 and 42220034 following 6 metre and a 3.5 metre rises, respectively), 1992 (42220026; 3 metre rise) and 1997 (42220033; 3 metre rise).
- Some of the 1970s bores continue to rise, for example: 42220018 (rapid 1 metre rise 1981 to 1985, plateaued to 1997, then continues to rise (total of 2 metres to present); 42220024 rose 3.7 metres from 1985 to 2002 and appears to again be rising, and 42220027 rose 4 metres from 1985 to 2005, and seems to have plateaued, 42220032 rose 19 metres from 1985 to 2005 and now seems to have plateaued.
- Some are hardly active, or have been dry since installation (eg 42220019, 20, 21, 22, 23, 28, 2930, 31).
- The two bores closest to the St George township (42220056 and 42220057) have both dropped in water level (a total of 70 to 80 cm) from the early 1990s (installation) to present.
- With the most recently drilled bore, 42220209, there has been an apparent 50 cm rise in water level from installation in 2002.

In conclusion, water level data from the monitoring bores can only be regarded as "sufficient" to determine overall trends with time. In particular, it is difficult to draw conclusions for shorter time periods, except in sporadic periods of good data continuity. Obvious errors in records exist in water level records (inexplicable spikes and dips for 1 reading). EC and pH data should not be used unless it is specified that the water in the bore has been removed and fresh water sampled.

C. Recent investigations –

1. Water quality analysis and development

Results of water quality analysis from the air lifting, hand bailing and subsequent re-development exercise in June 2006 are given in Appendix 4. Figure 6 presents the EC data from the irrigation waters and the water collected in the lysimeters at the eight deep drainage sites. The "St George S" site is located 500 metres from monitoring borehole 42220032.

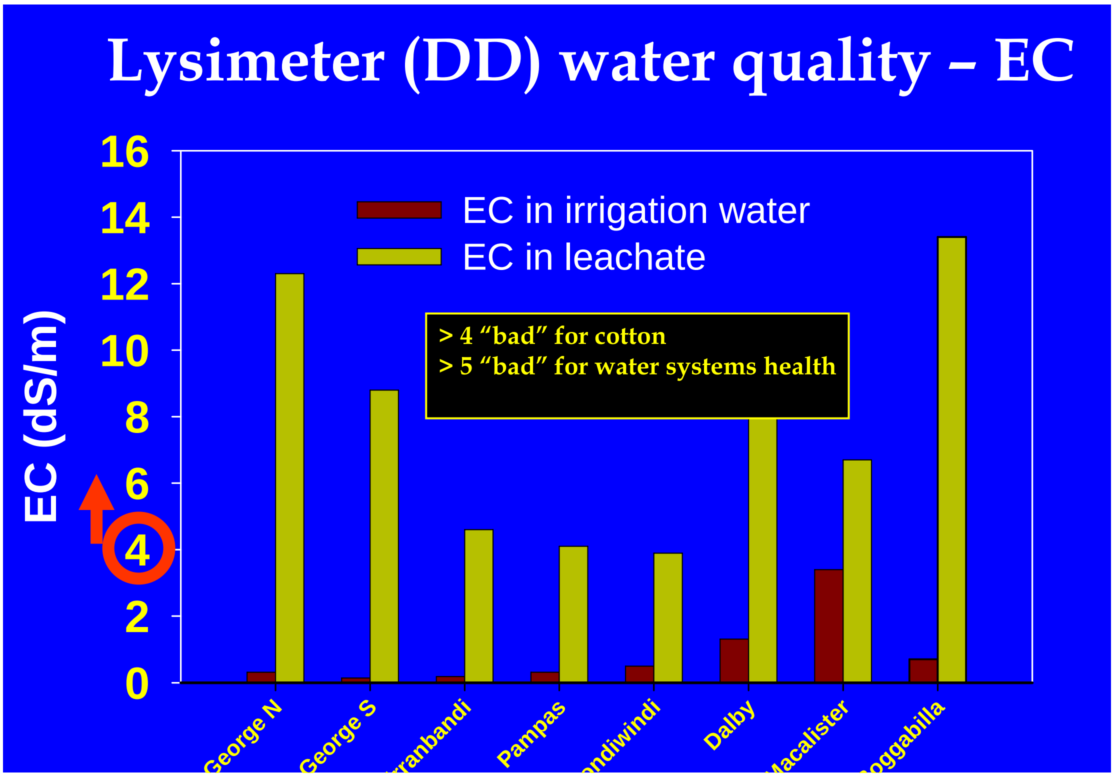

Figure 6. Electrical conductivity (EC) of the irrigation water and the water collected in the lysimeters at each of the eight deep drainage sites.

There is wide variance in the EC levels recorded in the monitoring boreholes. Bores 42220019 and 42220020 had the largest EC values after water level recovery, 20.94 and 18.45 ds/m, each of which is far greater than the maximum EC value recorded in lysimeter waters (13.8 ds/m). Bores 42220030 and 42220053 also had values greater than 13.8 ds/m; 14.23 and 18.5 ds/m. Values greater than 4 and 5 are considered "bad" for cotton growth and water systems health, respectively. These data demonstrate that there is no apparent correlation between bore depth and large EC values (note all bores are slotted close to the bottom of the bore length); 42220018 and 42220019 being relatively shallow (11.3 and 12.6 metres), 42220030 and 42220053 being deeper (26.3 and 20.1 metres). The two bores closest to St George town, 42220056 and 42220057, have the next largest EC values: 4.4 and 5.1 ds/m. These values are above the tolerance of most crops. All other bore waters had EC values less than 3 ds/m with many being less than 1 ds/m.

2. General Condition of Bores

Results of down hole video inspections of December 2006 are given in Appendix 5. In general, the outcome of the down borehole monitoring demonstrated that the majority of bores were in good condition, with sound casing and joints, and clean slots. A few cracks in the casing were found (for example 42220019 had a crack at the join between the casing and the slotted section; not considered problematic as located close to the slotted section). Worse were gaps between PVC casing sections in bore 42220033, that appeared to be leaking water from outside the bore casing. Several bores had slots that were clogged with silt (42220022) or an algae like substance (422200209). Plans are current to either replace (re-drill) these monitoring bores, or to clean them (acetic acid) of accumulated algal growth. Additionally, video observations showed that the majority of the bores had sumps and that they varied in nature, particularly that some (of the PVC casings) had holes drilled through (approximately 3mm in diameter), and some did not. Because the sumps are located below the slots in the bore, their nature may have strong implications for water levels that occur below the slots inside the sumps. Bores without sumps were: 42220027, 42220053, 42220054, 42220056, 42220057.

3. Data Loggers

After extensive research of data loggers suitable for monitoring water levels in shallow monitoring bores, the loggers chosen were Schlumberger Mini-Diver Model DI 501[16]. The accuracy of these loggers is 0.5 cm of water, and the resolution is 0.2 cm of water. On each measurement, the Diver registers the date and time, groundwater level and temperature. Logger dimensions are 22 mm diameter and length 90 mm, making them ideal for 50 mm monitoring bores. The loggers have been set to record the pressure exerted upon them twice a day, at 12am and 12pm. There is a 1:1 linear relationship between the pressure recorded by the logger and changes in water levels, and a manual water level reading is taken at installation and removal of the logger, in order to correlate changes in logged pressure to real changes in SWL. One "Baro" logger was purchased to correct the logger data for changes in local barometric pressure. This is done during a routine logger download when all loggers are read using a unique optical reader, and then compensated for barometric pressure changes using purpose built software. The baro logger is installed in bore 42220024.

Figure 7. Schlumberger Mini-Diver Model DI 501; logger being read in the purpose built optical reader.

Pressure loggers were installed in 10 wet boreholes in December 2006, along with one barometric pressure logger (located in the middle of the "nest" of monitoring bores), and an additional 6 were installed in January 2007. Each logger was suspended by braided stainless steal wire, utilising the existing cap of the monitoring bores to suspend them. The length of the wire was determined for each borehole, taking into account the SWL in the bore, the general trend and size of fluctuations in the water levels. This was to ensure the logger was more than 1 m below the current SWL and will never be greater than 10 m below the current SWL in the life of the project.

In February 2007, each logger was downloaded. Appendix 6 presents the water level plots of three of those loggers over the six week period of logging. In this period of logging, boreholes 42220024 and 42220025 both rose by 1 cm per day, and 42220032 rose and fell by 20 cm to 30 cm over the same period. Boreholes 42220024 and 42220025 have a smooth graph, with no diurnal effects. Borehole 42220032

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[16] http://www.aqualab.com.au/products/diver_mini.htm

fluctuates between each reading – however this fluctuation changes, indicating that diurnal effects are not strong here. Boreholes 42220024 and 42220025 are shallow (less than 10 m in depth) and borehole 42220032 is deeper (greater than 30 m in depth), and taps the Griman Creek formation (the underlying bedrock).

References

Clarke, J.D.A., and Riesz, A.L. (2004). Fluvial Architecture of the Subsurface of the Lower Balonne Area, Southern Queensland, Australia. CRC LEME Open File Report 162.

Kernich, A.L., C. F. Pain, C.F., Clarke, J.D.A. (2005). Geomorphology of the lower Balonne River, southern Queensland, Australia. Geophysical Research Abstracts, Vol. 7, 02508.

Pullar, I., and Cook, M. (2001). Watery Sauces: a people’s history of the Water Resources Commission (Queensland) and its Predecessors 1881 – 1995.

Appendix 1

Suggested local contacts:
- Farmers / owners on or beside whose property the wet monitoring boreholes occur

42220018 - Chad Prescott - 4625 2163 (or Ian Hill?)
42220019 - John Dowling - 0417 722 634
42220022 - James Thomas - 0427 252 128 (or Scott Armstrong? - 0418 721 444)
42220023 - Rob Jakins? - 0427 255 541
42220024 - Cubbie St George - try Craig Brimblecombe
42220025 - Andrew Lyons - 4625 2106
42220027 - Darren Armstrong - 0418 876 385
42220030 - Henry McDonald - 0427 747 813
42220032 - Bill Knights - 0419 252 170
42220033 - Cubbie St George - try Craig Brimblecombe
42220053 - Rogan - Cleave (0418 721 564) or Glen (0418 720 448)
42220054 - Rogan - Cleave or Glen
42220034 - Chad Prescott or Henry McDonald ?
42220056 - was Moon's block - could be Jeff, Andrew or David and may not be)current? Phone: 0427 255 148)
42220057 - ??try Peter Haslem - 0428 657 325 - (local consultant)
42220209 - Chad Prescott (or Glen Price?)

Appendix 2

Geomorphology of the lower Balonne River, southern Queensland, Australia.

Kernich, A.L., C. F. Pain, C.F., Clarke, J.D.A. (2005).

Geophysical Research Abstracts, Vol. 7, 02508.

Abstract

The landscape has a complex evolutionary history. Bedrock consists of the Griman Creek Formation, deposited as marine sediment in the Cretaceous. This unit has been slightly deformed and extensively weathered to form silcrete and ferricrete in varying amounts. The weathering profile is believed to strongly influence the groundwater characteristics in the area by forming an aquiclude for the overlying alluvial sediments.

Coincident with the erosion and weathering quartz gravels were deposited and are now extensively duricrusted and preserved as remnants forming zones of inverted relief. These are inferred to be Early Tertiary in age. Much of the present landscape consists of a series of juxtaposed depositional surfaces. These are the surface expression of an incised and infilled valley succession formed from the Pliocene onwards by the palaeo-Balonne, Moonie, Maranoa and Condamine Rivers.

The oldest of the depositional surfaces is the Maranoa surface. At present there is little active channel flow on the surface and it now has a slightly weathered and eroded form. The Maranoa surface is Pliocene – Early Pleistocene in age. At some point following the deposition of this feature, the Balonne River was diverted to its present course between two low rises upstream from the township of St George. After it changed course, the Balonne River flowed to the east of its present course. At the same time the Moonie River was bringing material from further east and presumably because it was blocked by sediments from the Balonne River, turned to the south to take up its present course.

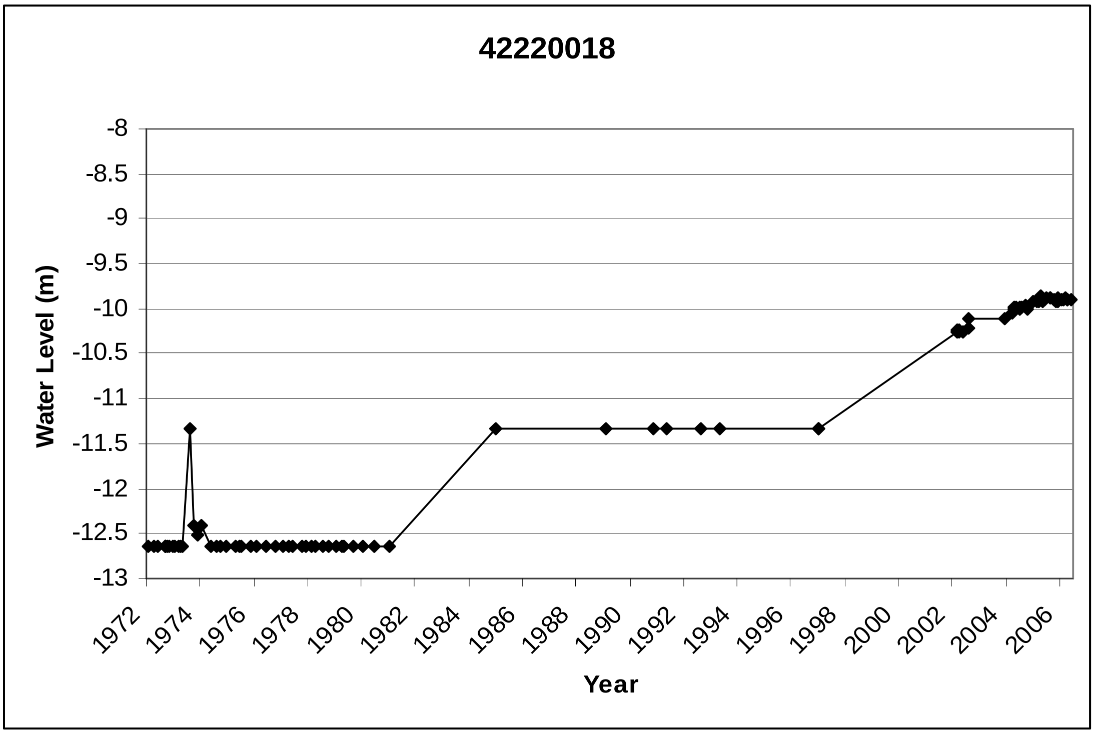
These changes in sedimentation patterns on the fluvial plain formed a series of different depositional surfaces. The Modern Balonne River system consists of a number of easily recognised segments. In the north, the modern Balonne River channel is deep and well established. To the south the modern channel opens out onto an anastomosing plain with branching and reconnecting small-scale channels. Source bordering dunes have also formed along the western and eastern sides of the modern Balonne River and are prominent in large dunes in the south along the present Moonie River. However, they are not apparent in older landscape elements.

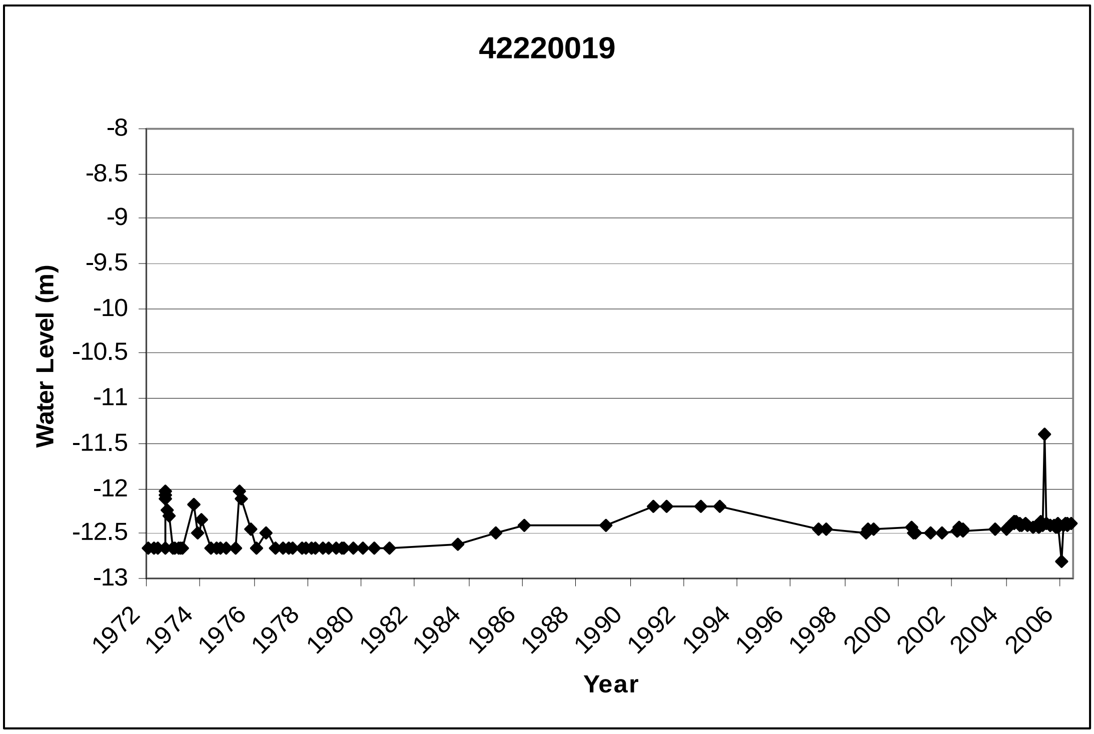
The surface distribution of regolith materials on most geomorphic units is a fair indication of the complexity of regolith materials at depth. Regolith distribution patterns of former channels in the major alluvial geomorphic units can be described, even if their actual location can not be predicted. Surface mapping unfortunately does little to characterise the sub-surface character of the Griman Creek formation which is present at depth throughout the study area and is a crucial factor in the ground water flow systems. Overall, however, knowledge of the surface distribution of regolith materials, their boundary character, and the processes that are responsible for that

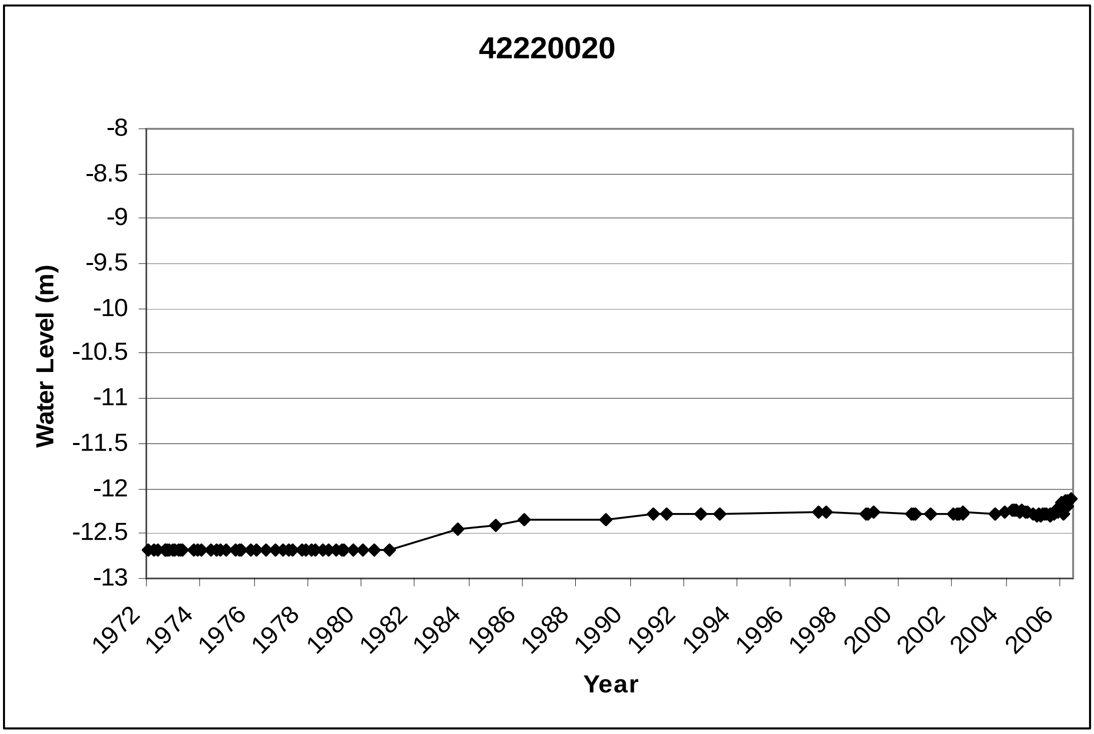
distribution, can be used as part of the input into models of the 3D regolith architecture, and of the evolution of the Lower Balonne landscape.

Areas that may be a salinity hazard have also been identified through this study of the regolith and landforms of the Lower Balonne area. Predominantly these are located along the eastern boundary of the Maranoa surface. These are areas of concern because of their sodic soils, the potentially active seepage of saline water that the geomorphic evidence indicates to be going on in the area, and their proximity to the current Balonne River, which may receive some of the saline efflux.

Historic Water Level Graphs (borelogs) of the St George Monitoring Bores






42220020
Water Level (m)
-8
-8.5
-9
-9.5
-10
-10.5
-11
-11.5
-12
-12.5
-13
1972
1974
1976
1978
1980
1982
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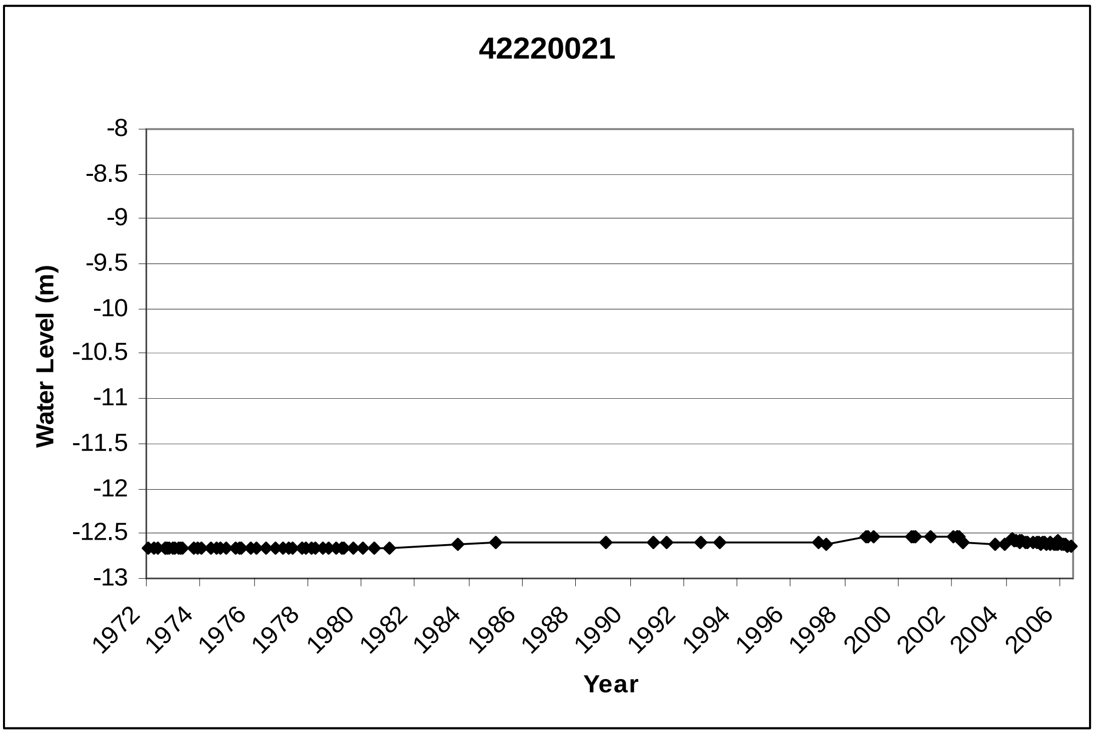
2004
2006
Year


42220021
Water Level (m)
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-8.5
-9
-9.5
-10
-10.5
-11
-11.5
-12
-12.5
-13
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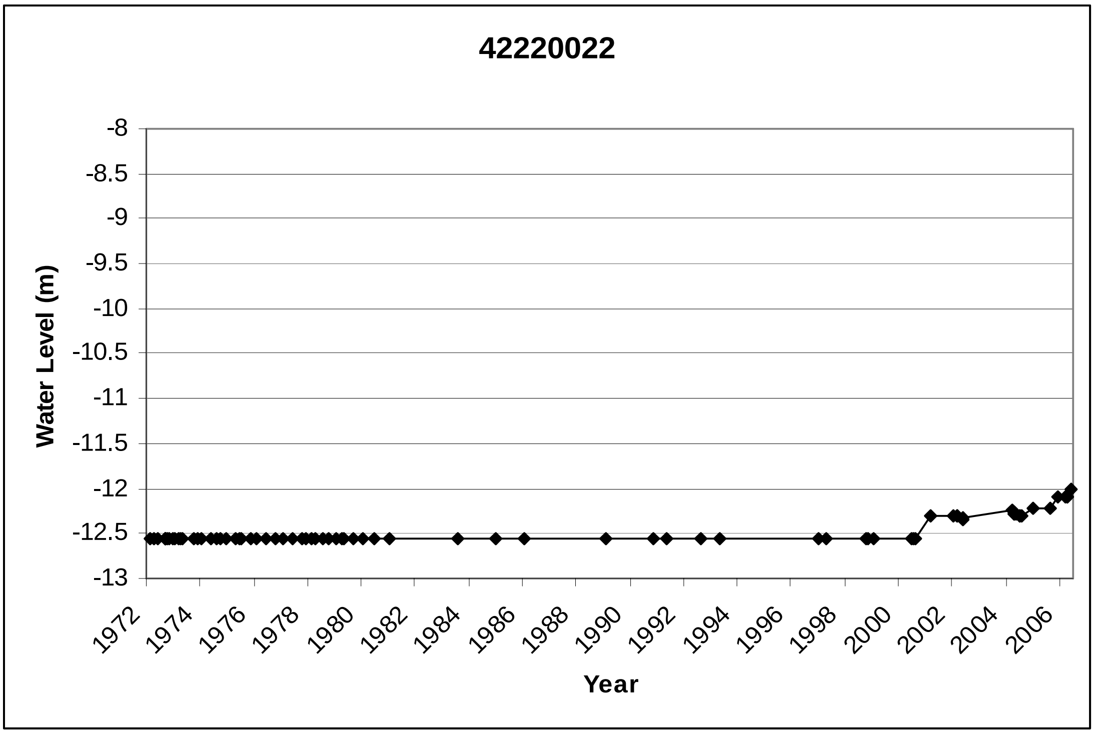
2006
Year


42220022
Water Level (m)
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-9
-9.5
-10
-10.5
-11
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-12.5
-13
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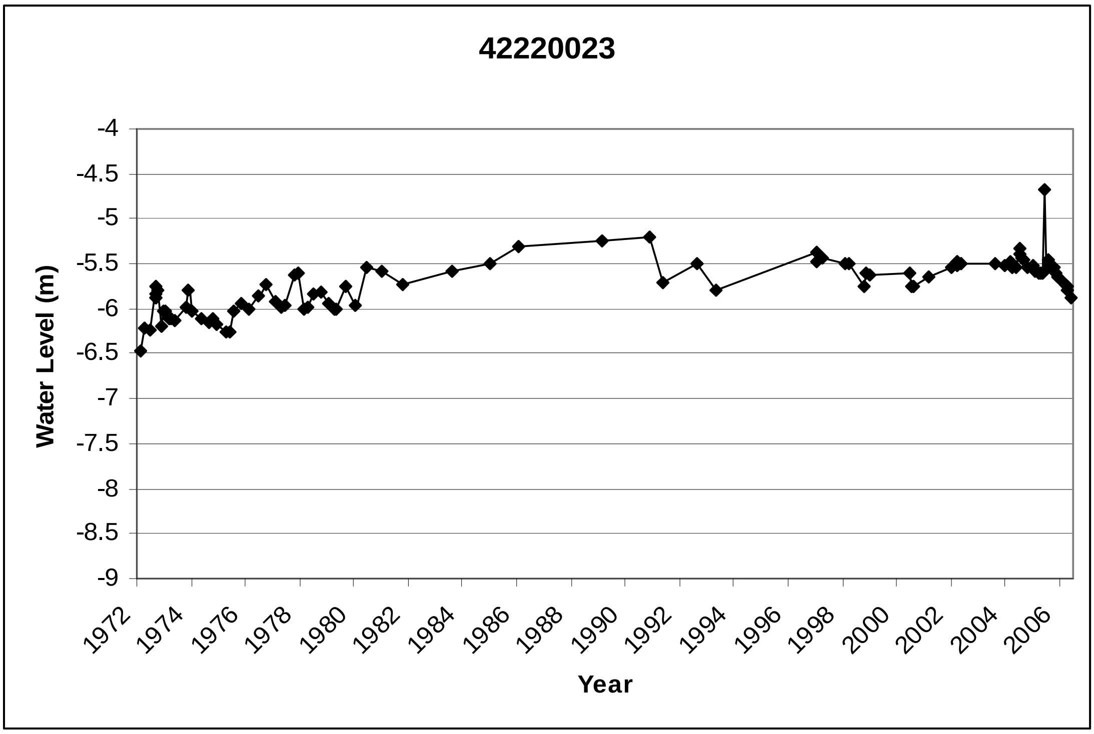
Year


42220023
Water Level (m)
-4
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8.5
-9
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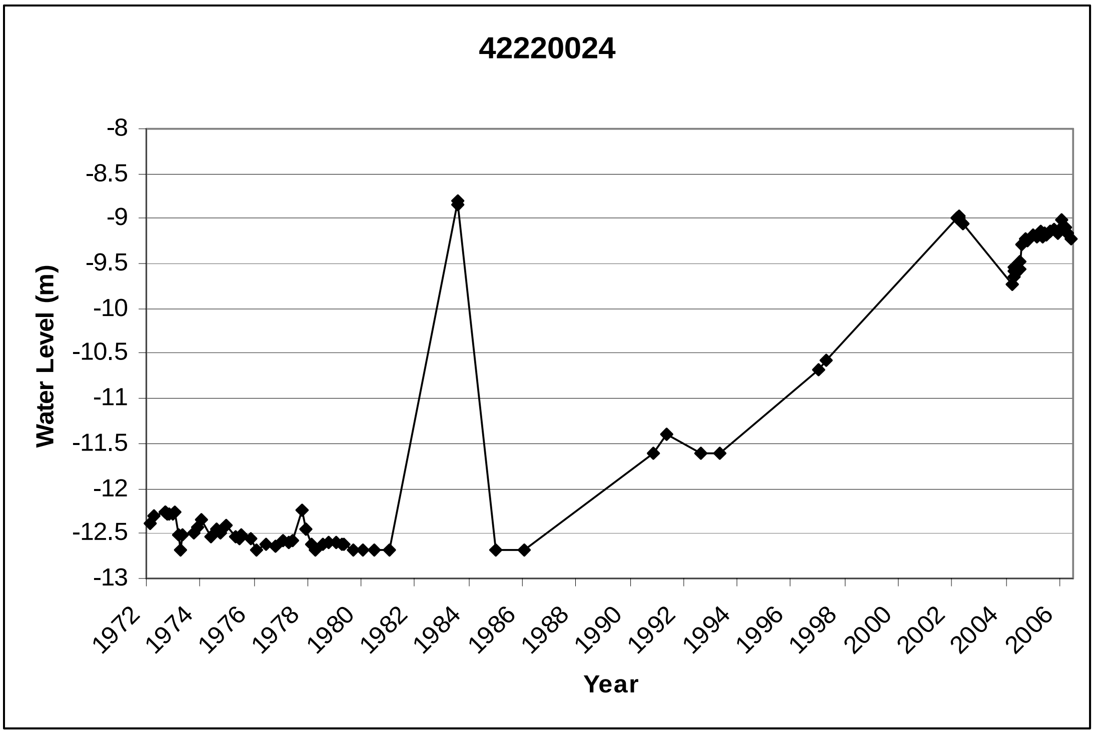
Year


42220024
Water Level (m)
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-12.5
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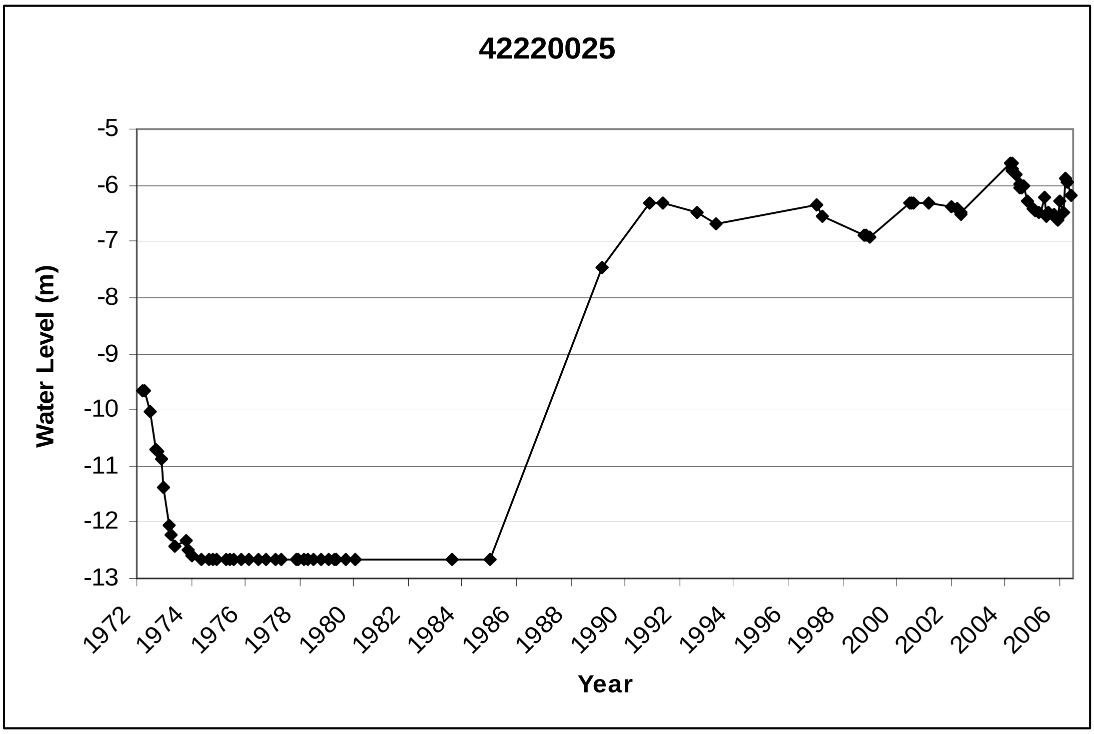
2006
Year


42220025
Water Level (m)
-5
-6
-7
-8
-9
-10
-11
-12
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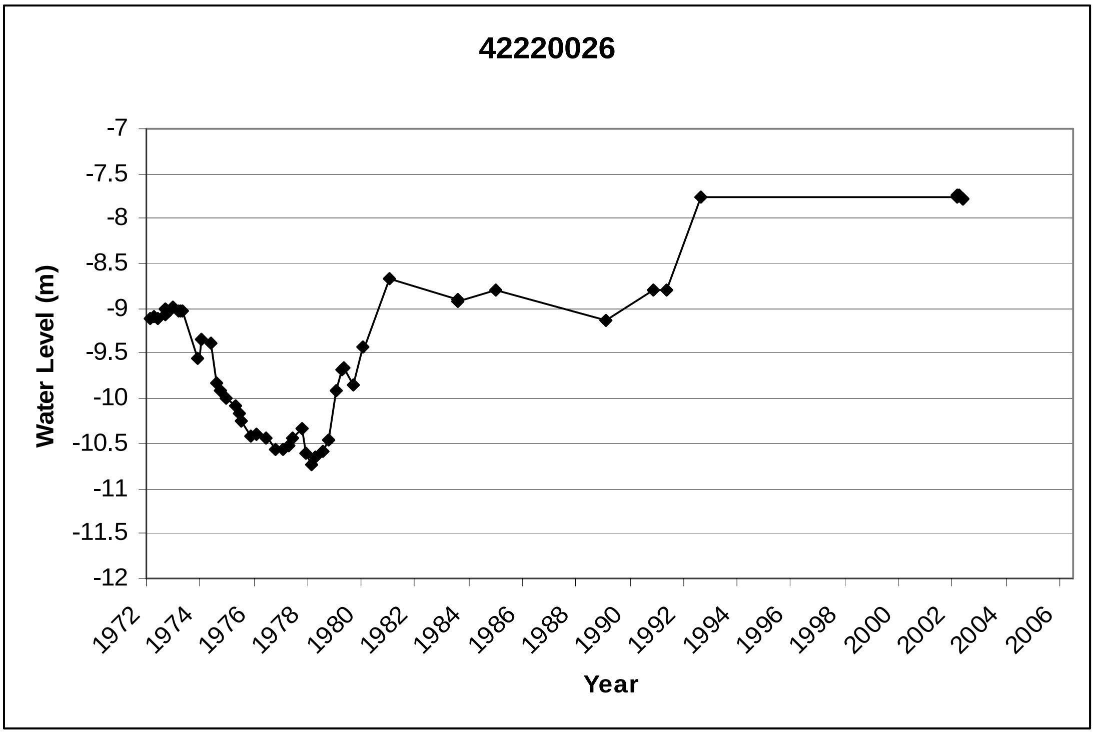
2006
Year


42220026
Water Level (m)
-7
-7.5
-8
-8.5
-9
-9.5
-10
-10.5
-11
-11.5
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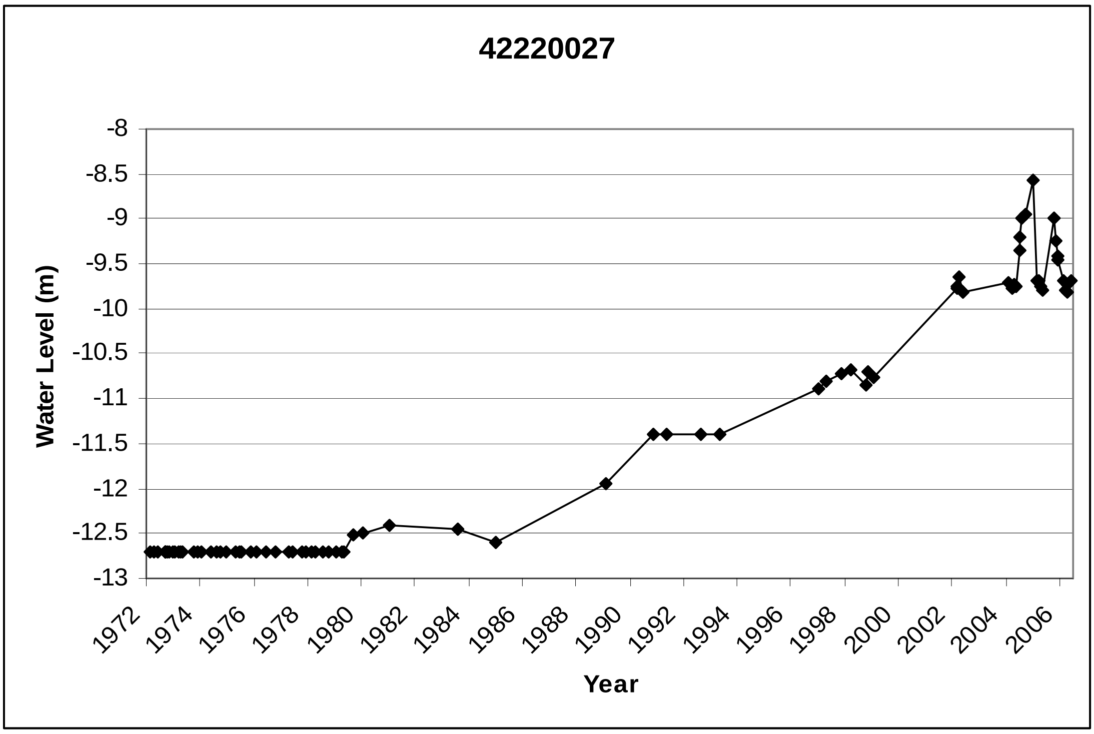
2006
Year


42220027
Water Level (m)
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-10
-10.5
-11
-11.5
-12
-12.5
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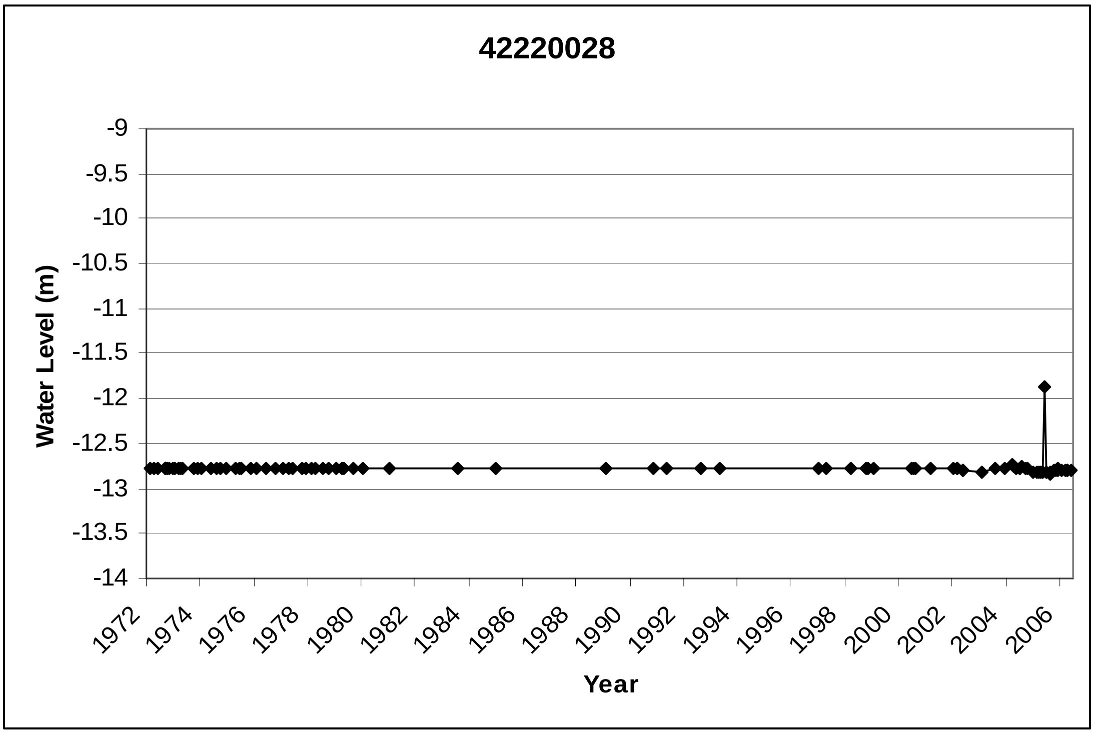
2006
Year


42220028
Water Level (m)
-9
-9.5
-10
-10.5
-11
-11.5
-12
-12.5
-13
-13.5
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1978
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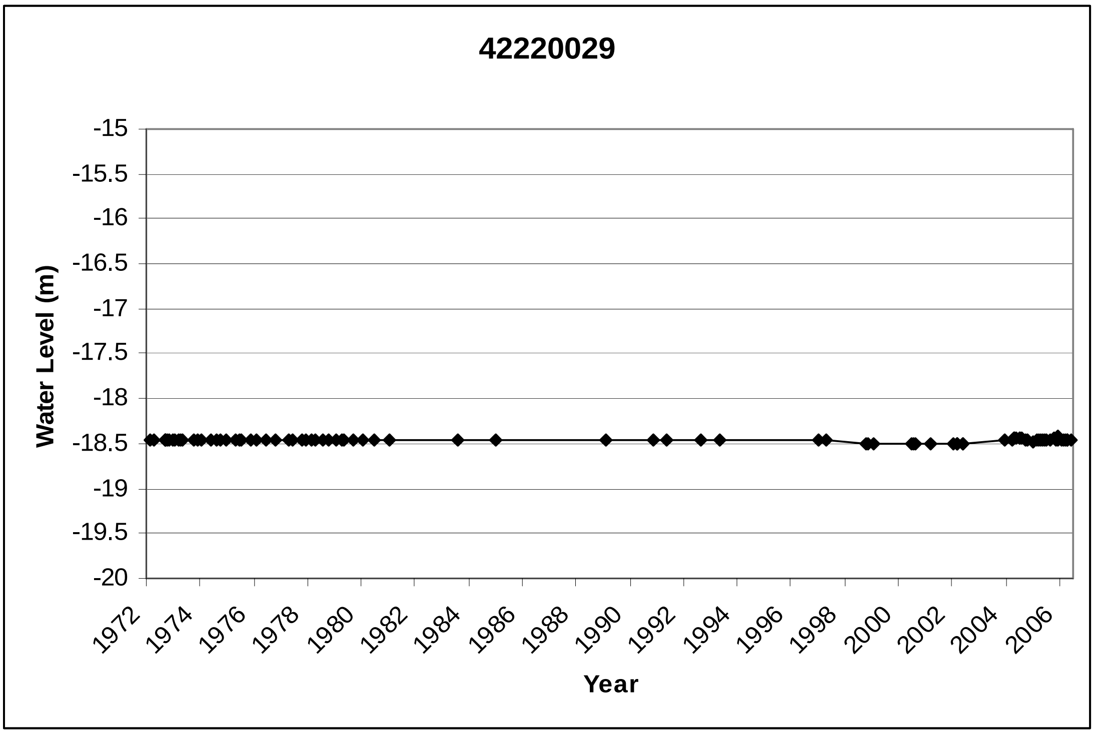
2004
2006
Year


42220029
Water Level (m)
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-17
-17.5
-18
-18.5
-19
-19.5
-20
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1974
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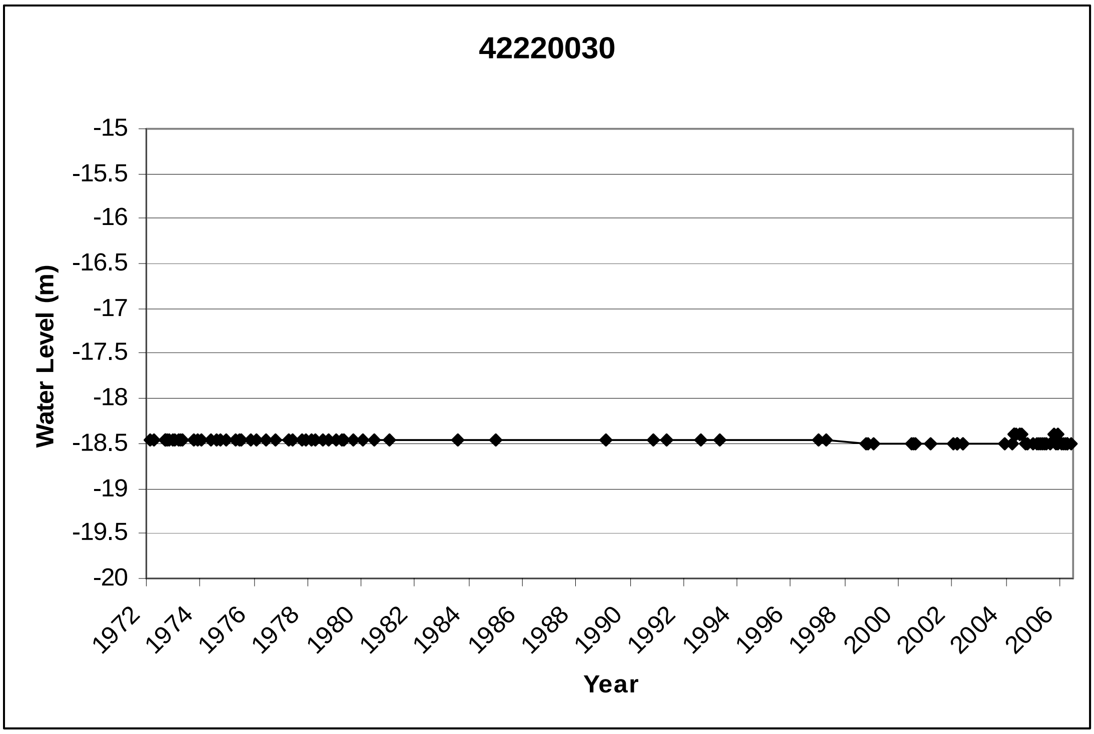
2006
Year


42220030
Water Level (m)
-15
-15.5
-16
-16.5
-17
-17.5
-18
-18.5
-19
-19.5
-20
1972
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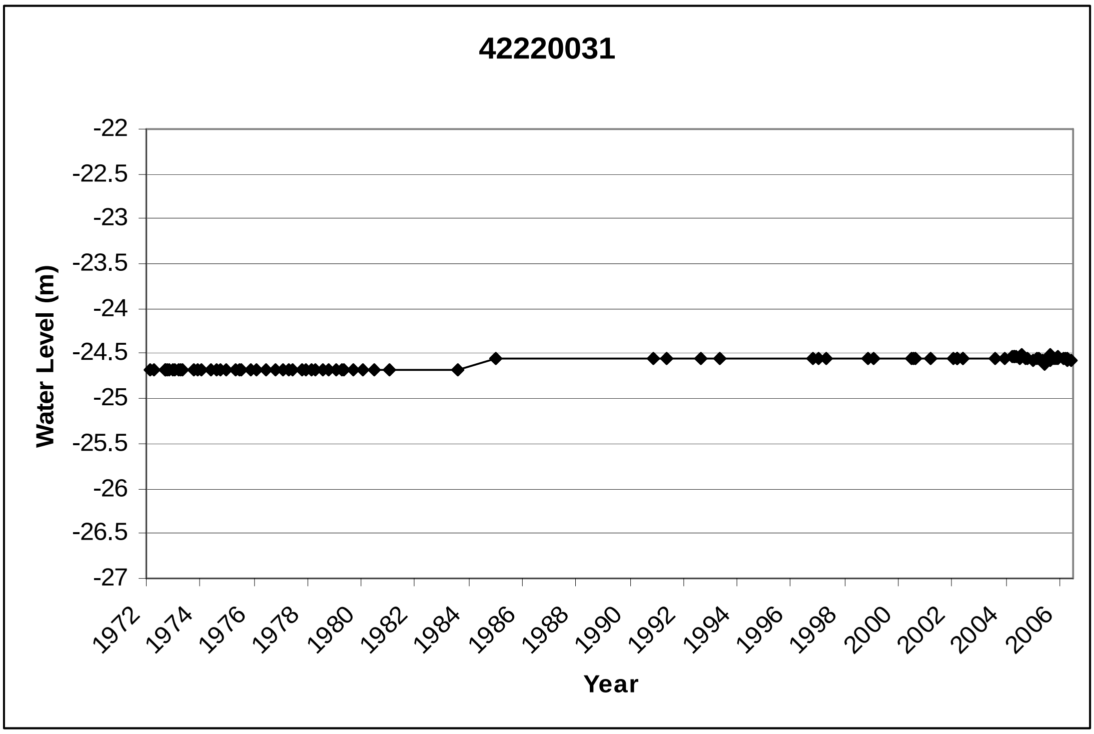
2002
2004
2006
Year


42220031
Water Level (m)
-22
-22.5
-23
-23.5
-24
-24.5
-25
-25.5
-26
-26.5
-27
1972
1974
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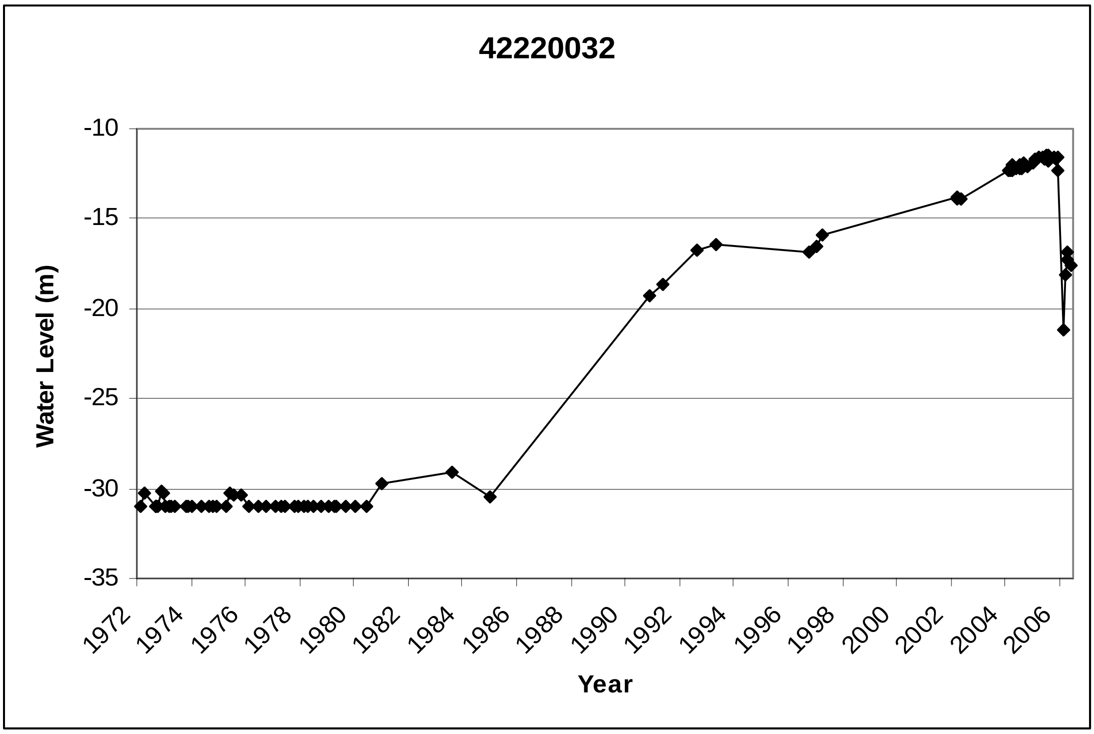
2004
2006
Year


42220032
Water Level (m)
-10
-15
-20
-25
-30
-35
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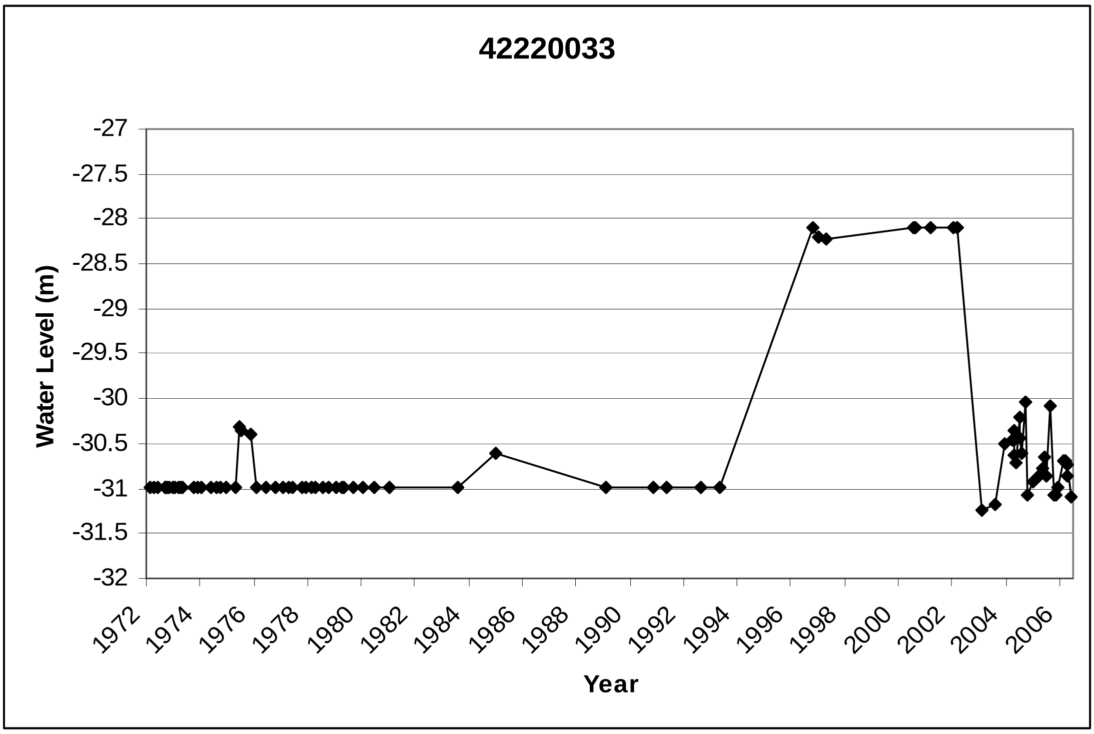
2006
Year


42220033
Water Level (m)
-27
-27.5
-28
-28.5
-29
-29.5
-30
-30.5
-31
-31.5
-32
1972
1974
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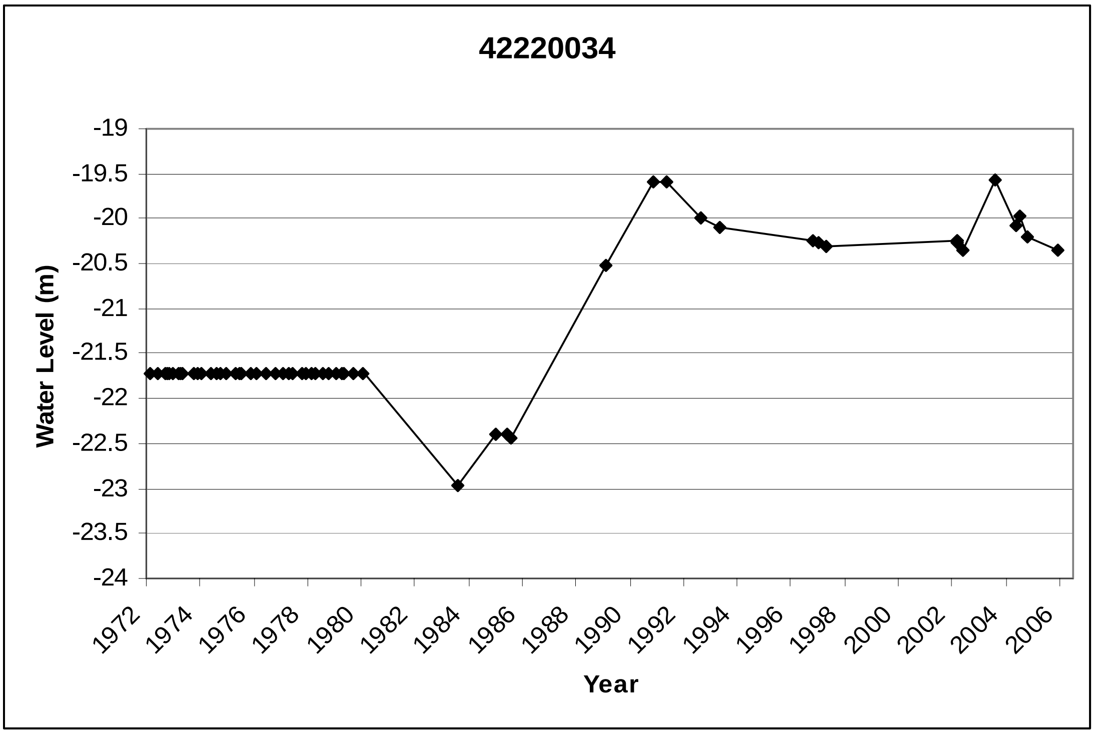
2004
2006
Year


42220034
Water Level (m)
-19
-19.5
-20
-20.5
-21
-21.5
-22
-22.5
-23
-23.5
-24
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1974
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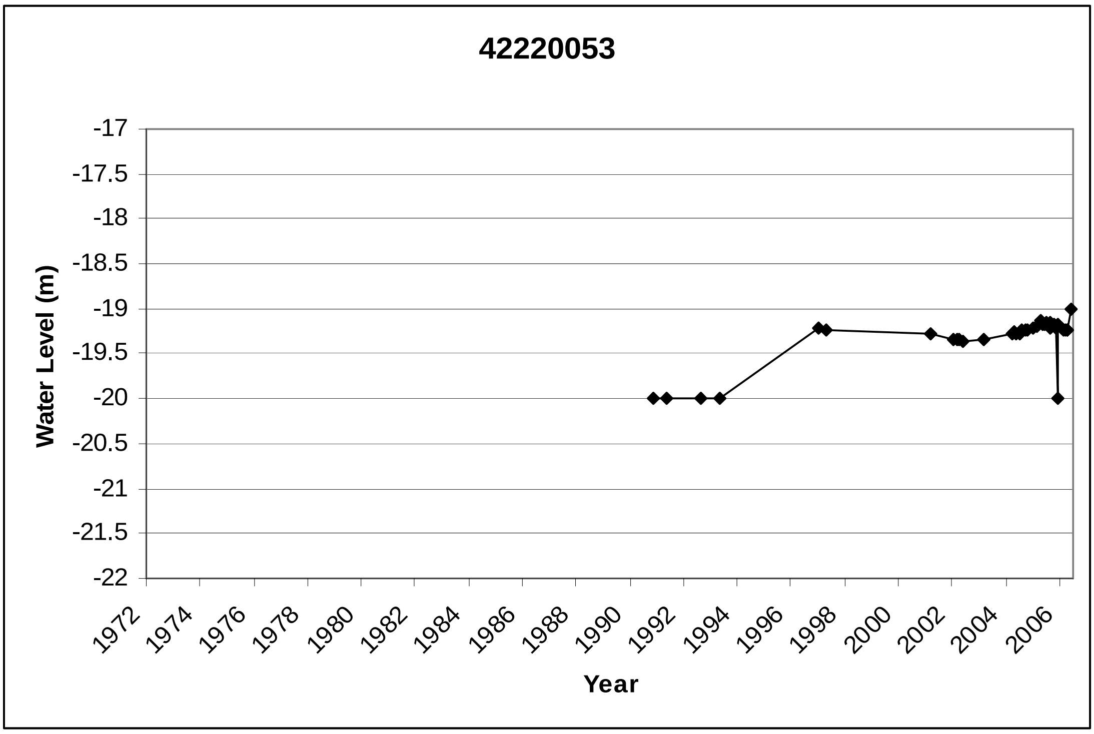
2004
2006
Year


42220053
Water Level (m)
-17
-17.5
-18
-18.5
-19
-19.5
-20
-20.5
-21
-21.5
-22
1972
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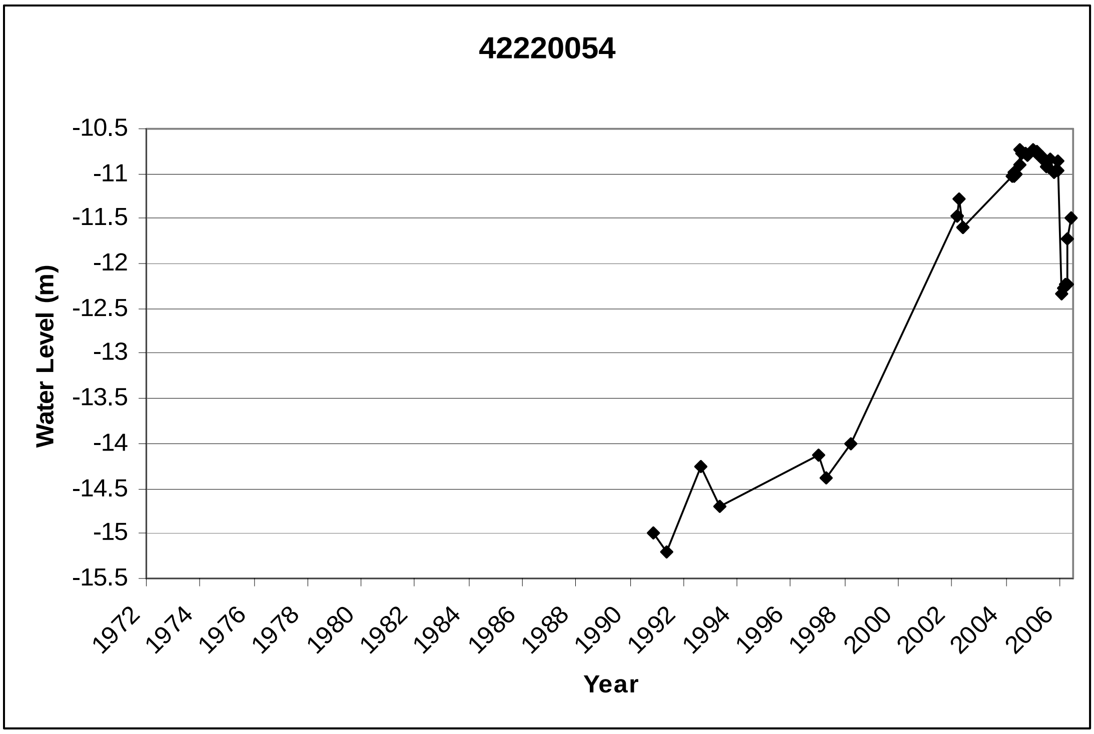
2004
2006
Year


42220054
Water Level (m)
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-11
-11.5
-12
-12.5
-13
-13.5
-14
-14.5
-15
-15.5
1972
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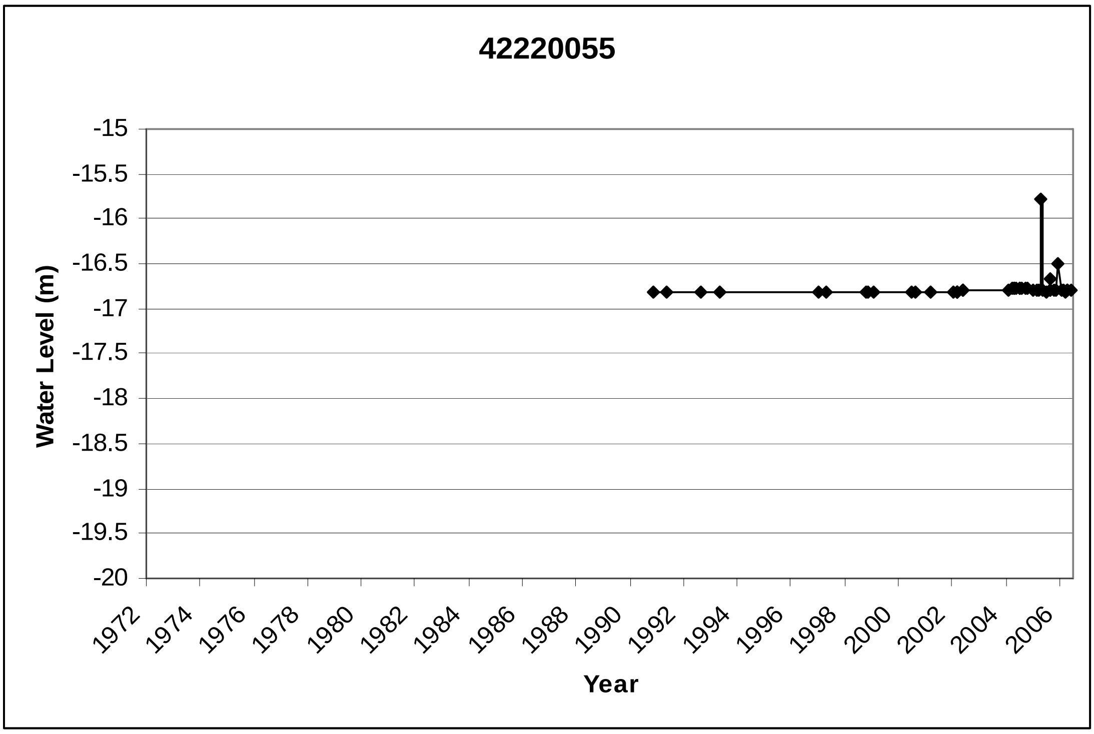
2004
2006
Year


42220055
Water Level (m)
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-16
-16.5
-17
-17.5
-18
-18.5
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-19.5
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1972
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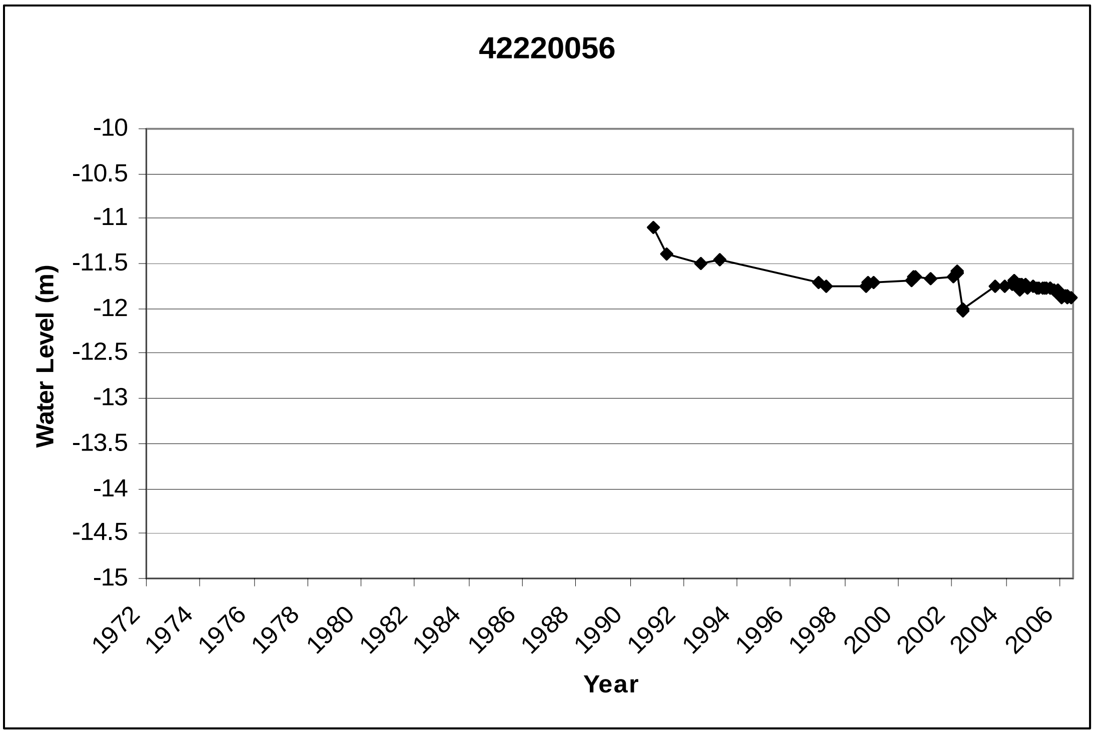
2004
2006
Year


42220056
Water Level (m)
-10
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-11
-11.5
-12
-12.5
-13
-13.5
-14
-14.5
-15
1972
1974
1976
1978
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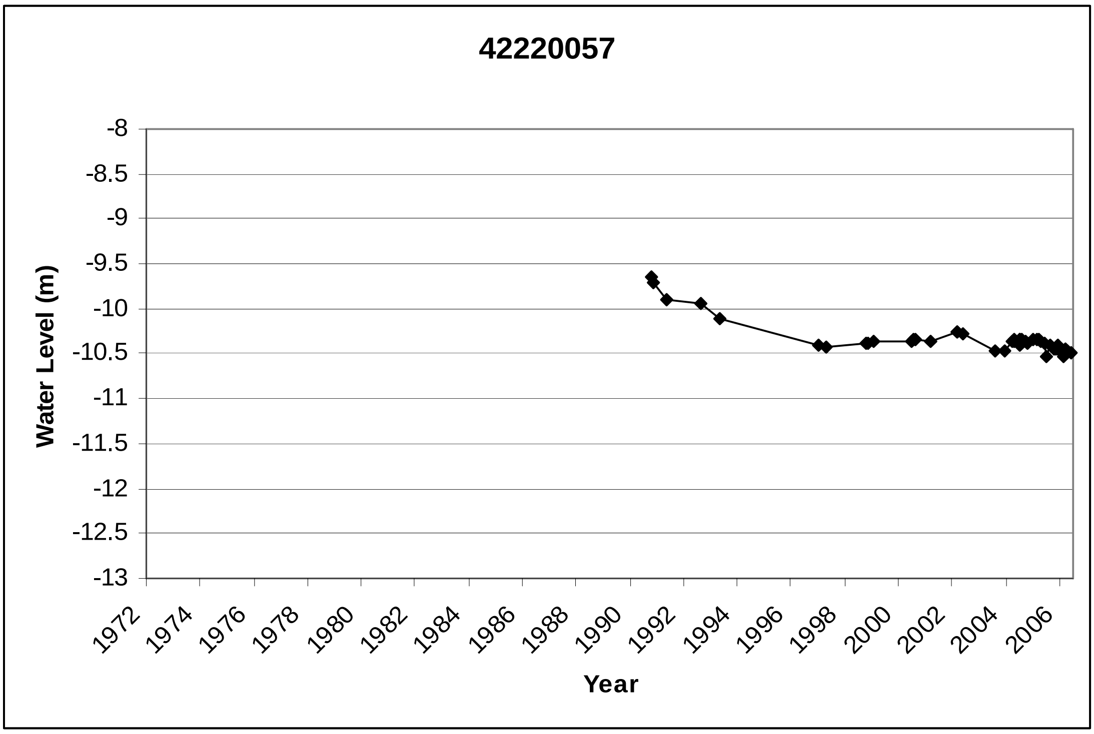
2002
2004
2006
Year


42220057
Water Level (m)
-8
-8.5
-9
-9.5
-10
-10.5
-11
-11.5
-12
-12.5
-13
1972
1974
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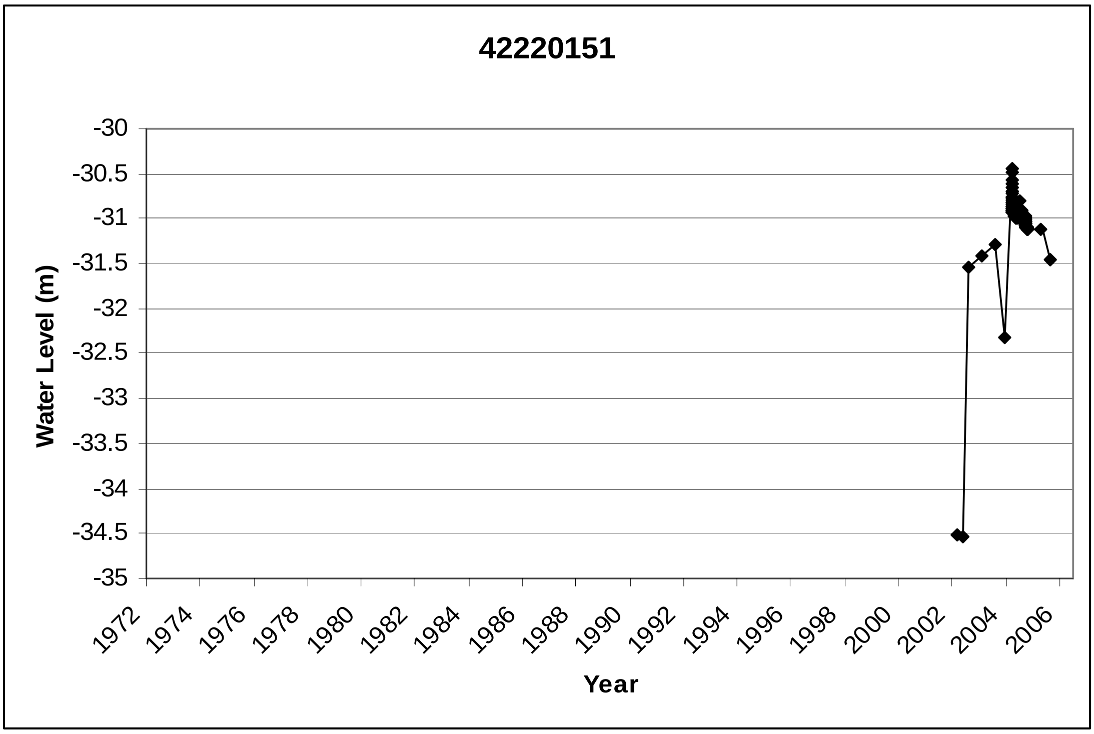
2006
Year


42220151
Water Level (m)
-30
-30.5
-31
-31.5
-32
-32.5
-33
-33.5
-34
-34.5
-35
1972
1974
1976
1978
1980
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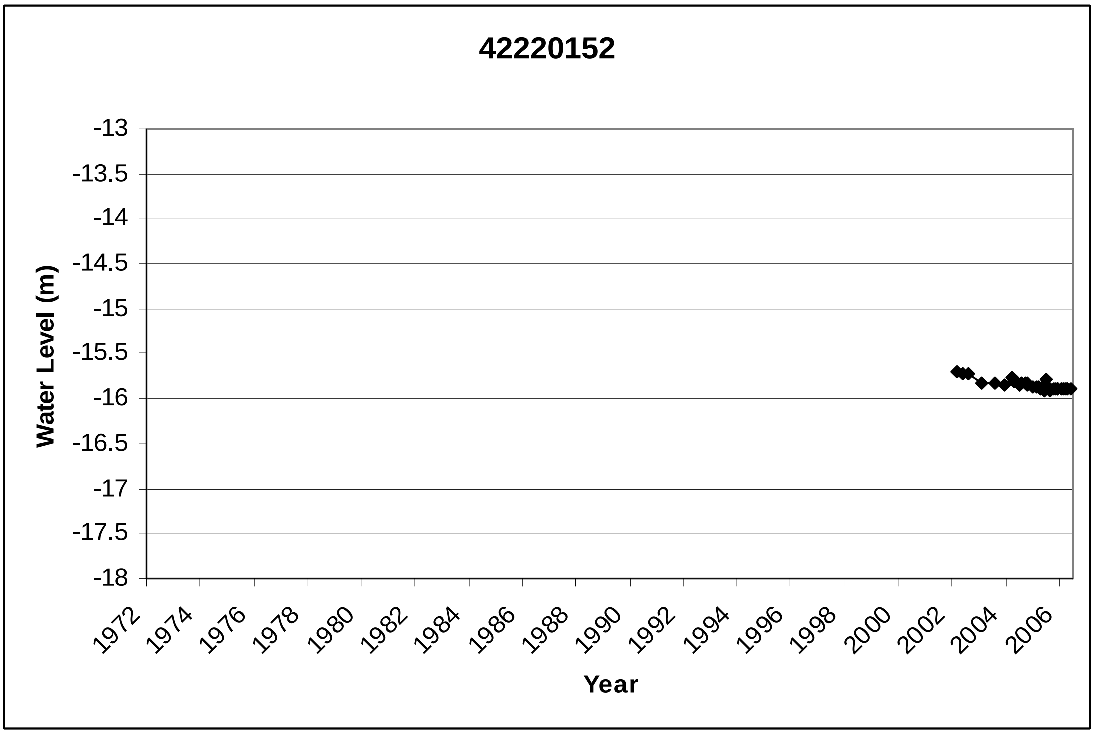
1998
2000
2002
2004
2006
Year


42220152
Water Level (m)
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-13.5
-14
-14.5
-15
-15.5
-16
-16.5
-17
-17.5
-18
1972
1974
1976
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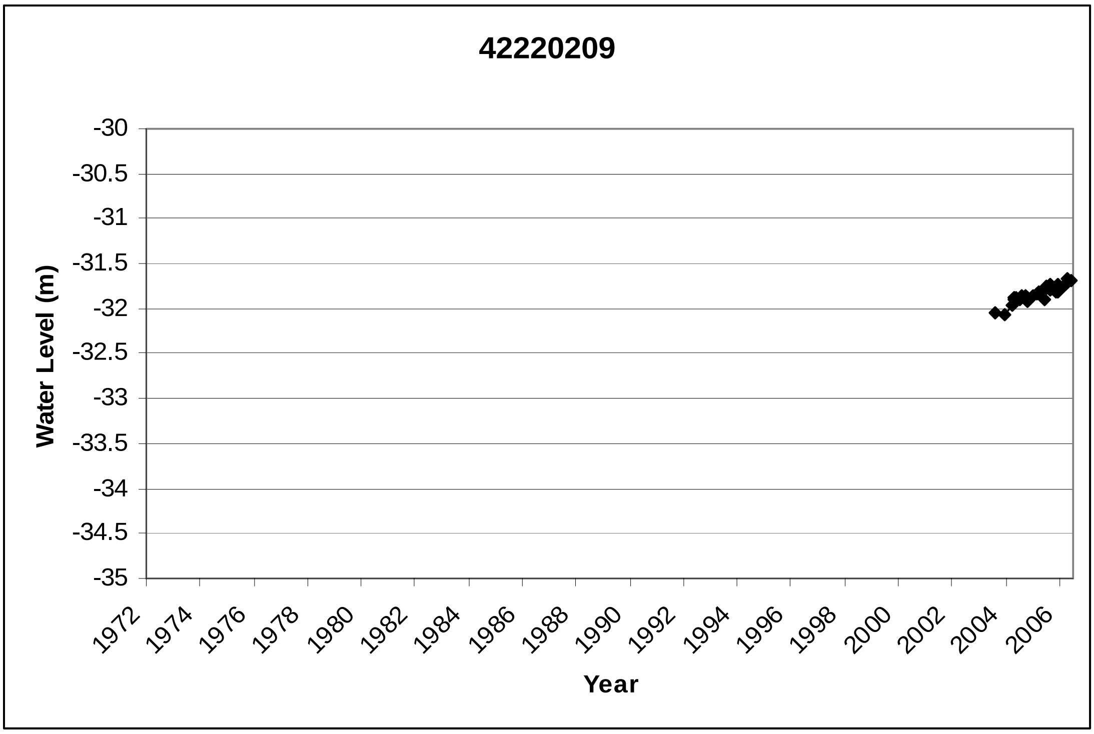
2000
2002
2004
2006
Year


42220209
Water Level (m)
-30
-30.5
-31
-31.5
-32
-32.5
-33
-33.5
-34
-34.5
-35
1972
1974
1976
1978
1980
1982
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2006
Year

Appendix 4

Water Quality Analysis – St George boreholes and local water-supply bodies

Between the 19th and the 21st of June, 2006, DNR&W conducted water quality analysis and development via air lifting and hand bailing of sixteen Departmental monitoring bores in the St George Irrigation Area, Queensland. Weirs and channels were also sampled for water quality. Water quality (Electrical Conductivity [EC] and pH) was analysed in the field for water sitting in the bores at arrival on site. In bores that had a sufficient depth of water, samples were taken from the top of the water column, and then the bottom of the water column and analysed separately. Water in each bore was then air lifted or hand bailed. During air lifting and hand bailing, water was removed equivalent or greater to three to four times the volume of water in each bore, allowing for development of the bore as well as enabling accurate sampling of water from the aquifer, rather than stagnant water from the bore.

The Registered Numbers (RN) of the bores that quality analysis was conducted on were:

42220018
42220019
42220022
42220023
42220024
42220025
42220027
42220030
42220032
42220033
42220034
42220053
42220054
42220056
42220057
42220209

The condition and findings for each bore will now be discussed.

42220018
The water in this bore was air lifted, and produced sand and silt.

	EC (ds/m)	pH
Before air lifting	12.8	7.2
After water level recovery	20.94	7.3

42220019
The water in this bore was hand bailed, as there was not enough water in the hole for air lifting to be successful.

	EC (ds/m)	pH
Before bailing	18.6	4.9
After water level recovery	18.45	4.8

42220022

There is minimal water in this bore. Water quality for this bore was not tested, as there was less than 20 cm of water in the bore, making it difficult for airlifting and bailing.

42220023

This bore was air lifted and produced approximately 0.25L/s. The bore took approximately five minutes to recover to its original water level.

	EC (ds/m)	pH
Before air lifting (top of water column)	0.37	6.6
Before air lifting (bottom of water column)	0.38	6.7
After water level recovery	0.38	8

42220024

	EC (ds/m)	pH
Before air lifting (top of water column)	2.68	7
Before air lifting (bottom of water column)	2.94	7
After water level recovery	-	-

42220025

	EC (ds/m)	pH
Before air lifting (top of water column)	0.56	7.2
Before air lifting (bottom of water column)	0.65	7.1
After water level recovery	0.55	7.1

42220027

The water in this bore was very dark in colour, had a distinctive smell and was quite thick and sludgy. This got better after air lifting and proceeded to become clear.

	EC (ds/m)	pH
Before air lifting	0.66	6.6
End of air lifting	0.74	6.9
After water level recovery	0.73	6.6

42220030

The air lifting blew out muddy water, which was replaced by clear water. The water level in this bore recovered immediately after air lifting ceased.

	EC (ds/m)	pH
Before air lifting	1.15	7.7
End of air lifting	14.23	7.8
After water level recovery	-	-

42220032

	EC (ds/m)	pH
Before air lifting (top of water	1.54	7.2

column)		
Before air lifting (bottom of water column)	2.04	7.2
After water level recovery	2.01	7.5

42220033
This bore was not air lifted, due to time constraints and the fact it is not tapping the alluvial aquifer. The water was sampled for EC and pH.

	EC (ds/m)	pH
Water column	1.46	7.52

42220034
In June 2006, the steel protector of this bore was found to be cut off at ground level, and the PVC casing had been broken off. Due to this, there was no access to the water inside the bore for sampling or analysis. Consequently, this bore has been restored, and is again able to function as a monitoring bore.

42220053
The bore produced silt and sand when air lifted.

	EC (ds/m)	pH
Before air lifting	16.85	7.1
After water level recovery	18.5	7.1

42220054
This bore had a very slow recovery time in relation to other bores in the area.

	EC (ds/m)	pH
Before air lifting (top of water column)	0.06	7.4
Before air lifting (bottom of water column)	0.07	7.2
After water level recovery	1.24	6.7

42220056

	EC (ds/m)	pH
Before air lifting (top of water column)	3.02	7.6
Before air lifting (bottom of water column)	4.45	7.10

42220057

	EC (ds/m)	pH
Before air lifting (top of water column)	4.69	7.6
Before air lifting (bottom of water column)	5.42	7.6
End of pumping	5.15	8.2

42220209

	EC (ds/m)	pH
Before air lifting	1.65	8.1

Appendix 5

Down the hole video investigation of the "wet" monitoring boreholes

The Registered Numbers (RN) of the bores that down hole video was conducted on in the period 11-15 December 2006 were:

42220018
42220019
42220022
42220023
42220024
42220025
42220027
42220030
42220032
42220033
42220034
42220053
42220054
42220056
42220057
42220209

General Condition of Bores
The condition and findings for each bore will now be discussed.

42220018

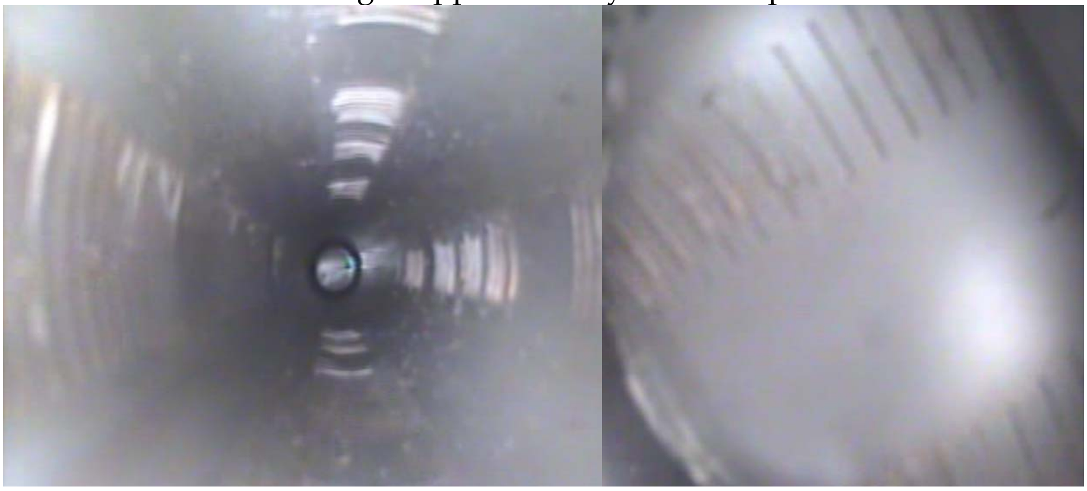
The bore is in good condition, with casing and joints intact. Slots could not be seen due to the clarity of the water, which was muddy. The presence of a sump could not be seen for the same reasons.

42220019

The bore casing is generally in good condition, with the exception of a sizeable crack above the join between the casing and slotted section. The slots are unobstructed.

Sump from 12.2 m to 15.59 m (end of hole) with holes drilled.

42220019 - Crack in casing at approximately 11.5 m depth.

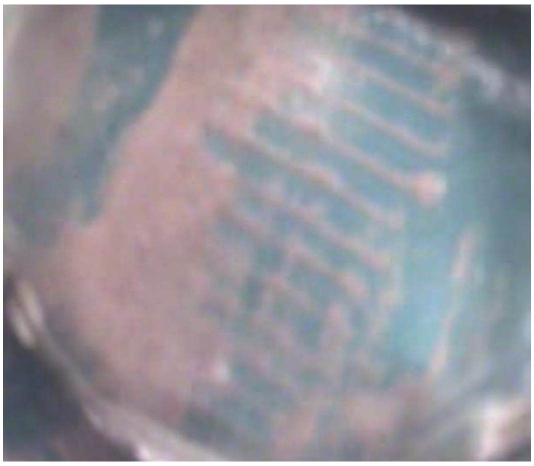


42220019- Slotted casing between 11.6 m and 12.2 m depth.

42220019- Drilled holes in the sump below the slotted casing, 12.2 m to 12.59 m.

42220022

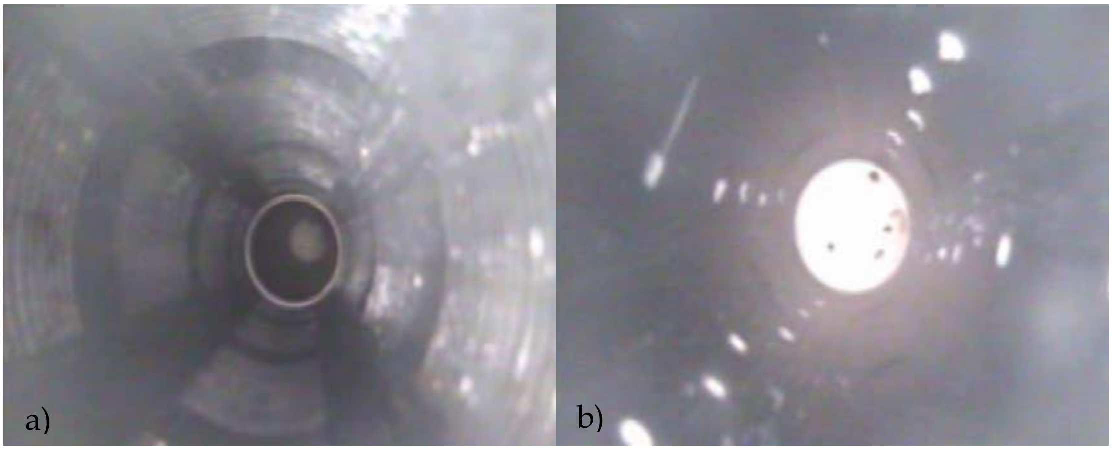
The bore casing is in good condition, with casing and joints intact. The slots (11.6 m to 12.2 m) are clogged with silt or similar, and there is a good possibility that they are not functioning correctly. There is minimal water in this bore.



42220022- Slots in casing (11.6 m – 12.2 m).

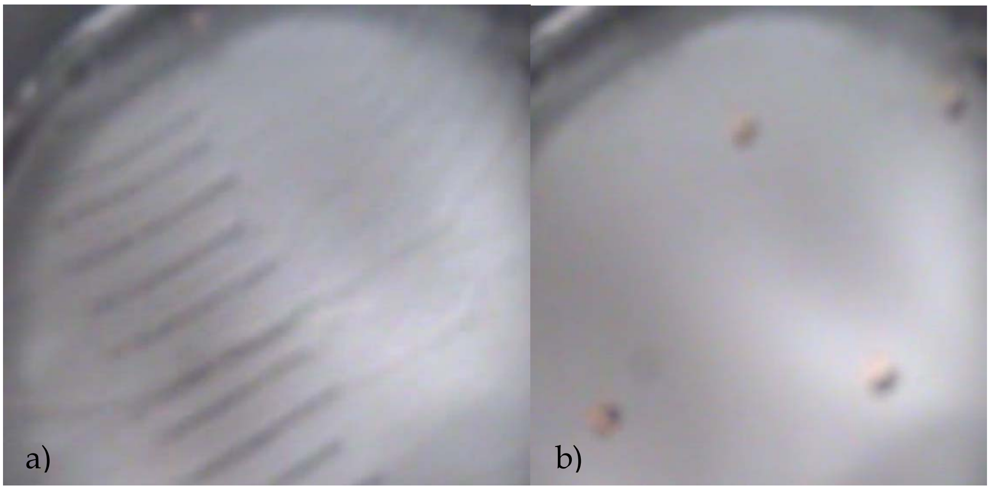
42220023

The bore is in good condition, with casing and joints intact. The slots (11.6 m to 12.2 m) appear to be in good condition. There is a sump from 12.2 m to 12.48 m with holes drilled in it.



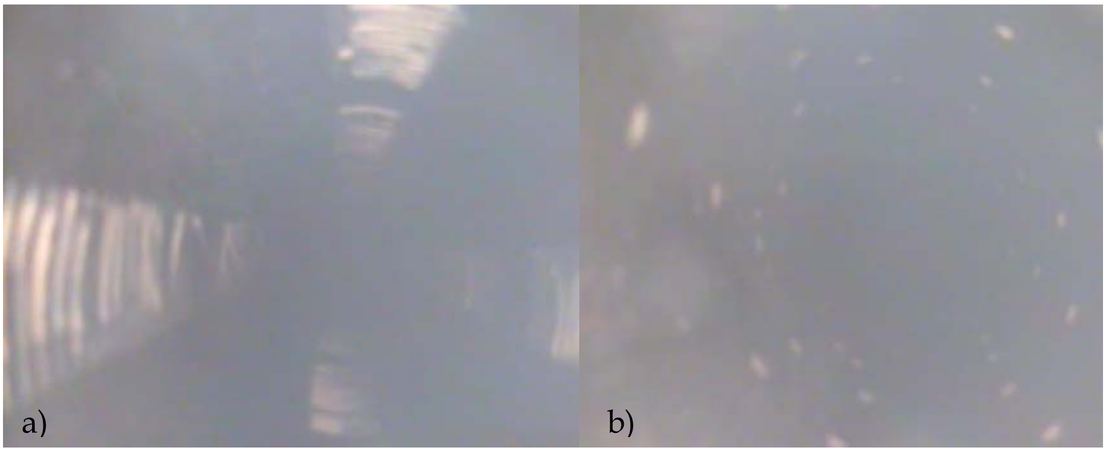
42220023- Slots in casing (11.6 m – 12.2 m) (a) and drilled holes in sump (12.2 m – 12.48 m) (b).

42220024
The bore is in good condition, with casing and joints intact. The slots (11.6 m to 12.2 m) appear to be in good condition. There is a sump from 12.2 m to 12.76 m with holes drilled in it.



42220024- Slots in casing (11.6 m – 12.2 m) (a) and drilled holes in sump (12.2 m – 12.76 m) (b).

42220025
The bore is in good condition, with casing and joints intact. The slots (11.6 m to 12.2 m) appear to be in good condition. There is a sump from 12.2 m to 12.92 m with holes drilled in it.



42220025- Slots in casing (11.6 m – 12.2 m) (a), and drilled holes in sump (12.2 m – 12.92 m) (b).

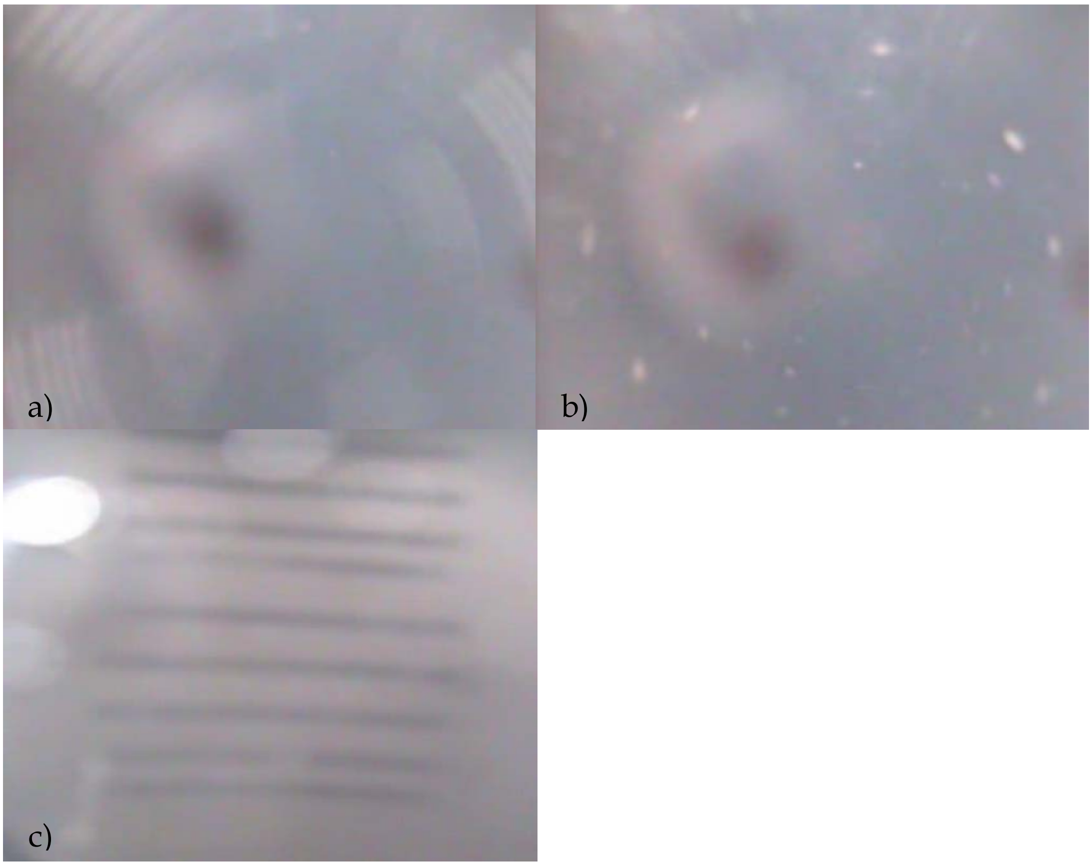
42220027

The bore is in good condition, with casing and joints intact. The slots (11.5 m to 12.2 m) appear to be in good condition. There is no sump in this bore.

42220027 - Slots in casing (11.5 m – 12.2 m). The clarity of the image is compromised due to the quality of the water in the bore.

42220030

The bore is in good condition, with casing and joints intact. The slots (25.1 m to 25.7 m) appear to be in good condition. There is a sump with holes in it to 25.7 m, with approximately 20 cm of sump with no holes drilled in it.



42220030 - Slots in casing (25.1 m – 25.7 m) (a; c) and drilled holes in sump (25.7 m – 25.9 m) (b).

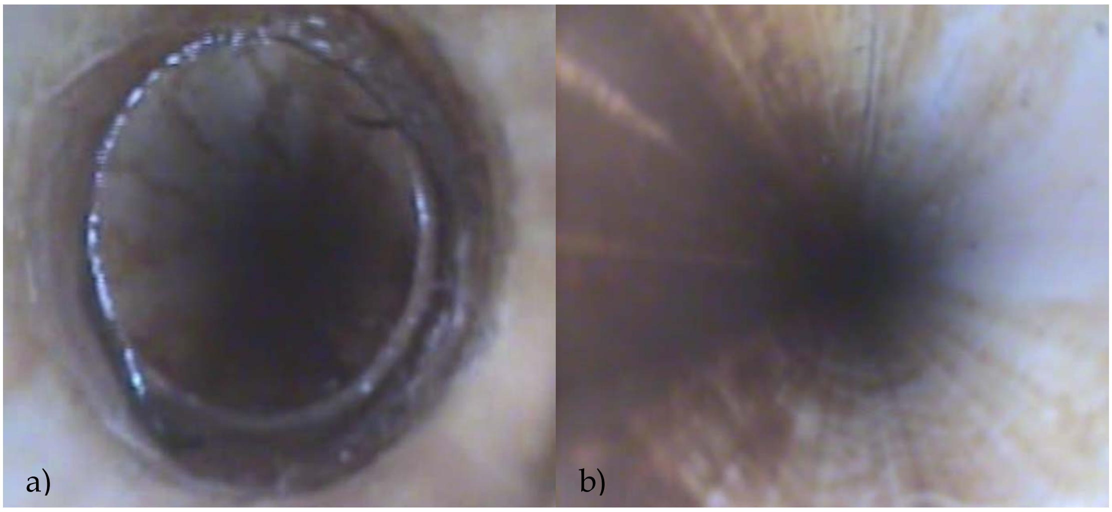
42220032

The bore is in good condition, with casing and joints intact. The slots (29.8 m to 30.5 m) appear to be in good condition. There is a sump to 31.07 m, with drilled holes at least some of the way; however the clarity of the water makes it hard to determine if they continue to the end of hole.

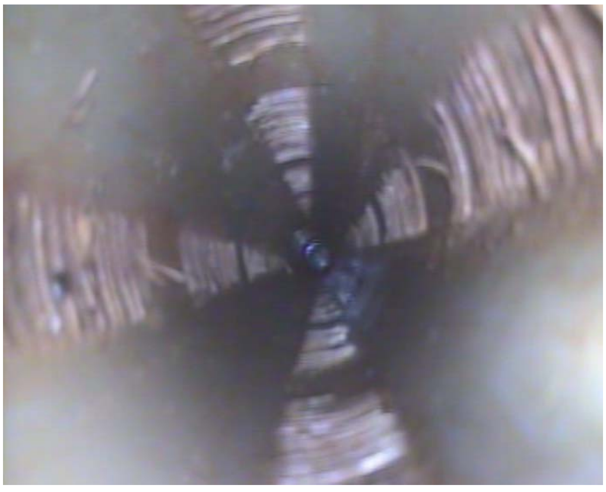
42220032 - Slots in casing (29.8 m – 30.5 m).

42220033

This bore is in a generally poor condition. While the casing itself is in good condition, there is a join at approximately 6 m that shows a gap between the two PVC lengths. There is minimal staining of the PVC above this join, and major staining below the join, suggesting that this is a source for water to enter the bore, and has done so at some stage. There was water visibly running down the casing on the first camera run – there is no other possible source to this water other than coming in at the join. This means that the bore is not functioning correctly as a monitoring bore. There also appears to be a crack at both the first (6 m) and second (12 m – 13 m) join. There is a sump in this bore, with holes drilled in it, from 30.47 m to 32.8 m.



42220033 - Join at approximately 6 m depth (a), showing a gap between the two PVC lengths; Staining on the inside of the casing below the join (b).



42220033 - Slots in casing (at 29.8 m – 30.47 m).

42220034
The bore is in good condition, with casing and joints intact. The slots (20.66 m to 21.33 m) appear to be in good condition. There is a sump to 22.97 m, with drilled holes at least some of the way; however the clarity of the water makes it hard to determine if they continue to the end of hole.


42220034 - Slots in casing (at 20.66 m – 21.33 m)

42220053
The bore is in good condition, with casing and joints intact. The slots, that appear spiral in nature, (18.6 m to 19.6 m) appear to be in good condition. There is no sump in this bore. However the cap at the bottom of the slotted section may have holes (3 mm diameter) drilled into it.


42220053 - Slots (spiral cut) in casing (at 18.6 m – 19.6 m).

42220054
The bore is in good condition, with casing and joints intact. The slots (17 m to 18 m) appear to be in good condition. There is no sump in this bore.

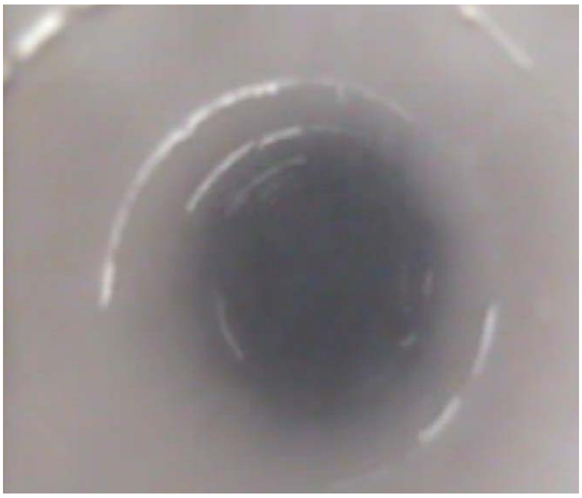

42220054 - Slots in casing (17 m – 18 m).

42220056
The bore is in good condition, with casing and joints intact. The slots (17 m to 18 m) appear to be in good condition. There is no sump in this bore.


42220056 - Slots in casing (17.1 – 18.1 m).

42220057

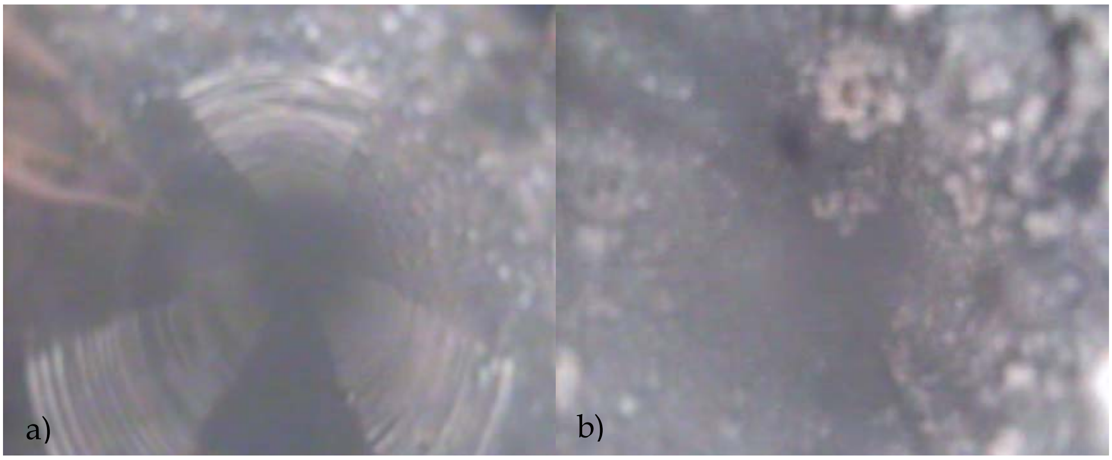
The bore is in good condition, with casing and joints intact. The slots (17 m to 18 m) appear to be in good condition. Due to the clarity of the water, it is difficult to determine if there is a sump in this bore, however it was drilled at the same time as 42220056, and it can be assumed that the slots continue to the end of hole.

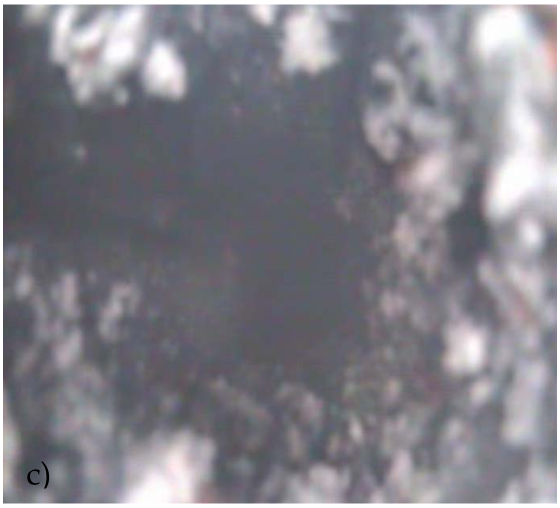


42220057 - Slots in casing (13 m – 14 m).

42220209

The bore is in good condition, with casing and joints intact. The slots (36 m – 39 m approximately) appear to be clogged with algae or similar, from a thinner layer to very thick. There is a sump in the bottom, most likely at least 1 m in length, however it is not known if there are holes drilled in it. The algae like substance growing on the slots indicates that they are not functioning correctly.





42220209 - Images of the slots at 33 m (a), 38 m (b) and 40 m (c).

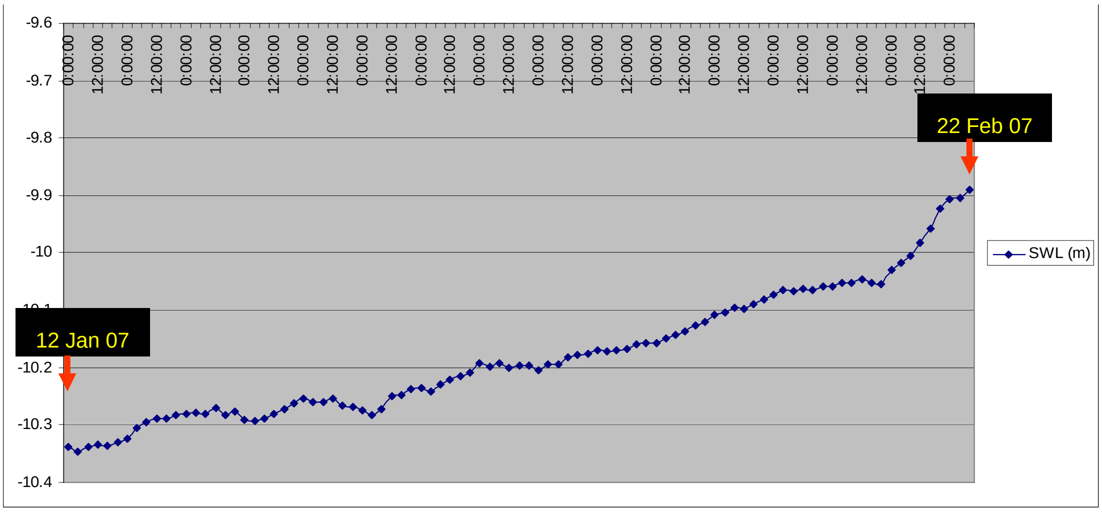
Recent logger (Mini-Divers) data

Three examples of recently collected logger data are presented here, to show:

- the nature of the data being collected
- the types of trends being collected

42220024

Water level has risen 45 cm in 40 days. The rise has been quite steady over that period and there are no apparent diurnal fluctuations.

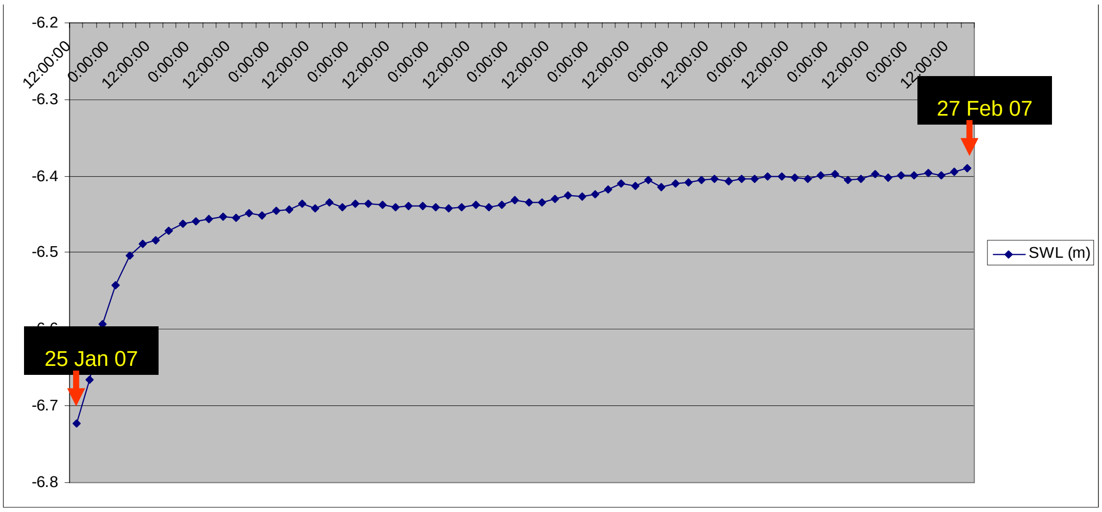


22 Feb 07

12 Jan 07

42220025

Water level has risen 33 cm in 30 days; and rose 26 cm in the first 5 days. Similar to 4222024 the rise has been steady and shows no diurnal fluctuations



27 Feb 07

25 Jan 07

42220032

The water level dynamics in this deeper (31.1 metres) hole is quite different to 4222024 and 42220025 (12.8 and 12.9 metre deep boreholes). In a 40 day period, the water level has risen and fallen several times, eg it dropped 26 cm from the 3 to 8 February, then rose 29 cm from the 8 to 21 February 2007.
Overall, the water level response curve is more erratic than 4222024 and 42220025, yet again there are no apparent diurnal fluctuations.