BSES Limited

FINAL REPORT – RWUEI PROJECT 12

MANAGEMENT OF FURROW IRRIGATION TO IMPROVE WATER USE EFFICIENCY AND SUSTAIN THE GROUNDWATER RESOURCE – A CASE STUDY IN THE BURDEKIN DELTA

by

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PR04001

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SUMMARY

The Burdekin Delta region depends on groundwater for irrigation and urban supply. Therefore, any adverse impacts on the groundwater resource are undesirable. Field studies were implemented to improve knowledge and understanding of impacts of current and modified irrigation management practices on crop water use, productivity and long-term sustainability of the Burdekin Delta groundwater system. Field trials were established on six sites representing different soil types of the Delta comparing conventional (CONV) and best management practice (BMP) irrigation systems. The BMP applied was site specific, and was determined by consultation with BSES extension officers and the individual grower. Sites were instrumented to measure irrigation application, crop water use and the quality of water draining beneath sugarcane crops.

By using BMP irrigation, a reduction in water application of 15 and 14% was achieved during the 2001-2002 and 2002-2003 irrigation seasons, respectively. This equated to an average saving of 6.4 and 2.9 ML/ha, respectively. Crop production figures indicated an increase of 5% (7 t/ha) in 2001-2002 season and a decrease of 3% (4 t/ha) in 2002-2003. The combination of reduced water and increased yield in the 2001-2002 season resulted in a 24% overall increase in productivity across farms. The combination of reduced water and reduced yield in the 2002-2003 season resulted also in an increase in productivity of 11%. This was in line with the Cane Productivity Initiative (CPI) where an increase in productivity of 20% is expected across the Burdekin district.

Deep drainage was calculated from each irrigation and summed for each season. By using BMP irrigation, deep drainage was reduced by 11 and 19% in the 2001-2002 and 2002-2003 irrigation seasons, equating to an average 1.8 and 1.9 ML/ha reduction in deep drainage respectively. Individual irrigation drainage water was analysed for nitrate-nitrogen, these figures were applied to drainage figures. Using BMP irrigation there was a reduction in nitrate-nitrogen loading across the Delta by 18% in 2001-2002 season (4.8 kg/ha) and by 39% (4.3 kg/ha) in the 2002-2003 season.

Investigations into pesticide movement and acquisition by the groundwater resource were undertaken. There was no level of pesticides detected in groundwater samples. This was matched by soil water samples at 1.5 m and soil cores at 1.5 m. This is good news for the industry; there must now be a concerted effort to maintain this.

From economic analysis of different irrigation system we can conclude that maintaining current furrow-irrigation practices is the most attractive option. Implementing centre-pivot irrigation systems is the second most attractive option, as it has higher net present value than furrow. Implementation of trickle irrigation is the least attractive to growers due to high initial capital outlay. Furrow irrigation remains most attractive under current water pricing schedules when key parameter values are varied.

This project could not have been undertaken without the support from RWUEI, BSES Limited, NPIRD, CSIRO, the North and South Burdekin Water Boards and the valuable cooperation of the participating cane growers.

1.0 BACKGROUND

The Burdekin Delta is a major irrigation area situated in the dry tropics on the northeast coast of Queensland. The climate and environmental conditions are ideal for the production of sugarcane, which occupies 95% of the cropping area in the delta. Production from the first blocks of irrigated cane began in 1885 and has expanded to over 40,000 ha (2002). As the cane area under irrigation increased, pressure on the groundwater resource also increased. By the 1960s there was an apparent overdraft on the groundwater resource. Investigations by the Irrigation and Water Supply Commission (O'Shea 1967) resulted in the implementation of an artificial groundwater recharge scheme in the eastern part of the Delta. Pumping plants diverted water to recharge areas through natural and artificial channels.

The Delta region overlies a large unconfined aquifer system that is in contact with the ocean. An active artificial recharge program, carried out by the North and South Burdekin Water Boards since the mid 1960s, aims to maintain sufficient aquifer potential to control the intrusion of seawater. Recharge methods are directly through large natural and artificial recharge pits, recycling of water through soil, and water spreading (Bristow *et al.* 2000). Recycling refers to where excess irrigation water (from on-farm bores) drains past the crop root zone and returns through the soil to the groundwater. Water spreading is where the water boards pump water, which is too turbid for use in the recharge pits, into their channel system to be used for irrigation water, using the soil to filter out the turbidity.

Increasing pressure from environmental and regulatory bodies has raised questions about some of the above practices, their long-term impacts on water management and the subsequent sustainability of the Burdekin Delta aquifers. Of particular importance are questions relating to the impacts of current and improved irrigation management strategies on deep drainage to the aquifers and chemical loading of these waters. The possible contamination of groundwater with nitrate-nitrogen (or any pollutant) is of concern in regard to health and environment issues. Nitrate-nitrogen at levels above 50 mg/L for children under 3 months of age and 100 mg/L for adults are toxic, because it interferes with the ability of haemoglobin to transport oxygen (Addiscott *et al*. 1991). High nitrate-nitrogen concentrations are also detrimental to fresh water and marine ecosystems. Nitrate-nitrogen is of particular concern, as it is widely used and/or generated in agricultural systems, it is mobile in soils, and it is released from soil organic reserves (Keating *et al.* 1996).

Key field sites, including some currently used for the RWUEI Adoption Program were selected, characterised and instrumented to provide estimates of the quantity and quality of drainage leaving the root zone under current and BMP irrigation. As well as providing direct evidence of the impacts of BMP on deep drainage and, hence WUE, many barriers to the adoption of BMP should be removed by demonstration of these principles at sub-field level. Simultaneously, it has provided measures of the impact of BMP, compared to current systems, on environmental performance.

2.0 OBJECTIVES

This project aimed to improve the knowledge of the impacts of current and modified water-management practices (including recycling, water spreading, artificial recharge and on-farm irrigation practice) on long-term sustainability of the Burdekin Delta groundwater systems through the following objectives:

- **Quantify the impact of best irrigation practice on WUE and associated deep drainage on accession of environmentally sensitive compounds to the delta aquifers.**

Best irrigation practice has increased WUE on Delta farms by reducing the amount of irrigation water applied and increasing the production of cane from these farms. A reduction in water application of 15 and 14% was achieved during the 2001-2002 and 2002-2003 irrigation seasons, respectively. The reduction in irrigation application reduced the amount of deep drainage and nitrate-nitrogen losses below the root zone. The reduction in deep drainage was 1.8 and 1.9 ML/ha from the 2001-2002 and the 2002-2003 seasons, respectively, resulting in reduced leaching of 4.8 and 4.3 kg/ha nitrate-nitrogen over the two seasons. Crop production figures indicated an increase of 5% (7 t/ha) in the 2001-2002 season and a decrease of 3% (4 t/ha) in the 2002-2003 season. The combination of reduced water application and increased yield resulted in an average 18% overall increase in productivity across farms over the two seasons. This was in line with the Cane Productivity Initiative of CSR, where an increase in productivity of 20% is expected across the Burdekin district.

- **Link these studies to the DNR assessment of aquifer dynamics of the Lower Delta groundwater and the companion NPIRD funded activity to facilitate model development for long-term scenario analysis.**

Constant links have been made with the NPIRD project, with combined data sets being produced for the 2001-2002 and 2002-2003 seasons. The results have been used to validate the APSIM-Sugarcane model components via the NPIRD project. A number of papers have been published using combined data sets. Links have also been made to the soils-mapping project in the Burdekin.

- **Involve stakeholders in the participative research and development process to demonstrate economics and integration of BMP furrow irrigation into the farming system.**

A committee of local stakeholders, the Lower Burdekin Initiative (LBI), was formed at the beginning of the RWUEI and NPIRD projects. Participants of this committee were water board representatives, research organisations and other project officers working in the Delta region. Regular meetings of this committee were held and progress reports given. This process aided data collation and ensured that projects were not repeating other work and that projects aimed at a common goal. Yearly management meetings were held with wide community involvement.

- **Undertake a desktop study to scope economics of other irrigation systems for opportunity to deliver WUE and environmental targets.**

This objective was undertaken under the umbrella of the CRC - Sustainable Sugar Production. Results from the model indicate that maintaining current furrow irrigation practices is the most attractive option to growers under the current pricing schedule. Implementing centre-pivot irrigation systems is the second most attractive option, as it has a higher net-present-value than furrow irrigation. Implementation of trickle irrigation is the least attractive to growers, due to high initial capital outlay. Furrow irrigation remains most attractive under current water-pricing schedules when key parameter values are varied due to the cost of implementing other irrigation systems.

3.0 RESEARCH METHODS

Ten field sites across the Delta region were chosen by the CSIRO/NPIRD project for monitoring during early 2001. Site and soil descriptions for these sites are given in Charlesworth *et al.* (2002). Six of these sites were intensively monitored as described below by both the BSES/RWUEI and CSIRO/NPIRD projects for crop production, nitrate-nitrogen movement and deep-drainage volumes.

Site details including management practices and crop details are given in Appendix 1. Two treatments were applied to each site in paired strips, one termed conventional (CONV), representing traditional grower management of furrow shape, inflow rates and scheduling; the other termed best management practice (BMP), representing practices that aim to improve water-use efficiency by altering furrow shape, inflow rate, scheduling and/or irrigation system. The BMP treatment was site specific and the details of the irrigation management were decided in consultation with the grower, BSES staff and knowledge of the soil type and water quality at each particular site. Plot size varied from 13 to 32 rows and 250 to 650 m long, due to individual block and farm layout. These resulted in commercially meaningful irrigation units. This preference was chosen for logistical reasons in favour of within site replication. Table 1 outlines the sites and treatments in place.

Table 1 Outline of site details and treatments imposed

Site	Soil type	Variety	CONV treatment	BMP treatment
1	Sandy loam	Q117	U furrow, 0.75L/s	V furrow, 0.75L/s
2	Med cracking clay	Q127	Cultivation, 2L/s	No cultivation, 2L/s
3	Light cracking clay	Q183[A]	V furrow, 2.3L/s	V furrow, surge, 4.6L/s
4	Sandy loam	Q117	V furrow, 2.6L/s, minipan	V furrow, surge, 4L/s minipan
5	Sand	Q183[A]	V furrow, 1.2L/s minipan	V furrow, 2L/s, surge, minipan
6	Sandy loam	Q183[A]	U furrow, 2.4L/s	V furrow, 2.4L/s minipan

At sites 5 and 6, additional treatments were included during the 2002-2003 season. Site 5 included an additional treatment of fertigation, where fertiliser nitrogen was applied through irrigation water, split over a number of irrigations. Irrigation sets were watered as usual and allowed to drain for 24 h before fertiliser application. The equivalent amount of urea (167 kg urea) was dissolved in a tank of water an injected into fluming. Fertigation took place on the 12/9/02, 17/10/02 and 6/11/02.

At site 6, the BMP treatment was split, one side received full fertiliser application (220 kg/ha nitrogen) and the other side received half fertiliser rate (110 kg/ha nitrogen). This was to demonstrate that the crop could access nitrate-nitrogen from the irrigation water where the level in irrigation water was high without adverse effects on crop production. This site had average nitrate-nitrogen levels of 10 kg/ML in the irrigation water during the 2001-2002 season. This level of nitrate-nitrogen in the irrigation water and application values of 20 ML/ha combined to result in 200 kg/ha of nitrate-nitrogen application. This site has a history of large nitrogen inputs and low CCS.

All sites had flow meters installed at the pump or in the fluming at the beginning of each irrigation set and growers kept appropriate records of irrigation applications for each treatment. This system worked effectively, with growers keeping concise records that also detailed rainfall events. This information allowed the analysis of individual irrigations for water balances as well as a comparison between treatments.

At harvest, the respective treatment areas were harvested by contractors and consigned separately to the mills allowing calculation of individual treatment yields (t/ha) and CCS. The harvest of these plots followed normal commercial practice. Crop Water Index (CWI) was calculated on each treatment for a comparison of water-use efficiency. The benchmark of Kingston (1994) has been modified for extension purposes to a CWI where:

$$CWI = \text{Cane yield} / (\text{Effective rainfall} + \text{Gross irrigation})$$

CWI was expressed as tonnes of cane/ML. Effective rainfall was calculated using a percentage of actual rainfall given in Robertson and Muchow (1997). A sugar productivity index, expressed as tonnes of CCS per ML water was also calculated to compare treatments.

All sites had logging equipment installed to monitor rainfall and changes in soil moisture conditions; matching equipment was installed on both the CONV and BMP treatments at each site. Equipment included EnviroSCAN® capacitance probes for soil moisture content, Campbell Scientific 229 probes for soil matric potential, and FullStop® sensors for wetting front detection. These equipment allowed the analysis of soil water movement through the soil profile to a depth of 1.5 m.

Deep drainage was calculated for each irrigation event and accumulated for each season. The following equation was used:

$$\text{Deep drainage} = (\text{Irrigation} + \text{Rainfall}) - (\text{Runoff} + \text{Evapotranspiration})$$

Where irrigation was measured by flow meters, rainfall was measured using dataloggers in each trial, and runoff was estimated at 10% from Holden *et al.* (1997). Evapotranspiration at each site was estimated using the FAO 56 method (Allen *et al*. 1998) being the product of daily potential evapotranspiration and crop factors. Potential evapotranspiration was calculated using the Penman-Monteith equation from weather data collected at Kalamia Mill (Inman-Bamber pers comm.). Crop factors were derived by Inman-Bamber and McGlinchey (2003).

A 500-mL irrigation-water sample was taken from the fluming at each irrigation event to measure the amount of nitrate-nitrogen entering the soil system by this means and to monitor electrical conductivity. Soil water samples were obtained at each irrigation event by using super quartz (PTFE/quartz) suction samplers (Prenart, Denmark). These were installed at three specific depths (0.3, 0.6 and 1.5 m) to sample the water from irrigation and rainfall as it moved through the soil profile. Immediately prior to irrigation and for 48 h after, a vacuum was applied to each suction sampler with portable vacuum pump. Negative pressure was retained in the samplers using a 250 mL Schott bottle attached to the sampler (Figure 1). Water samples from BMP treatments at sites 1, 2, 3 and 4 and all water samples from sites 5 and 6 were preserved with 0.1% w/v phenylmercuric acetate (PMA) solution stored in a refrigerator and analysed for nitrate-nitrogen by auto-colorimetry. Water samples from sites 1, 2, 3 and 4 conventional treatments were frozen after collection for analysis by NPIRD/CSIRO. Soil water samples from BMP treatments were bulked for pesticide analysis, and stored in glass bottles in a cold room to await analysis.

Figure 1 **Project officer Jessica Klok with a Schott bottle attached to a suction sampler**

Soil cores to 1.5 m in 0.1 m increments were taken after harvest and prior to growers beginning irrigation and in October 2002 for pesticide and nitrate-nitrogen analysis. Soil samples were not taken at the beginning of trials. A limited number of samples was taken by the CSIRO/NPIRD project after harvest of the 2001 crop for nitrate-nitrogen analysis; these were used where appropriate for changes in soil nitrate-nitrogen content. Stainless-steel corers were used, with no lubricating oil, and four cores per plot were taken and bulked. All samples were stored at 4°C until analysis. Samples for pesticide analysis were analysed by GC-MS after appropriate extraction methods. Soils were extracted with 2M potassium chloride for nitrate-nitrogen determination.

Nitrate-nitrogen loading was calculated from individual irrigation event deep drainage values (ML/ha) and the nitrate-nitrogen concentration of soil water at 1.5 m (kg/ML) from each irrigation to give values of kg of nitrate-nitrogen/ha loading to the aquifer for each site and treatment. Soils mapping data was obtained from the DNR soils-mapping project in the Delta region. From this each site was assigned a percentage of the total Delta area. A whole-of-Delta nitrate-nitrogen loading figure was calculated from these data.

The economics of alternative irrigation practices for sugarcane production in the Burdekin Delta were evaluated using a multi-period mathematical programming model to estimate the responsiveness of water demand to price changes and to alternative water management and irrigation practices – CANEIRRI model. This model was developed by Qureshi *et al.* (2001) using GAMS software (Brooke *et al.* 1998). The CANEIRRI model was used to evaluate the effects of changes in water charges and output prices on sugarcane farmer investment in farm development through irrigation system changes from flood to centre-pivot or drip irrigation. The model uses the output from a biophysical simulation model to predict crop yields of sugarcane under different irrigation levels linked to a linear programming model to assess water price implications for a representative farm in the study area. Parameter inputs are given in Qureshi *et al.* (2002).

4.0 RESULTS AND DISCUSSION

Results of these irrigation trials span two irrigation seasons, 2001-2002 and 2002-2003. The treatments applied were compared using a percentage advantage/disadvantage of the BMP system over the CONV system, as statistical analysis was not viable.

4.1 Irrigation application

Irrigation applications for the 2001-2002 and 2002-2003 seasons are summarised in Table 2. Irrigation applied for the 2001-2002 season ranged from 11.4 to 70.8 ML/ha, with the average 27 ML/ha. BMP treatments averaged 15% lower water application than conventional. Irrigation in the 2002-2003 season ranged from 13.7 to 33.3 ML/ha, with the average 19 ML/ha. Irrigation volumes for the second season were lower than the previous season, despite dry conditions prevailing. BMP treatments in this season averaged 14% lower water application than conventional practices. This highlights the fact that even in years when irrigation application was reduced across the Delta, savings can still be made using best irrigation practices. Soil type contributed to the variation in water application rates between sites; sites where most water was applied were generally the most permeable soil type. An exception to this was site three where the soil was medium clay. This site has an irrigation water electrical conductivity of about 1 dS/m, which aids the infiltration of water. Irrigation water containing enough soluble salts prevents the soil crumbs from breaking up when wet; this permits water to soak through the soil easily.

Table 2 **Summary of irrigation applications and effective rainfall each site and treatment (ML/ha)**

Site	Treatment	Total irrigation 2002 (ML/ha)	Effective rainfall 2002 (ML/ha)	Total irrigation 2003 (ML/ha)	Effective rainfall 2002 (ML/ha)
1	CONV	21.8	2.6	20.1	2.7
	BMP	21.8		19.5	
2	CONV	12.8	2.7	15.6	2.8
	BMP	11.4		13.7	
3	CONV	34.0	2.7	18.3	2.7
	BMP	23.7		16.9	
4	CONV	22.4	2.3	21.8	2.5
	BMP	20.9		19.9	
5	CONV	70.8	1.7	33.3	2.1
	BMP	46.9		23.6	
6	CONV	19.9	2.8	18.2	2.7
	BMP	18.9		16.2	

Major improvements in total water applications were made where the irrigation advance rates were increased. In particular, surge irrigation decreases the amount of water applied, this was demonstrated dramatically in 2001-2002 at sites 3 and 5 where water applied was decreased by 10 and 25 ML/ha, respectively, representing savings of 33 and 44%, and in 2002-2003 at site 5 reducing water application by 29%. Surge irrigation provides a more uniform soil wetting down the length of the furrow by watering two sets of furrows intermittently. The water is switched from one set to the other at increasing frequencies; at the end of each pulse, the soil has time to consolidate and sediment in the water allowed to settle. This reduces the infiltration rate for the next pulse, which advances more rapidly over the previously wetted soil. Figure 2 shows a surge valve in operation.

Figure 2 **Surge valve installed at site 5**

In the 2002-2003 season, water application differences between treatments at site 3 were not as pronounced as in the first irrigation season. There was a change of management of the block during this period. Scheduling at site 6 did not influence the amount of irrigation applied in either season, but rather changed the way that it was applied, with smaller irrigation amounts applied more regularly. This site was scheduled to minipan evaporation (Appendix 2), where irrigation occurred when growth had dropped to half of the maximum growth to reduce stress between irrigations. Due to practical site limitations, it was only possible to maintain minimal management differences at sites 1 and 2; this is reflected in similar water applications and yields between treatments. Site 1 had limitations of the size of the block and differences between years in the ability of the grower to get water through the furrow. Site 2 underwent three ownership changes during these trials and new owners were not always kept informed by the previous owners in regard to requirements for the trial.

All sites received similar calculated effective rainfall amounts with the exception of site 5 due to lower water holding capacity of the soil and lower rainfall received. Actual effective rainfall figures could be lower than the figures reported here, since greater than 50% of total rainfall was received over a single 5-d period in 2001-2002. Rainfall was more spread during the 2002-2003 season, although total rainfall was lower.

4.2 Crop water-use efficiency

Yields from the 2001-2002 season across treatments ranged from 112 to 184 t/ha (Table 3), with and average of 144 t/ha; BMP treatments had an average 5% yield advantage over the conventional treatment. At site 6 there was a 12% yield increase, with little difference in total irrigation application. Here, the number of irrigations may give some insight into the efficiency of application. The CONV treatment received 15 irrigations compared with 22 for the BMP. Thus, the crop may have experienced less stress between irrigations. EnviroSCAN data from this site show (Appendices 3a-b) that crop water extraction under BMP irrigation was uniform between irrigations. Crops grown under conventional irrigation show a slowing down of crop extraction 2-3 d before the next irrigation. Sites 3, 4 and 5, irrigated with surge as the BMP treatment, also show increased yields (5-10 t/ha), with no differences in the number of irrigation applications, suggesting that irrigation water application was more efficient for crop use.

Table 3 Crop yield, CCS, water indices and sugar yield per ML for each treatment during 2001-2002

Site	Treatment	Yield (t/ha)	CCS	CWI (t/ML)	t sugar /ML
1	CONV	129	15.3	5.28	0.90
	BMP	129	15.3	5.28	0.90
2	CONV	129	15.0	8.35	1.52
	BMP	129	15.0	9.15	1.70
3	CONV	112	15.9	3.04	0.52
	BMP	119	15.6	4.49	0.78
4	CONV	161	15.3	6.53	1.10
	BMP	171	15.3	7.35	1.25
5	CONV	147	13.6	2.09	0.29
	BMP	151	13.6	3.03	0.43
6	CONV	162	11.8	7.15	0.96
	BMP	184	11.8	8.49	1.15

CCS levels did not differ between treatments. This was expected, as treatments were managed identically for fertiliser, herbicides and insecticides and drying-down time from the last irrigation to harvest was the same for all treatments at any one site. In the 2002-2003 season, the additional treatments at sites 5 and 6 could have shown differences in CCS due to changes to treatments, which involved changed fertiliser management.

Crop-water indices provide an estimate of how efficiently the crop uses the water applied. CWI varied from 2 t/ML on highly permeable sandy soils to 9 t/ML on heavier medium clay with an average of 5.8 t/ML (Table 3). This figure was below the approximately 8 t/ML average figure calculated by Kingston (1994) and was due largely to the lower application efficiency of furrow irrigation on the permeable Delta soils. Table 3 shows that the BMP treatment increased the CWI by an average of 16.5% compared to conventional treatment due to less water being applied and larger crops grown, i.e. BMP irrigation increases the yield per ML of water applied compared to conventional practice. It was an aim of this project to demonstrate to growers that by using BMP it is possible to increase cane yields using the same or less irrigation water and changing water management.

Yields from the 2002-2003 season ranged from 113 to 164 t/ha across all treatments (Table 4), with an average of 132 t/ha. BMP did not improve crop production in this season; there was a 3% reduction in cane yield compared to the conventional treatment across all sites. This was an unexpected result from the BMP system. The prevailing dry conditions may have had an impact on the system, with reduced applications adversely affected crop growth. At site 5, there was harvester damage in the BMP section that reduced subsequent yields. Site 4 was the only site where BMP irrigation improved crop production; a 19 t/ha advantage was achieved. These results highlight the variability of the seasons and the need for longer-term research for meaningful results. The lower overall yields produced in the 2002-2003 season compared to the 2001-2002 season are not unusual, sugarcane production is generally lower at each subsequent ratoon crop.

Table 4 Crop yield, CCS, water indices and sugar yield per ML for each treatment during 2001-2002

Site	Treatment	Yield (t/ha)	CCS	CWI (t/ML)	t sugar /ML
1	CONV	121	15.4	5.13	0.88
	BMP	119	15.5	5.42	0.95
2	CONV	118	13.5	6.57	1.03
	BMP	113	13.2	6.97	1.09
3	CONV	124	15.9	6.47	1.18
	BMP	115	16.4	6.45	1.23
4	CONV	145	13.7	5.97	0.91
	BMP	164	13.2	7.32	1.09
5	CONV	135	14.5	3.97	0.62
	BMP	120	15.5	4.83	0.83
6	CONV	161	14.6	8.01	1.34
	BMP	148	14.0	7.93	1.28

As in the previous season there were no noticeable differences in CCS between treatments, this was expected as the crops experienced the same management techniques.

CWI calculations for the 2002-2003 season show a range from 3.97 to 8.01 t/ML across all treatments. These results are similar to the previous season. BMP increased CWI by an average of 8% across all sites. Again, these results are similar to the previous season, with reduced application matching the reduced production. BMP irrigation improved CWI in five of the sites; site 3 had similar indices. The average CWI for this season was 6.25 t/ML, which is still lower than Kingston's (1994) figure. Although yields were reduced in this season, the reduced water input compensated to deliver an increase in CWI. The BMP treatment in this season was more efficient in using the water available.

By using BMP irrigation, an 8% increase in sugar production was achieved. BMP irrigation resulted in an average of 1.08 t sugar/ML and conventional irrigation an average of 0.99 t sugar/ML.

At site 5, the additional treatment of applying urea via fertigation split over a number of irrigation applications produced145 t/ha, 10 and 25 t/ha greater than the conventional and BMP treatments at that site, respectively. CCS levels did not differ; 15.2 units. CWI for the fertigation treatment was 5.41 t/ML. Fertigation at this site was a more efficient way of nitrogen application and the crop production was more efficient in the use of applied water.

At site 6, the additional treatment of reduced fertiliser application yielded 170 t/ha, 9 and 22 t/ha greater than the conventional and BMP treatments at this site, respectively. The CCS level was lower than the other two treatments at 13.7 units. This was not expected as a lower applied nitrogen rate has been linked to increased CCS levels. The increased yields however compensated for the lower CCS level. At current urea prices, this treatment saved up to $100/ha on fertiliser costs. This saving is not possible in all areas of the Delta, as there are large variations in the amount of nitrate-nitrogen available in irrigation water.

4.3 Irrigation-water quality

BSES and CSIRO laboratories were used for water analysis, with cross checks being made to ensure that data from both labs were comparable (Appendix 4). A comparison of labs, using standard nitrate-nitrogen solutions, was also made. The two laboratories have a correlation of greater than 99%. From this we have no hesitation in comparing nitrate-nitrogen values from each data set.

Samples of irrigation water were taken at each irrigation event from the fluming and analysed for nitrate-nitrogen content and electrical conductivity. Figure 3 shows average annual nitrate-nitrogen level at each site for the two seasons. Two of the six sites show a reduction in nitrate-nitrogen levels between seasons, the greatest being at site 3 (11 kg/ML down to 6 kg/ML). Two of the sites also show an increase in nitrate-nitrogen levels between seasons, the greatest being site 1, rising from 8 to 9 kg/ML. Three of the six sites have nitrate-nitrogen values that are consistently above the long-term trigger value of 5 kg/ML (ANZECC 2000) and are of concern for the effects on marine and freshwater environments. They are, however, below the short-term trigger values of 25 kg/ML nitrogen (ANZECC 2000). Long-term trigger values are based on maintaining crop yield, prevention of bioclogging irrigation equipment and minimising off-site impacts. Short-term trigger values have been developed to ensure that groundwater and surface water nitrogen does not exceed guidelines for drinking water (NHMRC 1996). The electrical conductivity levels were all below 1 dS/m, below the threshold that affects cane growth. BSES recommendations (Ham *et al.* 2000) are that levels below 2.2 dS/m are acceptable across differing soil textures and pose no threat to sustainability when there is no progressive accumulation of salinity in the root profile.

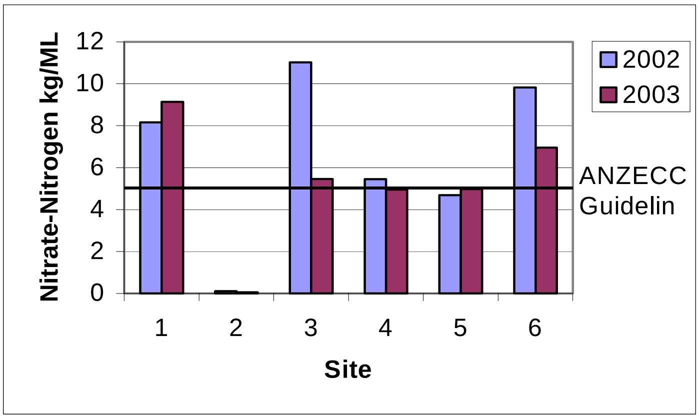

Figure 3 **Summary of irrigation water quality at all sites during 2001-2002 and 2002-2003 canegrowing seasons. The horizontal line represents the long-term trigger value of 5 kg/ML nitrate-nitrogen**

Samples of irrigation water (groundwater) were taken on three occasions during the 2002-2003 season for pesticide residue analysis. There were no quantifiable levels of any residue detected (Table 5). No MCPA, diuron, ametryn or pendimethalin was detected in any irrigation water sample. 2,4-D, atrazine and hexazinone were detected in trace levels once or twice at three sites over the monitoring period. These three chemicals are commonly used for broadleaf and grass weed control. Chlorpyrifos was detected in trace amounts at all sites; this chemical (as Lorsban®) is used for insect control in plant cane and as a controlled-release product (suSCon® Blue) for canegrub control. These results show that in terms of this method of analysis and these sampling times, the groundwater system is healthy with respect to pesticide residues. **This is good news for the Delta region, there is a need to highlight this to the industry and maintain the groundwater health.**

Table 5 Results from pesticide residue analysis on irrigation water samples

Site/Date	MCPA	2,4-D	Diuron	Atrazine	Ametryn	Chlorpyrifos	Pendimethalin	Hexazinone
1 01/10/02	ND	ND	ND	ND	ND	ND	ND	ND
1 29/11/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
1 16/07/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
2 08/10/02	ND	ND	ND	ND	ND	ND	ND	ND
2 26/11/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
2 23/04/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
3 10/10/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
3 09/11/02	ND	<LOQ	ND	ND	ND	<LOQ	ND	ND
3 09/07/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
4 14/10/02	ND	ND	ND	ND	ND	ND	ND	ND
4 19/11/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
4 01/05/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5 07/10/02	ND	ND	ND	<LOQ	ND	ND	ND	<LOQ
5 18/11/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
5 13/05/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
6 04/10/02	ND	ND	ND	<LOQ	ND	ND	ND	ND
6 26/11/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
6 13/05/03	ND	ND	ND	<LOQ	ND	<LOQ	ND	ND

ND – residue not detected, <LOQ – below the level of quantification (trace)

4.4 Soil-water quality

Careful fertiliser placement and irrigation management can influence the movement of sensitive compounds. Fertiliser should be placed subsurface near the cane stool to avoid losses in runoff or irrigation tail water. The timing of the fertiliser application should maximise the time for plant acquisition of nitrogen before temporary water logging (Calcino 1994). Irrigation management following fertiliser application is of great importance to reduce deep drainage and leaching before crop uptake, emphasising the importance of BMP.

Figure 4 shows soil water nitrate-nitrogen concentration sampled from 1.5 m at site 5 during the 2002-2003 season. The black line shows the irrigation water nitrate-nitrogen level, at the start of the season the level is 9 kg/ML and this falls to a stable level of about 5 kg/ML. Soil water nitrate-nitrogen levels peak for all treatments at 20-30 kg/ML nitrate-nitrogen. Peaks in soil nitrate-nitrogen concentration are later with fertigation and are associated with timing of fertiliser application. Levels in all treatments fell to below the irrigation water nitrate-nitrogen levels by the beginning of January 2003, suggesting continuing acquisition of available nitrogen by the crop.

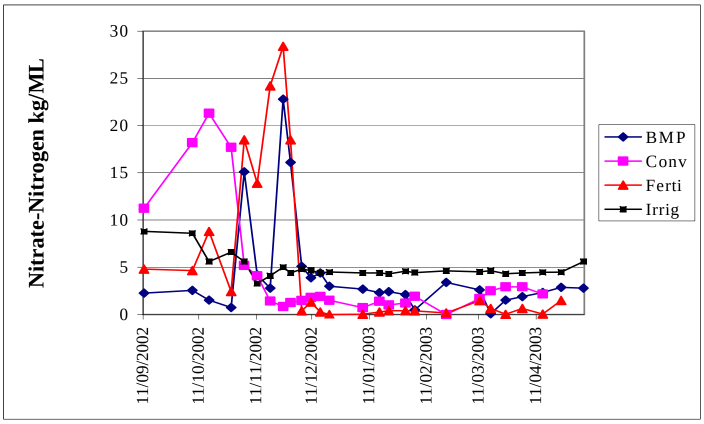

Figure 4 Nitrate-nitrogen concentrations at 1.5 m in the BMP, Conventional and Fertigation treatments compared to nitrate-nitrogen in the irrigation water at site 5 during 2002-2003

Site 6 included the third treatment of a reduced fertiliser application, as irrigation water at this site contained 8 kg/ML nitrate and it was expected that the cane would use the nitrate from the irrigation water. Figure 5 shows, that by reducing the amount of fertiliser applied, it is possible to reduce the concentration of nitrate in soil water. Both treatments will have the same amount of deep drainage (the BMP half treatment was imposed on the BMP set), but due to the reduction in nitrate-nitrogen concentration, there will be a lower nitrate-nitrogen loading. There were no visual differences in the crop grown on half the rate of fertiliser. This may be a way of saving fertiliser costs in times of low sugar prices.

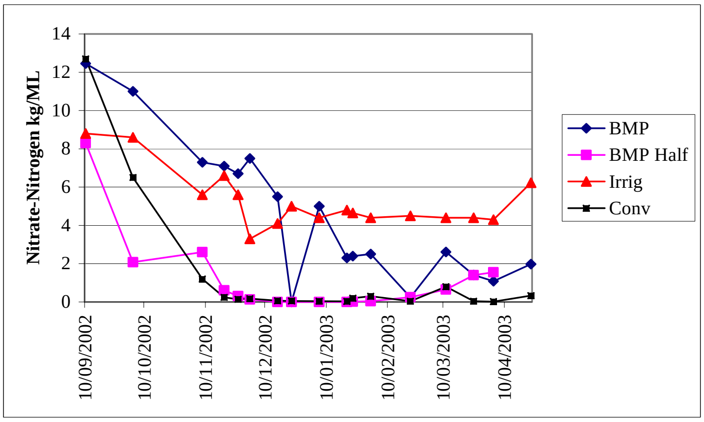

Figure 5 Nitrate-nitrogen concentrations at 1.5 m in the BMP, Conventional and BMP half-rate fertiliser treatments compared to nitrate-nitrogen in the irrigation water at site 6 during 2002-2003

Third-leaf samples were taken for analysis of nitrogen percentage (dry matter DM) to ensure that crops under different fertiliser regimes received adequate nitrogen for growth. Table 6 shows results from these samplings from sites 5 and 6; results from all sites are given in Appendix 6. The conventional treatment at site 5 had slightly higher leaf nitrogen values at the 14/8/02 sampling as the treatment had been fertilised conventionally prior to sampling; after fertigation began in the BMP/Fertigation treatments, the leaf nitrogen percentage remained slightly lower than the conventional and BMP treatments. The critical value of leaf nitrogen is 1.8%DM up to crop age of 16 weeks (112 d after harvest); these crops are above this critical value. Although the leaf nitrogen percentages are lower, final crop yields and CCS determine the profitability of this system. At site 6, there was no difference in leaf nitrogen percentages across all three treatments. This indicates that where elevated nitrate-nitrogen is found in irrigation water, nitrogen fertiliser application can be reduced without affecting the growth of the crop. Final yield and CCS figures determine the productivity of this system.

Table 6 Third-leaf nitrogen levels at sites 5 and 6

Site	Date (days after harvest)	Treatment	Leaf nitrogen (%)
5	14/8/02 (48)	Conventional	2.48
		BMP	2.23
		Fertigation (12/9/02)	2.25
5	16/10/02 (111)	Conventional	2.04
		BMP	2.05
		Fertigation (17/10/02)	1.93
5	1/11/02 (127)	Conventional	1.98
		BMP	1.95
		Fertigation (6/11/02)	1.85
5	29/1/03 (216)	Conventional	1.58
		BMP	1.63
		Fertigation	1.50
6	16/10/02 (116)	Conventional	1.82
		BMP	1.81
		Half fertiliser	1.82
6	29/1/03 (221)	Conventional	1.58
		BMP	1.47
		Half fertiliser	1.47

Soil-water samples from the suction samplers were bulked as necessary for pesticide analysis after nitrate-nitrogen readings were taken. Full results of pesticide analysis are given in Appendix 5. Soil-water results were compared to ANZECC guidelines given in Table 7. These guidelines have been set as environmental trigger values, which are designed to give protection of 90-99% of water species.

Table 7 **Freshwater trigger values for common pesticides. Reliability is the level of protection given to species**

Pesticide	**Trigger Value**	**Reliability**	**Source**
MCPA	1.4µg/L	90%	ANZECC
2,4-D	140µg/L	99%	ANZECC
Diuron	0.2µg/L	90%	Calculated ANZECC
Atrazine	0.7µg/L	99%	ANZECC
Ametryn	No data		
Chlorpyrifos	0.01µg/L	95%	ANZECC
Pendimethalin	No data		
Hexazinone	75µg/L	95%	ANZECC

Soil-water samples were taken over the two irrigation seasons of 2001-2002 and 2002-2003. A total of 67 samples from 1.5 m depth were analysed: 19 of these (28%) returned a measurable level of pesticide. No pendimethalin or ametryn was detected in any sample. One sample contained hexazinone below the trigger value (site 5 on 15/11/01); no other sample contained hexazinone. One sample contained MCPA below the trigger value (site 4 between 02/11/01 and 03/12/01); no other sample contained MCPA.

The herbicide atrazine was detected in four samples at site 2. Two of these were levels above the trigger value of 0.7 µg/L and two were below this level. Atrazine is moderately water soluble (33 mg/L), not tightly bound to soil particles and has the potential to leach in both dissolved and sediment-bound phases (Simpson *et al.* 2001). It was unusual that only one site returned positive values for this herbicide as it has been used at least twice each season at all of the sites.

Diuron was detected in 14 of the 67 samples analysed (Table 8) and all returned values well above the calculated trigger value of 0.2 µg/L. This is of concern, as diuron is persistent and the risk of off-site movement exists for about 3 months after application (Hargreaves *et al.* 1999).

Table 8 **Results of soil-water analysis for the herbicide diuron**

Site	**Date**	**Diuron (µg/L)**
1	26/08/01	0.55
2	24/10/02	0.60
3	29/09/01	0.70
3	23/10/01	0.25
3	28/11/01	0.35
3	14/12/01	0.35
4	02/11/01	0.30
4	19/11/01	0.35
4	03/12/01	0.50
5	13/08/01	0.50
5	01/10/01	0.75
5	12/11/01	0.55
6	27/09/01	0.90
6	16/10/01	0.90

2,4-D was detected in eight samples (Table 9), but all were well below the trigger value of 140 µg/L. 2,4-D has a higher potential to leach than atrazine, as the solubility is > 1000 mg/L and it is not as tightly bound to soil particles (Simpson *et al.* 2001).

Table 9 Results of soil-water analysis for the herbicide 2,4-D

Site	Date	2,4-D (µg/L)
1	26/08/01	0.20
1	09/11/01	0.80
3	28/09/01	0.20
3	28/11/01	0.15
3	14/12/01	0.15
4	19/11/01	0.15
5	18/08/01	0.15
5	01/10/01	0.20

Using individual-irrigation deep -rainage volumes calculated and concentration values from above, a whole-of-Delta loading value can be determined for each of these pesticides. There was a loading of 10.7 g of atrazine, 125.1 g of diuron and 28.9 g of 2,4-D across the Delta (57 796 ha) over the 2-year sampling period. These values calculate to minimal concentrations in the volume of drainage under furrow-irrigated sugarcane in the Delta region.

The lower occurrence of pesticides detected in the 2002-2003 season may be a result of a dryer season where pesticide use was reduced due to reduced weed pressure. These results highlight that, although there is no detectable level of any pesticide in the groundwater resource, there is a real and potential danger of these chemicals leaching to the aquifer in deep-drainage waters if best application technology is not followed.

These results confirm the low detection rate of pesticides in the groundwater at trial sites, due to low loading amounts of pesticides. This highlights that pesticides are moving through the soil profile to a certain extent, and, although pesticides like diuron are bound to the soil, they are still moving. It highlights the need for better awareness of growers and the implementation of best management practices such as those outlined in the Code of Practice for Sustainable Cane Growing (CANEGROWERS 1998).

4.5 Soil properties

Soil cores were taken during October/November 2002 to determine if any pesticide residues could be detected in the profile around the peak usage time. Analysis was performed on the 0.4-0.5, 0.9-1.0 and 1.4-1.5 m sections of the core to reduce the number of samples and to assess if further analysis of these cores was warranted. Site pesticide application data are given in Appendix 1.

Table 10 shows results from the 0.4-0.5 m soil cores from each site. There was no ametryn, chlorpyrifos, hexazinone or MCPA detected in any sample, but trace levels of pendimethalin and 2,4-D were detected in a number of samples. Diuron was detected at three of the six sites, in concentrations of 0.009-0.041 mg/kg. These sites were soil sampled 30-40 d after diuron application. This information suggests that diuron has moved through the soil profile by sediment movement under irrigated conditions. Atrazine was detected at site 2, at 0.005 mg/kg. Atrazine is relatively stable in water and is, therefore, prone to movement through deep drainage and leaching.

Table 10 Results from pesticide analysis from soil cores 0.4-0.5 m (mg/kg)

Pesticide	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Diuron	0.009	0.033	ND	ND	0.041	ND
Atrazine	ND	0.005	ND	ND	ND	ND
Ametryn	ND	ND	ND	ND	ND	ND
Chlorpyrifos	ND	ND	ND	ND	ND	ND
Pendimethalin	ND	<LOQ	ND	ND	ND	ND
Hexazinone	ND	ND	ND	ND	ND	ND
2,4-D	<LOQ	<LOQ	<LOQ	ND	<LOQ	ND
MCPA	ND	ND	ND	ND	ND	ND

ND – residue not detected, <LOQ – below the level of quantification

Table 11 details pesticide results from the 0.9-1.0 m soil cores. Again there was no ametryn, chlorpyrifos, hexazinone or MCPA detected in any sample, but trace levels of pendimethalin and 2,4-D were detected in a number of samples, although fewer than in the previous cores. Diuron was detected at two of the six sites at levels of 0.023 and 0.006 mg/kg. These two sites also had diuron detected in the 0.4-0.5 m core, although the previous levels were greater. This indicates that diuron is moving through these soil profiles. Atrazine was found in trace levels at site 2, down from 0.005 mg/kg in the 0.4-0.5 m core.

Table 11 Results from pesticide analysis from soil cores 0.9-1.0 m (mg/kg)

Pesticide	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Diuron	ND	0.023	ND	ND	0.006	ND
Atrazine	ND	<LOQ	ND	ND	ND	ND
Ametryn	ND	ND	ND	ND	ND	ND
Chlorpyrifos	ND	ND	ND	ND	ND	ND
Pendimethalin	ND	<LOQ	ND	ND	ND	ND
Hexazinone	ND	ND	ND	ND	ND	ND
2,4-D	ND	<LOQ	<LOQ	ND	ND	ND
MCPA	ND	ND	ND	ND	ND	ND

ND – residue not detected, <LOQ – below the level of quantification

Results from the 1.4-1.5 m soil cores are given in Table 12. There were no quantifiable levels of any pesticide detected in any sample. There was a trace of atrazine at site 3 and a trace of ametryn at site 5. These two pesticides were not previously detected at these sites. There was no detection of diuron at any site, indicating that the herbicide moves slowly through the soil.

Table 12 Results from pesticide analysis from soil cores 1.4-1.5 m (mg/kg)

Pesticide	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Diuron	ND	ND	ND	ND	ND	ND
Atrazine	ND	ND	<LOQ	ND	ND	ND
Ametryn	ND	ND	ND	ND	<LOQ	ND
Chlorpyrifos	ND	ND	ND	ND	ND	ND
Pendimethalin	ND	ND	ND	ND	ND	ND
Hexazinone	ND	ND	ND	ND	ND	ND
2,4-D	ND	ND	ND	ND	ND	ND
MCPA	ND	ND	ND	ND	ND	ND

ND – residue not detected, <LOQ – below the level of quantification

These results highlight that there is potential for pesticides to enter the aquifer system through deep drainage and movement through soil. The absence of pesticides at the 1.5 m depths in the soil matches the absence of pesticides found in the groundwater (Table 5).

Soil cores were extracted with 2M KCl to determine nitrate-nitrogen concentrations. Soil samples were not taken from sites prior to instrumentation of equipment on BMP sites during 2001. Samples taken at harvest 2002 and early December 2002 from BMP sets were used to calculate the amount of nitrate-nitrogen in the soil. Table 13 shows the amount of nitrate-nitrogen in soils to 1.5 m at each site.

Table 13 Soil nitrate-nitrogen levels (mg/kg) to 1.5 m at BMP sites 2002-2003

Site	After harvest 2002	December 2002 (after fertiliser application)	Change in soil nitrate-nitrogen store
1	9.98	6.28	-3.70
2	12.13	48.45	+36.32
3	19.73	42.81	+23.08
4	15.54	69.26	+53.72
5	16.68	10.10	-6.58
6	14.03	5.74	-8.29

There are differences between the amounts of nitrate-nitrogen in soils after the harvest of the 2001-2002 crop (Table 13), with values ranging from 19.73 to 9.98 mg/kg dry soil. The lowest value was at site 1, which was a loamy sand with little nitrogen-holding capacity. The highest value was site 3, which was a light cracking clay with higher capacity for nitrogen retention by soil particles. This highlights the differences between soil classes and inherent nutrient levels. The amount of nitrate-nitrogen in soils after fertiliser application varied from 5.74 to 69.26 mg/kg dry soil. Three of the six sites had lost nitrate-nitrogen from the soil store and three had added nitrates to the soil store. Of the sites that lost nitrate-nitrogen, sites 1 and 5 are highly permeable sandy soils where nitrate-nitrogen can be easily leached; site 6 was a sandy loam. Where soil nitrate-nitrogen has increased (sites 2, 3 and 4) the soil textures were heavier. This emphasises the need for careful fertiliser application and irrigation management when fertilising.

4.6 Deep drainage

Drainage was calculated on an irrigation event basis using the mass-balance equation given previously. This method assumes that the change in soil store is zero as the soil is wetted to the same degree at each irrigation event. Appendices 3a-b give EnviroSCAN data that show each irrigation event wetting the soil profile to the same degree. This confirms the assumption of zero change in soil moisture over the crop period. Table 14 shows calculated drainage volumes. It illustrates that there is not always less drainage with BMP irrigation practices. Site 6 has 4.64 ML more drainage in the BMP than in the conventional in the 2001-2002 season and 3.79 ML more deep drainage in the 2002-2003 season. This was a deviation from what was expected. Here the increased frequency of irrigation associated with BMP maintained soil moisture at a higher level (Appendices 3e-f). This would have aided water movement through the soil profile and increased deep drainage.

Table 14 Calculated deep drainage amounts (ML/ha) for crop years 2001-2002 and 2002-2003

Site	**2001-2002**		**2002-2003**	
	CONV	**BMP**	**CONV**	**BMP**
1	13.90	13.90	10.97	10.44
2	2.65	1.67	1.39	0.12
3	24.29	20.34	9.01	7.76
4	15.56	14.29	11.98	10.28
5	50.21	27.09	20.43	11.69
6	11.27	15.91	7.39	11.18

The 2002-2003 season drainage figures are less than the 2001-2002 season. This is a reflection of the reduced irrigation application in the second season (Table 2). This highlights the variability between seasons and the need for long term research to fully understand any changes made to the system and impacts on environmental health.

Individual irrigation event drainage figures and nitrate-nitrogen concentrations obtained at 1.5 m by the suction samplers at each irrigation were used to calculate season cumulative nitrate-nitrogen loading potential to the aquifer (Table 15). BMP irrigation practices reduce the amount of nitrate-nitrogen leached via deep drainage. These results were consistent between the 2001-2002 and the 2002-2003 seasons. Season cumulative deep-drainage figures for each site and treatments are given in Appendix 7.

Table 15 **Cumulative nitrate-nitrogen loading (kg/ha) for the 2001-2002 and 2002-2003 seasons**

Site	2001-2002		2002-2003	
	CONV	BMP	CONV	BMP
1	70.4	46.8	87.4	48.9
2	11.5	8.1	13.2	8.4
3	202.1	143.6	28.3	7.2
4	217.3	192.6	106.4	69.4
5	83.2	23.8	52.9	41.5
6	85.9	70.1	23.7	14.7

BMP irrigation practices reduced nitrate-nitrogen loading by 32.2%, an average of 35.9 kg/ha, across sites in 2001-2002, and by 42.2%, an average of 21.9 kg/ha, across sites during 2002-2003. The reduction in nitrate-nitrogen was a combination of reduced deep drainage and lower concentration of nitrate-nitrogen in soil water samples. Table 15 shows the additional benefits of BMP irrigation practice and the significant gains to the health of the underground water resource by implementation of BMP irrigation.

Further reductions in nitrate-nitrogen leaching were made from the additional treatments included at sites 5 and 6. Fertigation reduced nitrate-nitrogen leaching from 41.5 kg/ha under BMP to 8.7 kg/ha. At site 6, reducing fertiliser application by 100 kg nitrogen/ha, reduced nitrate-nitrogen leaching from 14.7 kg/ha to 7/9 kg/ha. By changing fertiliser management in conjunction with BMP irrigation, it is possible to reduce nitrate-nitrogen leaching by 56.7% (29.4 kg/ha) across sites compared to conventional practices.

From the DNR soils-mapping project being carried out across the Delta, each site was assigned a proportion of the total Delta area based on soils information (Table 16). These figures were used in calculating total nitrate-nitrogen losses across the delta region (Table 17).

Table 16 **Area of the Delta represented by each site**

Site	Soil	Area (ha)
1	Loamy sand	4419
2	Clay silty clay	7591
3	Silty loam – silt	12311
4	Clayey loam - loam	26072
5	Sandy loam – sand	1735
6	Sandy clay	5668
Total area		57796

Table 17 – Total nitrate-nitrogen loading across the Delta region (t)

Site	2001-2002		2002-2003	
	CONV	BMP	CONV	BMP
1	311.10	206.81	386.22	216.08
2	87.29	61.49	100.20	63.76
3	2488.05	1767.86	348.40	88.64
4	5665.45	5021.47	2774.06	1809.39
5	144.35	41.29	91.78	72.00
6	486.88	397.33	134.33	83.32
Total	9183.12	7496.25	3834.99	2333.19

Table 17 highlights the potential to reduce nitrate-nitrogen losses across the Delta. By applying BMP irrigation across the region it was possible to reduce nitrate-nitrogen losses by 18% in the 2001-2002 season and by 39% in the 2002-2003 season. This represents substantial fertiliser savings across the region and reduced potential for aquifer accumulation.

Caution is needed in interpretation of these data. Any minor error in calculations will be magnified in the final result. This is compounded by variability within sites, particularly where a reduction in nitrate-nitrogen loss was realised at sites with minimal irrigation management differences. The large difference between seasons again highlights the need for longer- term research to fully understand the difference that BMP irrigation can make to the health of the underground water system.

4.7 Soil-water monitoring

Soil-moisture monitoring devices were used within this study to assess soil water movement rates included FullStop®, Campbell Scientific 229 sensors and EnviroSCAN® monitoring systems. Diagrams of each of these instruments are given in Appendix 8.

FullStop® were placed 1.5 m below the soil surface and detected the soil wetting front using a float switch (Hutchinson and Stirzaker 2000). These were installed to provide details of when the wetting front reached the drainage zone (assumed to be below 1.5 m) and for soil-water sample collection. The wetting front detection capabilities of the FullStop® were not realised in these trials with incoherent and unbelievable data being recorded (Appendix 9). Soil-water samples were rarely collected regularly from the devices despite logger readings indicating a wetting front had reached the equipment. Upon recovery of the equipment, it was noted at three of the six sites that cane roots had grown down the installation pathway and formed a mat of roots in the funnel of the FullStop® preventing water collection.

The 229 probes are cylindrically shaped ceramic bodies containing a thermocouple and heating element (Anon. 1999). These were inserted 0.3, 0.6 and 1.5 m below the soil surface. These equipment were installed to give data to be used in soil water flux calculations to determine deep drainage from treatments. The 229 sensor measures soil water matric potential in the -10 kPa to -1000 kPa range. These studies assumed drainage occurred when the soil saturated matric potential was in the range 0 to -10 kPa. This is outside the normal operating range of the 229 sensors. Results from the sensor show the soil matric potential to fluctuate when soils are saturated (Appendix 9). Work by the NPIRD project using 229s to calculate deep drainage volumes resulted in data showing more drainage occurred in an irrigation period that water applied (data not shown). This resulted in a lack of faith in the equipment to fulfil the purpose for which they were purchased.

EnviroSCAN probes from Sentek were inserted in furrows to a depth of 1.5 m and rows to a depth of 1.0 m. EnviroSCAN sensors continuously monitor changes in soil moisture, highlighting the crop's dynamic water use with respect to environmental conditions and irrigation management strategies (Anon. 2000). This equipment was used to monitor irrigation scheduling at site 6. It highlighted the differences in plant extraction of soil moisture under the two irrigation systems (Appendices 2c-d). Information was also used to demonstrate zero change in soil store between irrigations for deep drainage calculations.

Comparing 229 data and EnviroSCAN data (Appendices 9a-d) from the same period of time highlight the lack of sensitivity of 229 sensors. Appendices 9a-b are from site 1. 229 data show the soil matric potential to be above -20 kPa for the period, whilst EnviroSCAN data show fluctuations at the 0.4 m level indicating plant removal of water and irrigation events. The soil moisture at 1.5 m was low for site 1 (between 5 and 10 mm) from EnviroSCAN data; soil matric potential was below -20 kPa.

Appendices 9c-d show 229 and EnviroSCAN data from site 4 during the same period. The matric potential of the soil was always above -20k Pa at this site, with soil moisture ranging from 25 to 35mm. Soil-moisture figures show definite peaks at irrigation, these were not indicated in the matric potential data. From this, we gained little confidence in using 229 data.

4.8 Economic scoping study

The methods and framework used in economic analysis are given in Qureshi *et al.* (2001). Further results are available in Qureshi *et al.* (2002). Details of water use and productivity from the 2000-2001 season from shared RWUEI/NPIRD sites were used in the analysis.

Using current water-pricing policy, furrow irrigation is the most attractive option for growers as the furrow system has a higher NPV than centre-pivot or trickle irrigation. When the pricing is changed to volumetric charging, centre pivot becomes the most attractive option to growers as it has lower application volumes and higher NPV than furrow or trickle irrigation. Trickle irrigation is not attractive under any water pricing policy due to high initial capital outlay.

5.0 IMPACT OF RESULTS AND RECCOMMENDATIONS TO FURTHER RESEARCH

By using BMP irrigation, a reduction in water application of 13% can be achieved. This equates to a saving of 2.9 ML/ha across delta farms. Crop production figures indicate an increase of 4.4 t/ha across delta farms. The combination of reduced water and increased yield result in an 18% overall increase in productivity across farms. This is in line with the Cane Productivity Initiative (CPI) where an increase in productivity of 20% is expected across the Burdekin district.

Deep drainage was calculated from each irrigation and summed for each season. By using BMP irrigation, deep drainage was reduced by 15% or 2.2 ML/ha. Individual irrigation drainage water was analysed for nitrate-nitrogen, these figures were applied to drainage figures. Using BMP irrigation there was a reduction in nitrate-nitrogen loading across the delta by 37.2% or 403.5 tonnes of nitrate-nitrogen across the delta (6.9 kg/ha).

Investigations into pesticide movement and acquisition by the groundwater resource were undertaken. There was no level of pesticides detected in groundwater samples. This was matched by soil water samples at 1.5 m and soil cores at 1.5 m. This is good news for the industry; there must now be a concerted effort to maintain this.

These results confirm that BMP irrigation can have greater returns for growers with less adverse impact on the groundwater systems in the delta region.

From economic analysis of using different irrigation system we conclude that maintaining current furrow irrigation practices is the most attractive option. Implementing centre pivot irrigation systems is the second most attractive option as it has higher net present value than furrow. Implementation of trickle irrigation is the least attractive to growers due to high initial capital outlay. Furrow irrigation remains most attractive under current water pricing schedules when key parameter values are varied.

This research has identified a number of areas where further work is warranted. These highlight 1) the need for long-term research to reduce between-season variability of measured inputs 2) the need to match equipment better with desired outcomes of the project 3) the need for further in-depth economic analysis of irrigation systems to include different water pricing and productivity inputs and 4) an analysis of the potential of other irrigation systems for delivering enhanced environmental outputs.

6.0 PUBLICATIONS ARISING FROM THE PROJECT

Klok, J.A., Charlesworth, P.B., Ham, G.J. and Bristow, K.L. (2003). Management of furrow irrigation to improve water use efficiency and sustain the groundwater resource – Preliminary results from a case study in the Burdekin Delta. *Proc. Aust. Soc. Sugar Cane Technol.* 25 (CD ROM).

Klok, J.A. (2003). Dealing with water issues in the Delta. *Australian Sugarcane* 7(2): 11-12.

Klok, J.A. and Charlesworth, P.B. (2003). Management of furrow irrigation to improve water use efficiency and sustain the groundwater resource. Synopses of CRC Activities 1995-2003.

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APPENDIX 1 Site details

Site 1

The block was 8.3 ha of first ratoon Q117 at the beginning of trials. Average row lengths were 260 m, facing north-south. Soil survey details show a clay loam surface over sand with clay lenses at varying depths. The clay lenses were added artificially to impede deep drainage.

This site had instruments from RWUEI monitoring the BMP treatment set and NPIRD equipment monitoring the conventional set. The BMP irrigation for this block was a change in furrow shape from a broad U-shape to a narrow V-shape with higher inflows on the V-furrow to increase advance times and reduce water application. The furrow was formed with the grower's equipment and was not done satisfactorily.

Soil samples were taken between harvest 2002 and first irrigation, early December 2002, and after the 2003 harvest.

Herbicides used were Gramoxone, 2,4-D and Diorex.

Management schedule:

Action	Date	Comment
Harvest	10/08/01	Harvest of plant crop
Irrigate	25/08/01	
Irrigate	10/09/01	
Cultivate	30/09/01	
Fertilise/Cultivate	01/10/01	230 kg/ha nitrogen
Irrigate	10/10/01	
Hill up	16/10/01	
Spray	19/10/01	
Irrigate	24/10/01	Irrigate on a 12-d cycle onwards
Harvest	30/07/02	
Irrigate	06/08/02	
Irrigate	19/08/02	
Cultivation	12/09/02	
Fertilise/Cultivate	12/09/02	230 kg/ha nitrogen
Hill up	20/09/02	
Irrigate	24/09/02	
Spray	29/09/02	
Irrigate	30/09/02	Irrigate on a 12-d cycle onwards
Harvest	19/09/03	

Site 2

The block was 10.2 ha of second ratoon Q127 with dual rows at the beginning of trials. Average row lengths were 450 m facing northwest-southeast. Soil survey results show medium clay over sand, the clay was to a depth of 0.8-0.9 m.

This site had instruments from RWUEI monitoring the BMP treatment set and NPIRD equipment monitoring the conventional set. The BMP irrigation for this block was minimum cultivation, with the conventional set being cultivated after harvest. Reducing the number of furrows irrigated each time increased inflows.

Soil samples were taken between harvest 2002 and first irrigation, December 2002, and after harvest 2003.

Herbicides used were Gramoxone, 2,4-D, Diorex and Velpar K4.

Management schedule:

Action	Date	Comment
Harvest	28/07/01	Harvest of 1st ratoon crop
Fertilised	29/07/01	227 kg/ha nitrogen
Spray	30/07/01	
Irrigate	01/08/01	
Irrigate	28/09/01	
Irrigate	17/10/01	
Spray	30/10/01	
Irrigate	04/11/01	Irrigate on 16-d cycle onwards
Harvest	21/06/02	
Fertilise	24/06/02	259 kg/ha nitrogen
Irrigate	25/06/02	
Spray	24/07/02	
Irrigate	13/08/02	
Irrigate	02/09/02	
Irrigate	23/09/02	
Irrigate	09/10/02	
Irrigate	23/10/02	
Spray	30/10/02	
Irrigate	08/11/02	Irrigate on 16-d cycle onwards
Harvest	19/06/03	

Site 3

The block was 7.8 ha of first ratoon Q183^A at the beginning of trials. Average row lengths were 650 m facing northwest-southeast. Soil survey results show medium clay over a clay loam, the medium clay was to a depth of 1.2-1.5 m.

This site had instruments from RWUEI monitoring the BMP treatment set and NPIRD equipment monitoring the conventional set. The BMP irrigation for this block was surge irrigation with 16 rows either side of the surge valve. Conventional was to irrigate 32 rows at a time.

Soil samples were taken between harvest 2002 and first irrigation, December 2002, and after harvest 2003.

Herbicides used were Gramoxone and 2,4-D.

Management schedule:

Action	**Date**	**Comment**
Harvest	25/09/01	Harvest of 1st ratoon crop
Irrigation	28/09/01	
Fertiliser/Cultivation	15/10/01	227 kg/ha nitrogen
Irrigation	23/10/01	
Irrigation	12/11/01	
Cultivation	27/11/01	
Irrigation	01/12/01	
Spray	13/12/01	
Irrigate	15/12/01	Irrigate on 20-d cycle onwards
Harvest	29/08/02	
Irrigation	10/09/02	
Cultivate	17/09/02	
Fertilise	18/09/02	225 kg/ha nitrogen
Irrigate	12/10/02	Irrigate on 20-d cycle onwards
Harvest	04/10/03	

Site 4

The block was 5.5 ha of first ratoon Q117 at the beginning of trials. Average row lengths were 550 m facing northeast-southwest. Soil survey results show a clay loam over sand, the clay loam was to a depth of 0.6-0.8 m.

This site had instruments from RWUEI monitoring the BMP treatment set and NPIRD equipment monitoring the conventional set. The BMP irrigation for this block was surge irrigation with 8 rows either side of the surge valve. Conventional was to irrigate 32 rows at a time.

Soil samples were taken between harvest 2002 and first irrigation, December 2002, and after harvest 2003.

Herbicides used were Gramoxone, MCPA and 2,4-D.

Management schedule:

Action	**Date**	**Comment**
Harvest	02/09/01	Harvest of plant crop
Irrigation	07/09/01	
Cultivate/fertilise	02/10/01	118 kg/ha nitrogen
Irrigation	01/11/01	
Spray	15/11/01	
Irrigate	19/11/01	Irrigate on 12-d cycle onwards
Harvest	28/06/02	
Irrigate	07/07/02	
Irrigate	10/09/02	
Cultivate/fertilise	17/09/02	225 kg/ha nitrogen
Irrigate	14/10/02	
Spray	28/10/02	
Irrigate	02/11/02	Irrigate on a 12-d cycle onwards
Harvest	30/06/03	

Site 5

The block was 5.5ha of plant Q183^{A} at the beginning of trials. Average row lengths were 300 m facing north-south. Soil survey results show a sandy loam over sand with gravel lenses throughout the profile. The sandy loam is to a depth on 0.8-1.0 m.

This site had instruments from RWUEI monitoring both BMP and conventional sets. The BMP irrigation for this block was surge irrigation with 10 rows either side of the surge valve. Conventional was to irrigate 13 rows at a time.

Soil samples were taken between harvest 2002 and first irrigation, December 2002, and after harvest 2003.

Herbicides used were Gramoxone Stomp, Velpar K4 and 2,4-D.

Management schedule:

Action	Date	Comment
Crop planted	05/04/01	Fertilised with 27 kg/ha nitrogen
Irrigation	07/04/01	
Spray	20/04/01	
Fertilised	23/04/01	50 kg/ha nitrogen
Irrigate	26/04/01	
Irrigate	25/05/01	
Irrigate	25/06/01	
Fertilise/Hill up	07/08/01	113 kg/ha nitrogen
Irrigation	15/08/01	
Irrigation	23/08/01	
Irrigation	31/08/01	
Irrigation	08/09/01	
Spray	18/09/01	
Irrigate	20/09/01	Irrigate on 7-d cycle onwards
Harvest	07/07/02	
Fertilise	14/07/02	230 kg/ha nitrogen
Irrigate	24/07/02	
Irrigate	18/08/02	
Spray	28/08/02	
Irrigate	10/09/02	Fertigate 11/09/02
Irrigate	25/09/02	
Irrigate	07/10/02	
Irrigate	17/10/02	Fertigate 18/10/02
Irrigate	28/10/02	
Spray	02/11/02	
Irrigate	05/11/02	Fertigate 6/11/02
Irrigate	11/11/02	Irrigate on 5-day cycle onwards
Harvest	26/7/03	

Site 6

The block was 7 ha of first ratoon Q183^{A} dual rows at the beginning of trials. Average row lengths were 450 m facing northeast-southwest. Soil survey results are unavailable for this site. From the proximity of this site to site 4 and from observations, the soils are a sandy loam over a sand. The sandy loam is to a depth of 0.8 m.

This site had instruments from RWUEI monitoring both BMP and conventional sets. The BMP irrigation for this block was scheduling the crop to a minipan and a change in furrow shape from a broad U-shape to a narrow V-shape. Conventional had broad U-furrows and no scheduling.

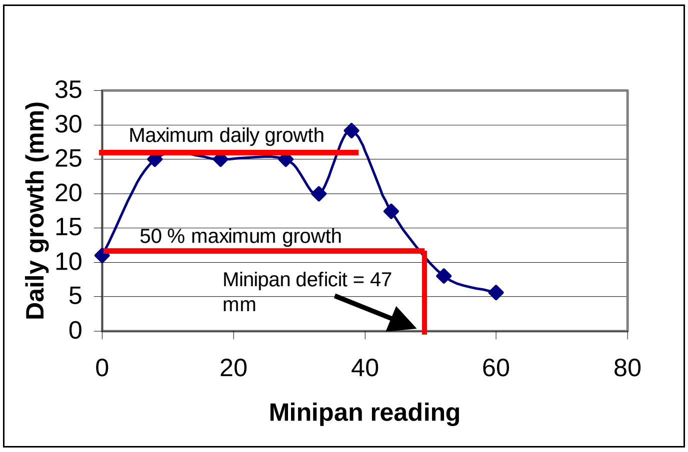
Soil samples were taken between harvest 2002 and first irrigation, December 2002, and after harvest 2003.

Herbicides used were Atrazine, 2,4-D, Gramoxone and Diorex.

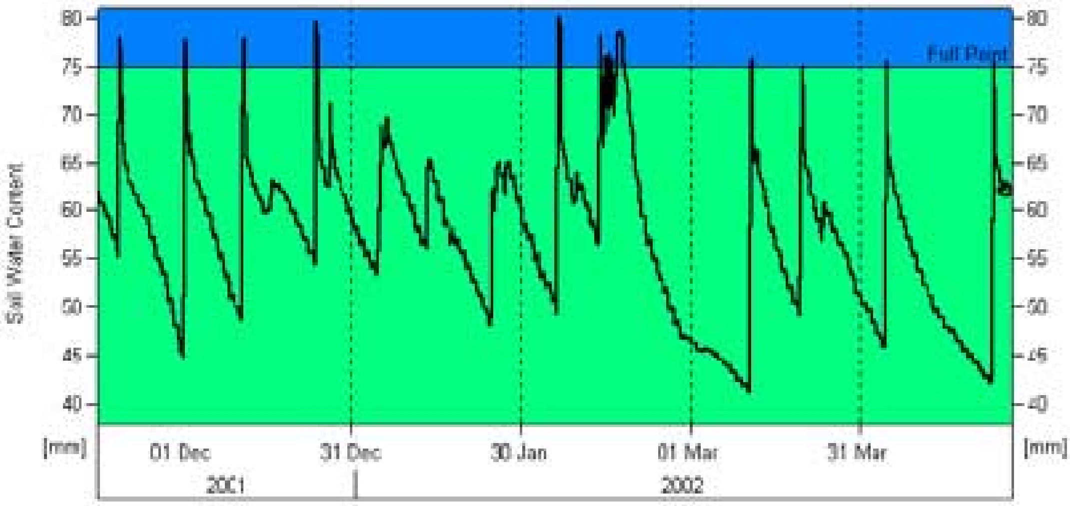
Management schedule:

Action	Date	Comment
Harvest	20/06/01	Harvest of plant crop
Irrigate	29/06/01	
Fertilise/Cultivate	16/07/01	260 kg/ha nitrogen
Irrigation	25/09/01	
Hill up	03/10/01	
Irrigate	17/10/01	
Spray	20/12/01	
Irrigate	25/12/01	Irrigate on 45 mm deficit minipan for BMP and 10-d cycle for conventional
Harvest	23/06/02	
Irrigate	29/06/02	
Fertilise	06/08/02	200 ka/ha nitrogen
Spray	02/09/02	
Irrigate	10/09/02	Irrigate on 45 mm deficit minipan for BMP and 10-d cycle for conventional
Harvest	18/08/03	

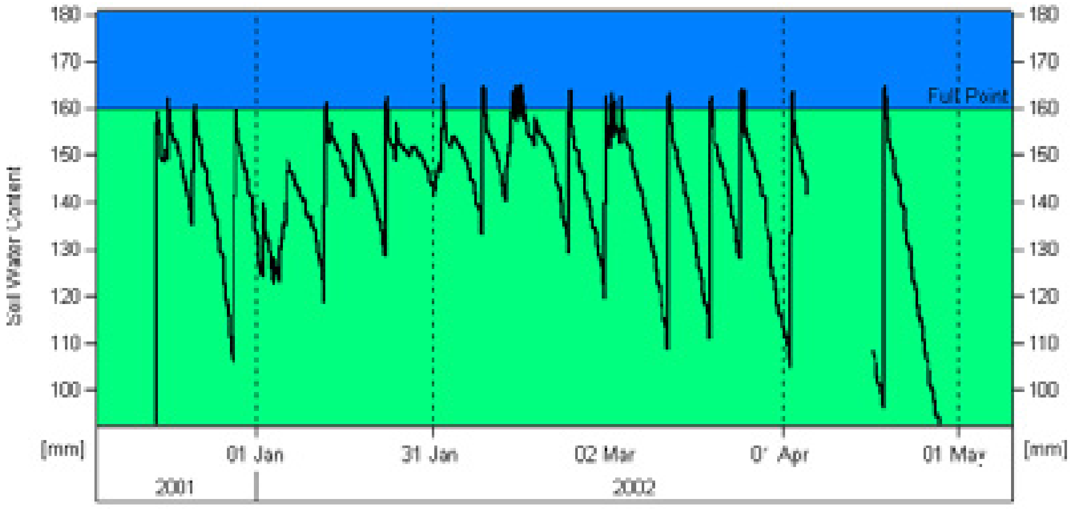
APPENDIX 2 Minipan calibration for site 6



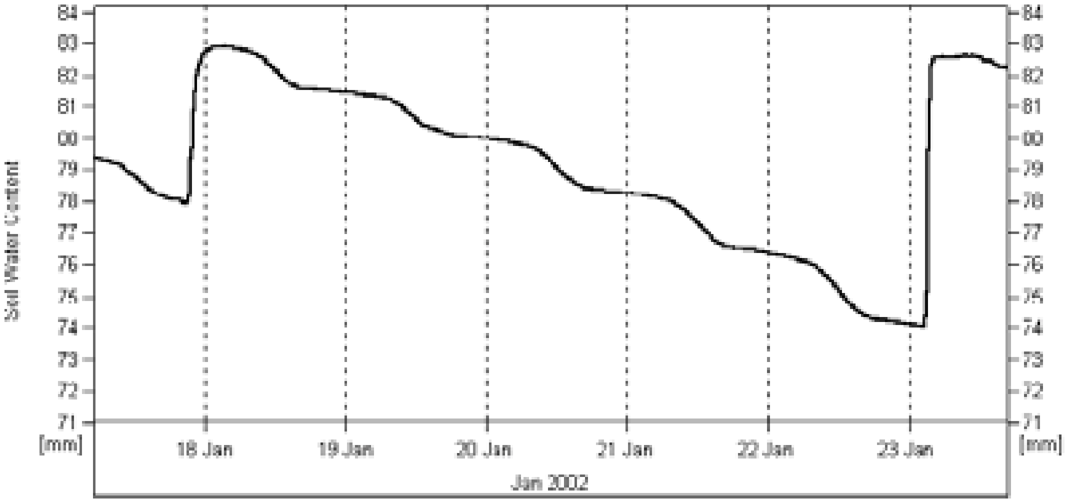
APPENDIX 3 EnviroSCAN® data



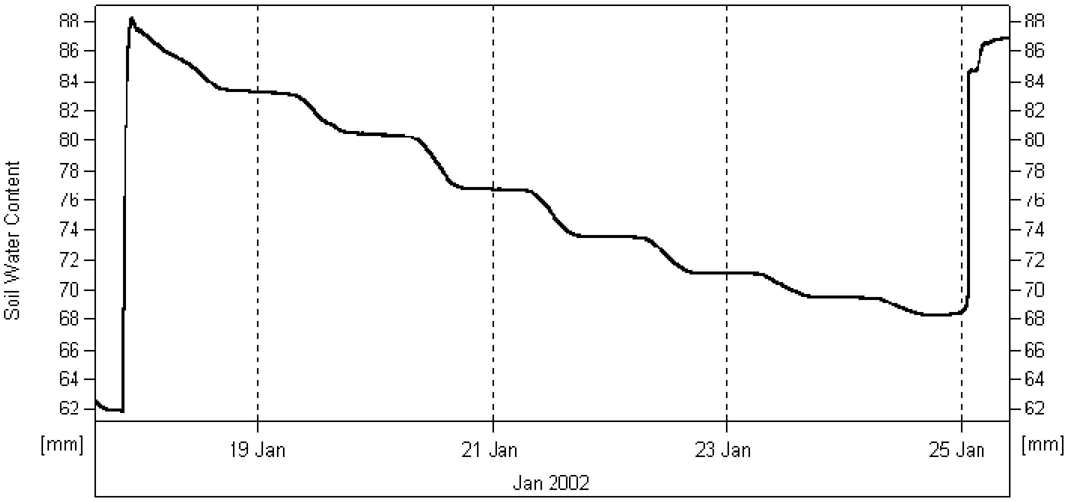
(a) EnviroSCAN data from site 1 showing wetting was similar each irrigation



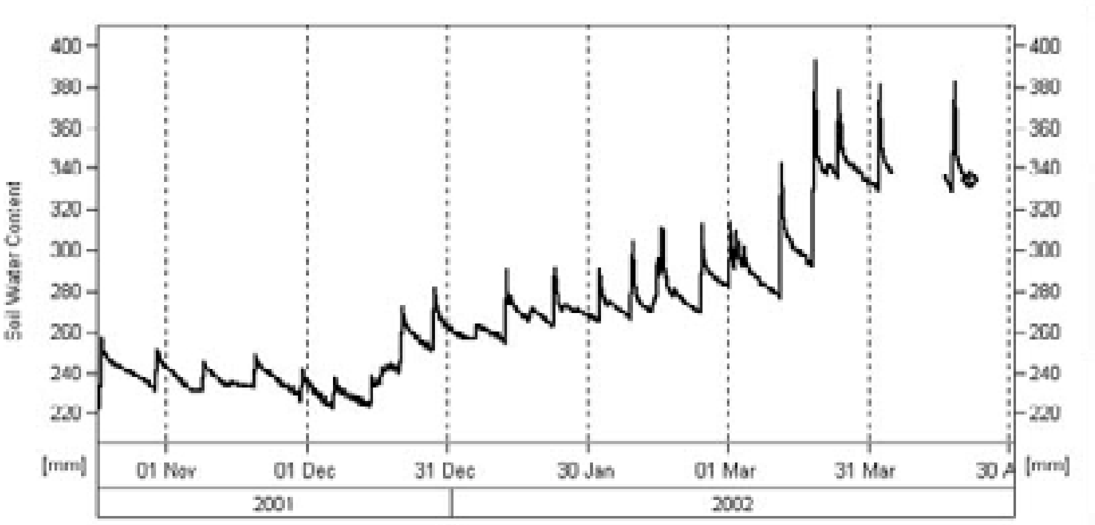
(b) EnviroSCAN data from site 6 showing wetting was similar each irrigation



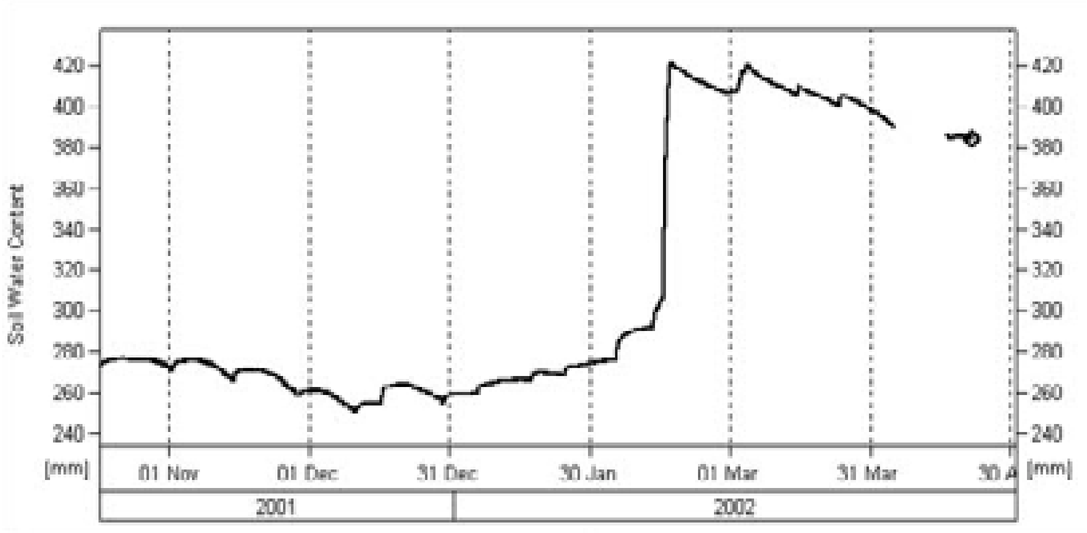
(c) EnviroSCAN data from site 6 showing the irrigation cycles for BMP treatment



(d) EnviroSCAN data from site 6 showing the irrigation cycles for conventional treatment

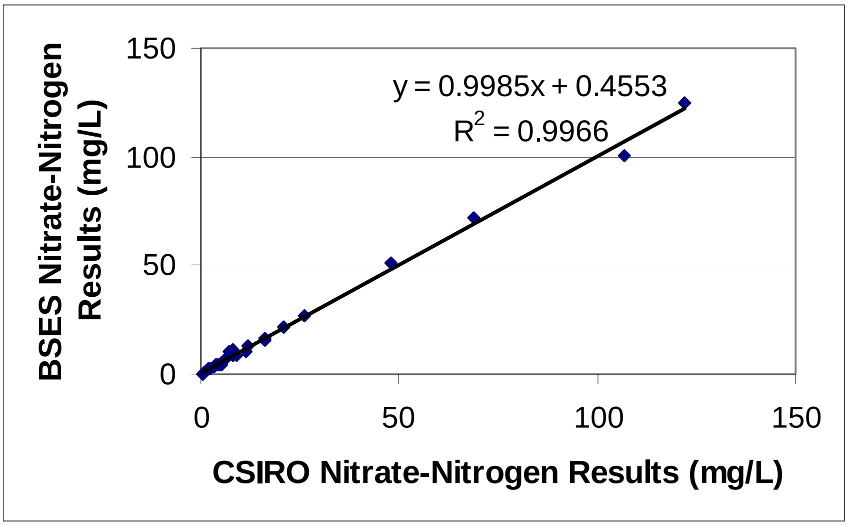


(e) EnviroSCAN data showing BMP irrigation increasing soil moisture over time at site 6

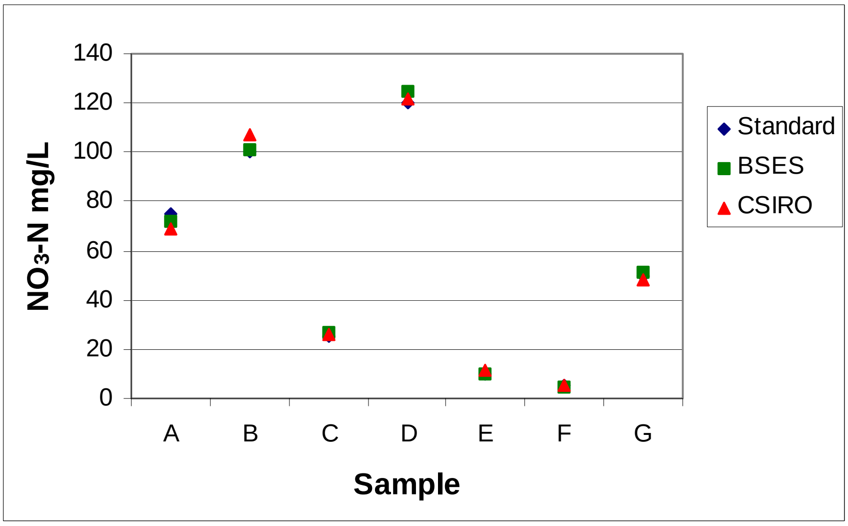


(f) EnviroSCAN data showing conventional irrigation maintaining soil moisture over time at site 6

APPENDIX 4 Laboratory cross checks between BSES and CSIRO



(a) Laboratory cross checks between BSES and CSIRO over the two seasons data. Checks occurred in February 2002, April 2002 and March 2003



(b) Comparison between BSES and CSIRO laboratories and standard nitrate-nitrogen solutions

APPENDIX 5 Pesticide residues in soil water samples 2001-2003

Site	Sample	Depth	Dates	MCPA	24D	Diuron	Atrazine	Ametryn	CP	Pendimethalin	Hexazinone
				µg/L							
1	BMP	150	26/08/2001	ND	0.20	0.55	ND	ND	ND	ND	ND
1	BMP	150	12/10/2001	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	23/10/2001	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	23/10/2001	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	9/11/2001	ND	0.8	ND	ND	ND	ND	ND	ND
1	BMP	150	11/12/2001	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	11/03/2002	ND	<LOQ	ND	ND	ND	ND	ND	ND
1	BMP	150	4/04/2002	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	10/05/2002	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	20/05/2002	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	11/9-26/11-5/2/02	ND	ND	ND	ND	ND	ND	ND	ND
1	BMP	150	26/11-13/12/02	ND	ND	ND	<LOQ	ND	<LOQ	ND	ND
1	BMP	150	9/1/03-27/3/03	ND	ND	ND	ND	ND	ND	ND	ND

Site	Sample	Depth	Dates	MCPA	24D	Diuron	Atrazine	Ametryn	CP	Pendimethalin	Hexazinone
				µg/L							
2	BMP	150	24/10-26/11/02	ND	ND	0.6	5.4	ND	<LOQ	ND	ND
2	Runoff		9/10/2002	ND	ND	24.52	ND	ND	<LOQ	ND	ND
2	BMP	150A	2/4-22/4/03	ND	ND	ND	0.3	ND	<LOQ	ND	ND
2	BMP	150A	19/1-17/3/03	ND	ND	ND	0.6	ND	<LOQ	ND	ND
2	BMP	150A	12/12-6/1/03	ND	ND	ND	0.8	ND	<LOQ	ND	ND

Site	Sample	Depth	Dates	MCPA	24D	Diuron	Atrazine	Ametryn	CP	Pendimethalin	Hexazinone
				µg/L							
3	BMP	150	28/9-23/1/02	ND	ND	ND	<LOQ	ND	<LOQ	ND	ND
3	BMP	60	28/9 - 14/12/01	ND	0.20	0.70	ND	ND	ND	ND	ND
3	BMP	30	28/9 - 28/11/01	ND	0.15	0.25	ND	ND	ND	ND	ND
3	BMP	30	23/10/2001	ND	ND	0.35	ND	ND	ND	ND	ND
3	BMP	30	14/12/2001	ND	0.15	0.35	ND	ND	ND	ND	ND
3	BMP	150	9/10-29/11/02	ND	<LOQ	ND	<LOQ	ND	<LOQ	ND	ND
3	BMP	150A	10/12/02-10/2/03	ND	<LOQ	ND	<LOQ	ND	<LOQ	ND	ND

Site	Sample	Depth	Dates	MCPA	24D	Diuron	Atrazine	Ametryn	CP	Pendimethalin	Hexazinone
				µg/L							
4	BMP	150	2/11/2001	ND	ND	0.30	ND	ND	ND	ND	ND
4	BMP	30	2/11 - 3/12/01	0.55	ND	0.35	ND	ND	ND	ND	ND
4	BMP	150	19/11/2001	ND	0.15	0.30	ND	ND	ND	ND	ND
4	BMP	150	3/12/2001	ND	ND	0.50	ND	ND	ND	ND	ND
4	BMP	150	23/1-6/2/02	ND	ND	ND	ND	ND	ND	ND	ND
4	BMP	150	13/02/2002	ND	ND	ND	ND	ND	ND	ND	ND
4	BMP	150	15/03/2002	ND	ND	ND	ND	ND	ND	ND	ND
4	BMP	150	12/04/2002	ND	<LOQ	ND	ND	ND	ND	ND	ND
4	BMP	150	22/4-9/5/02	ND	ND	ND	ND	ND	ND	ND	ND
4	BMP	150	15/10/02-15/3/03	ND	ND	ND	ND	ND	<LOQ	ND	ND

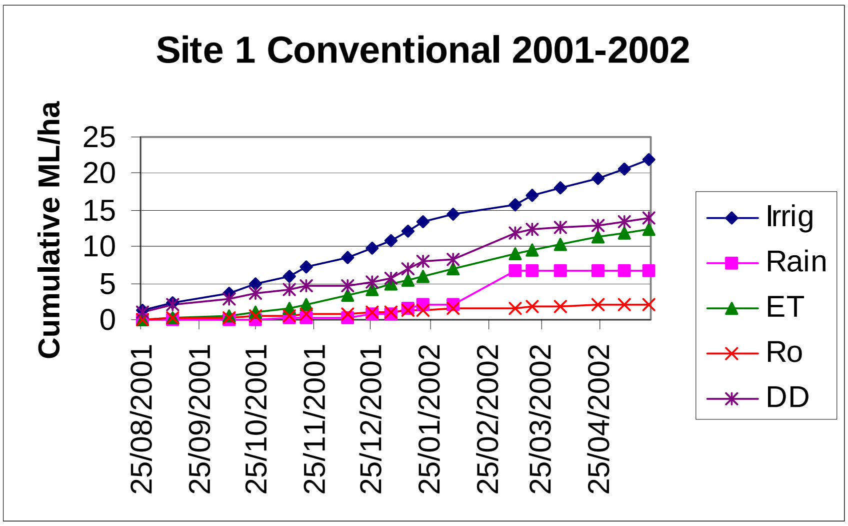
Site	Sample	Depth	Dates	MCPA	24D	Diuron	Atrazine	Ametryn	CP	Pendimethalin	Hexazinone
				µg/L							
5	BMP	150	13/8 - 1/10/01	ND	0.15	0.50	ND	ND	ND	ND	ND
5	BMP	150	15/11/2001	ND	ND	0.75	ND	ND	ND	ND	1.95
5	BMP	150	1/10 - 12/11/01	ND	0.20	0.55	ND	ND	ND	ND	ND
5	BMP	150	20/11-30/1/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	9/01/2002	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	15/02/2002	ND	<LOQ	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	12/02/2002	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	26/02/2002	ND	ND	ND	ND	ND	ND	ND	ND
5	BMP	150	5/04/2002	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	16/04/2002	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	14/05/2002	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150A	18/11 - 25/11/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	10/2-16/3/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	FERT	150A	21/1-10/2/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	25/3-14/4/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	FERT	150A	5/12-16/1/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	FERT	150A	21/2-6/5/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	BMP	150	6/5-19/5/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	FERT	150B	16/1-25/3/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
5	CONV	150B	10/02/2003	ND	ND	ND	ND	ND	<LOQ	ND	ND

Site	Sample	Depth	Dates	MCPA	24D	Diuron	Atrazine	Ametryn	CP	Pendimethalin	Hexazinone
				µg/L							
6	BMP	150	27/09/2001	ND	ND	0.90	ND	ND	ND	ND	ND
6	BMP	150	16/10 - 14/12/01	ND	ND	0.90	ND	ND	ND	ND	ND
6	BMP	150	23/01/2002	ND	<LOQ	ND	<LOQ	ND	ND	ND	ND
6	BMP	150	2/04/2002	ND	ND	ND	ND	ND	ND	ND	ND
6	BMP	150	18/04/2002	ND	ND	ND	ND	ND	ND	ND	ND
6	BMP	150	1/3-12/3/02	ND	ND	ND	<LOQ	ND	<LOQ	ND	ND
6	BMP	150	25/3-8/4/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
6	BMP	150	8/11-26/11/02	ND	ND	ND	ND	ND	<LOQ	ND	ND
6	HALF FERT	150A	23/12/02-6/1/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
6	HALF FERT	150A	11/3/03-4/4/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
6	HALF FERT	150A	20/1/03-1/2/03	ND	ND	ND	ND	ND	<LOQ	ND	ND
6	BMP	150	4/10/02-1/2/03	ND	ND	ND	ND	ND	<LOQ	ND	ND

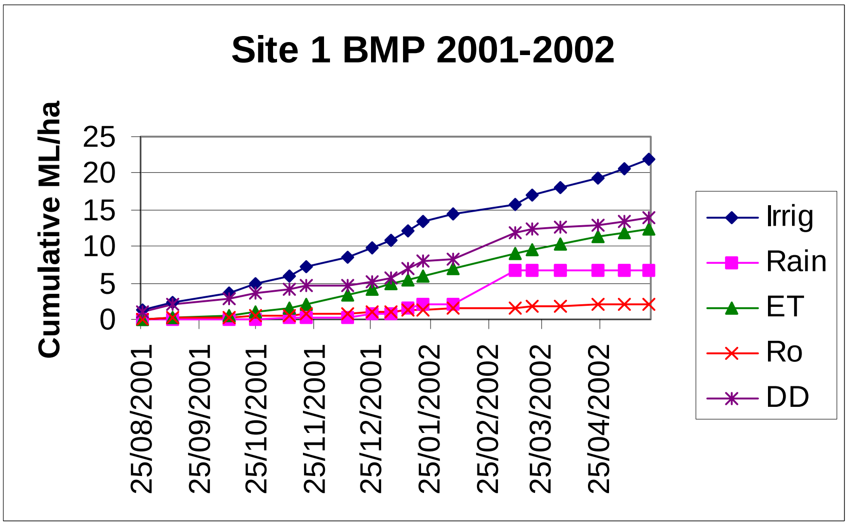
APPENDIX 6 Third-leaf nitrogen concentrations taken January 2003

Site (days after harvest)	**January 2003**	
	BMP	**CONV**
1 (183)	2.20	2.25
2 (172)	1.82	1.73
3 (241)	1.83	1.70
4 (207)	2.26	2.17
5 (178)	1.63	1.58
6 (173)	1.47	1.58

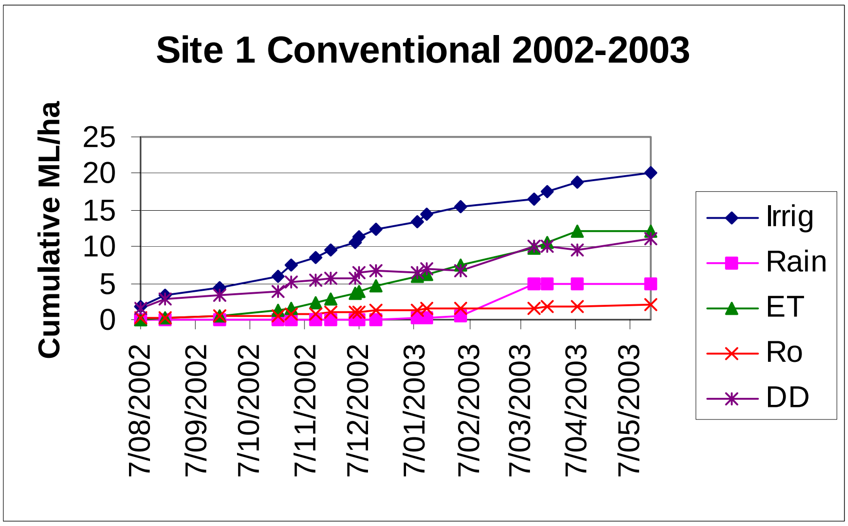
APPENDIX 7 Cumulative irrigation, rainfall, runoff, evapotranspiration and deep drainage at each site for the 2001-2002 and 2002-2003 seasons



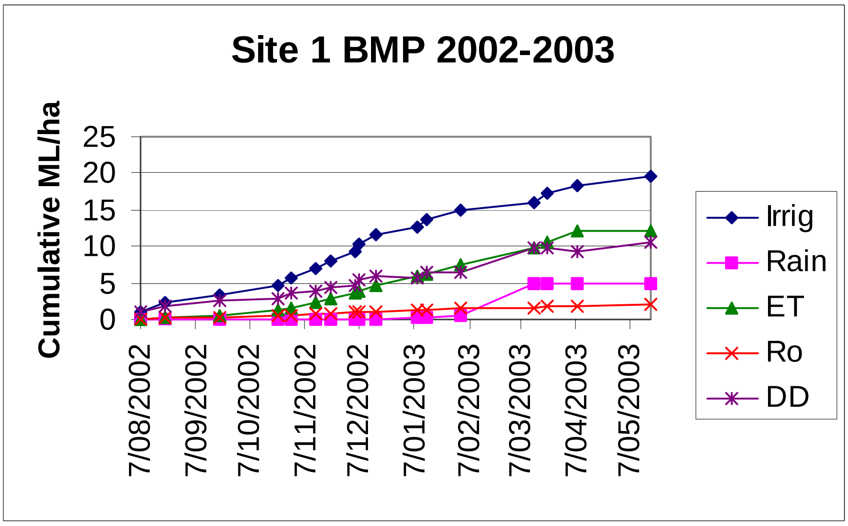
(a) Cumulative components of the mass-balance equation at site 1 conventional treatment during the 2001-2002 season



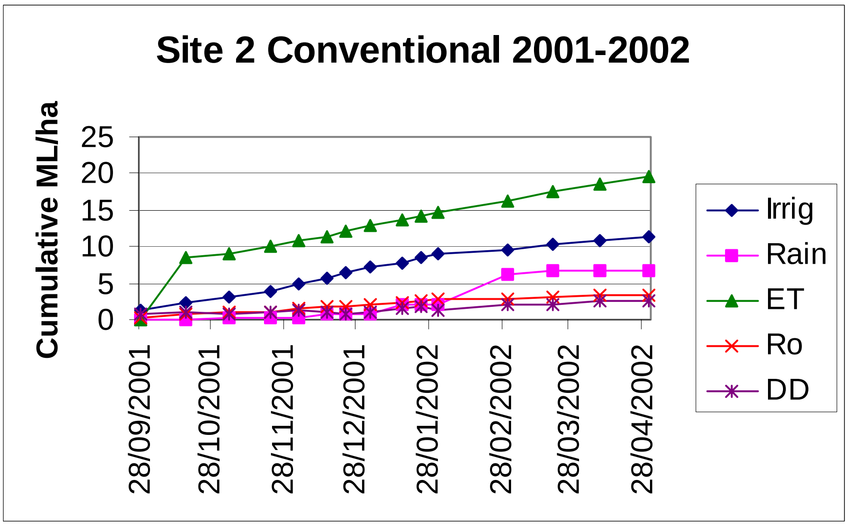
(b) Cumulative components of the mass-balance equation at site 1 BMP treatment during the 2001-2002 season



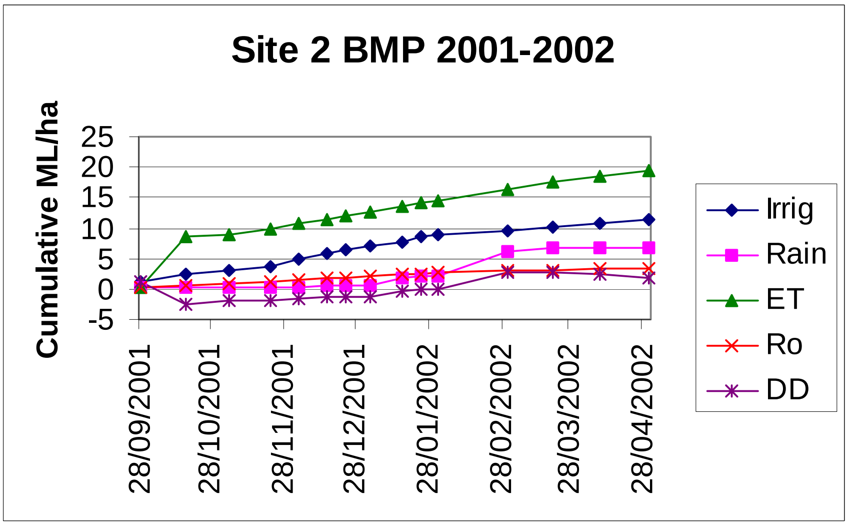
(c) Cumulative components of the mass-balance equation at site 1 conventional treatment during 2002-2003 season



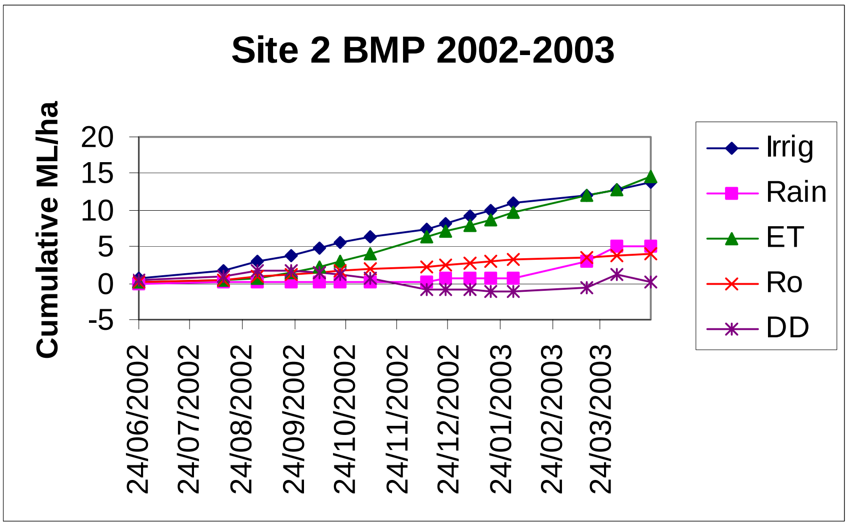
(d) Cumulative components of the mass-balance equation at site 1 BMP treatment during the 2002-2003 season



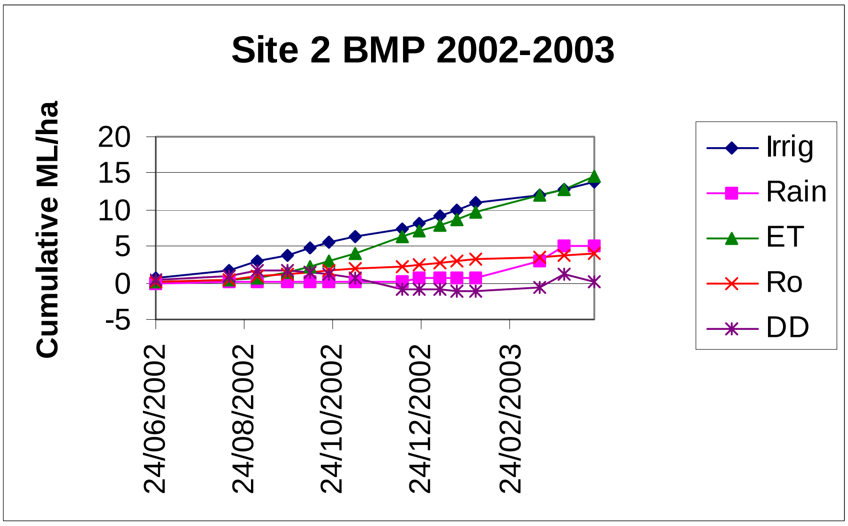
(e) Cumulative components of the mass-balance equation at site 2 conventional treatment during the 2001-2002 season



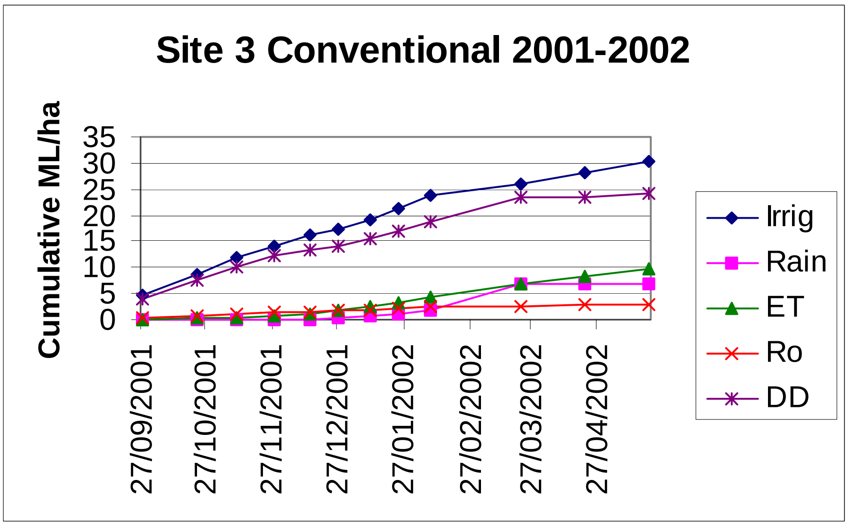
(f) Cumulative components of the mass-balance equation at site two BMP treatment during the 2001-2002 season



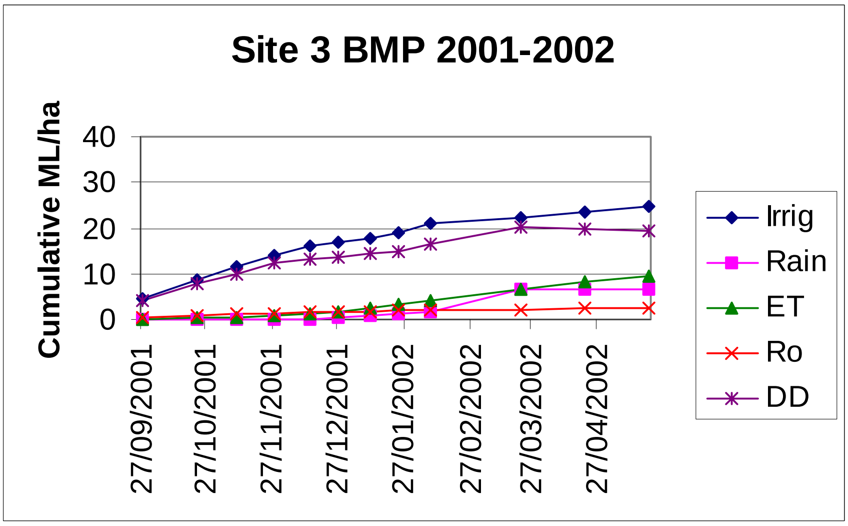
(g) Cumulative components of the mass-balance equation at site 2 conventional treatment during the 2002-2003 season



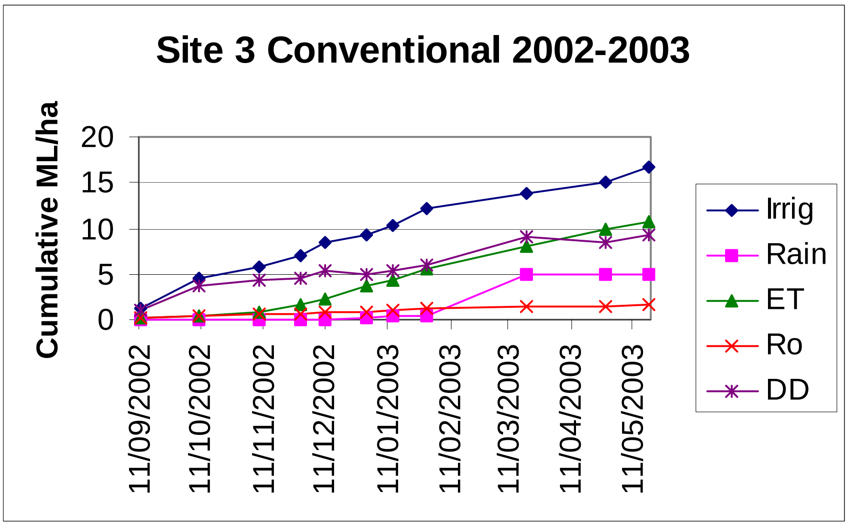
(h) Cumulative components of the mass-balance equation at site 2 BMP treatment during the 2002-2003 season



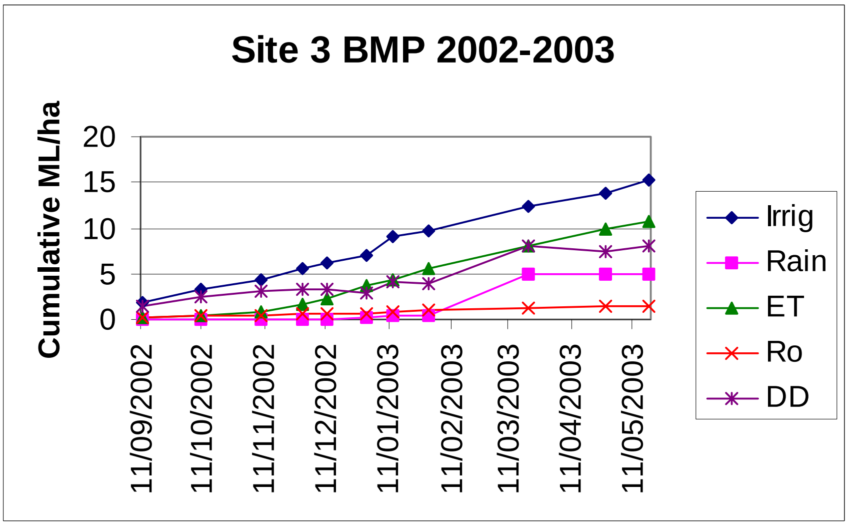
(i) Cumulative components of the mass-balance equation at site 3 conventional treatment during the 2001-2002 season



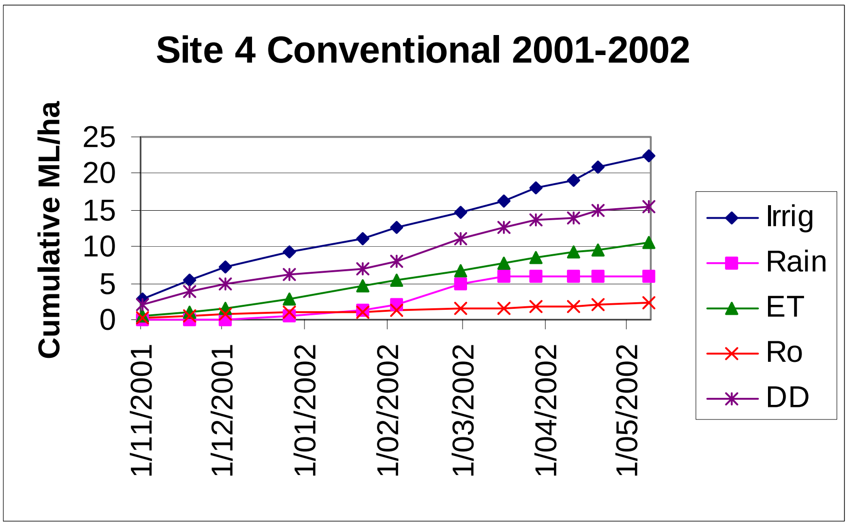
(j) Cumulative components of the mass-balance equation at site 3 BMP treatment during the 2001-2002 season



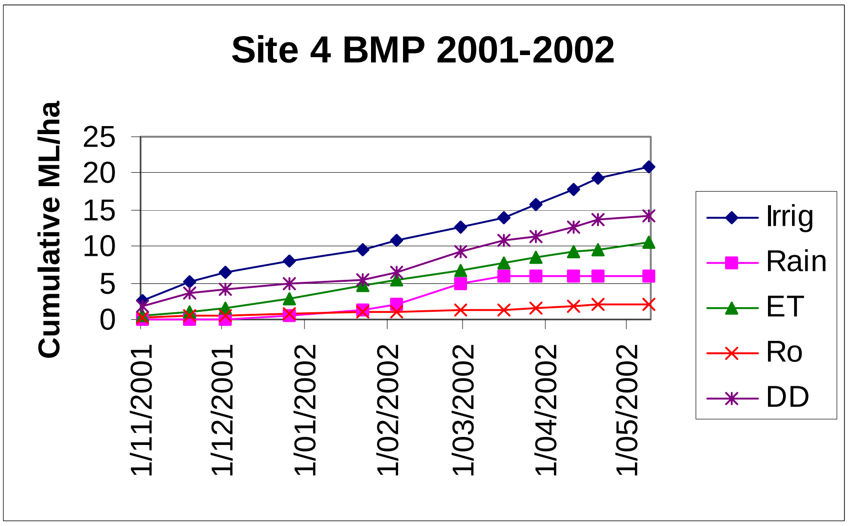
(k) Cumulative components of the mass-balance equation at site 3 conventional treatment during the 2002-2003 season



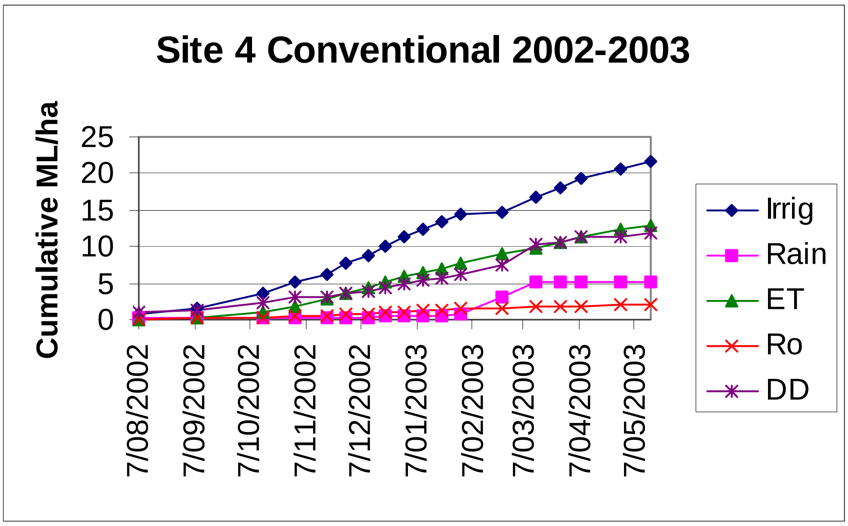
(l) Cumulative components of the mass-balance equation at site 3 BMP treatment during the 2002-2003 season



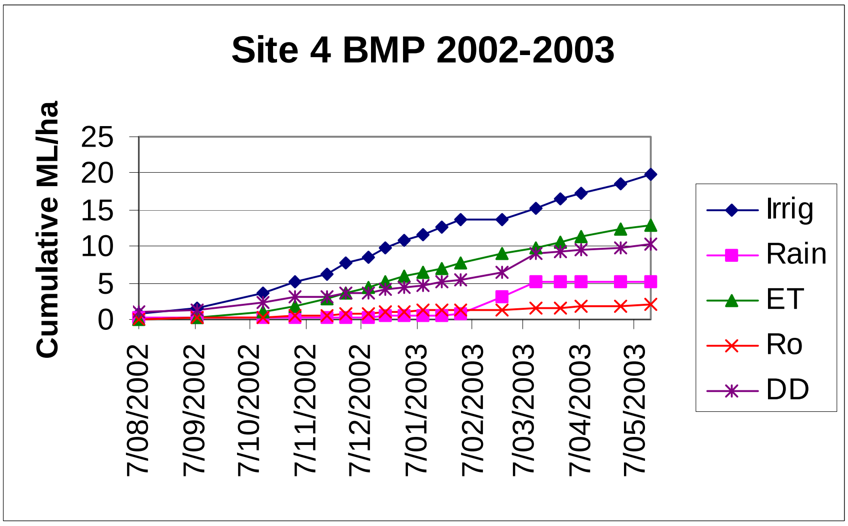
(m) Cumulative components of the mass-balance equation at site 4 conventional treatment during the 2001-2002 season



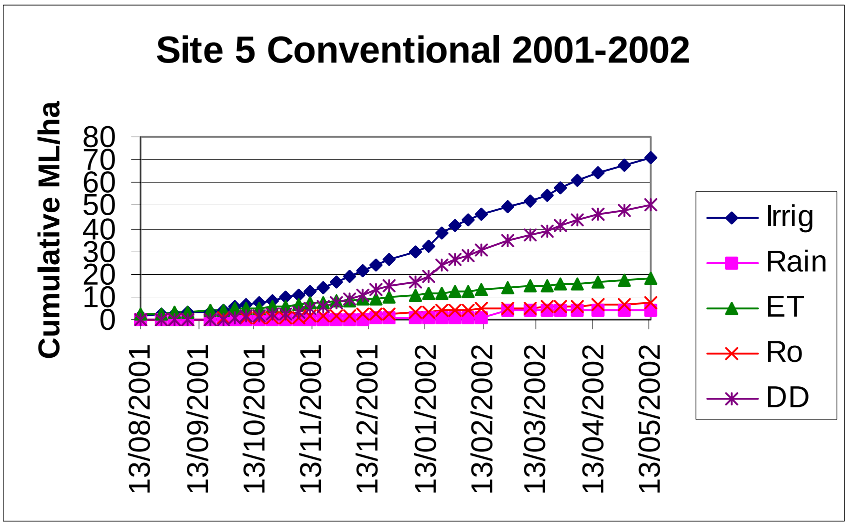
(n) Cumulative components of the mass-balance equation at site 4 BMP treatment during the 2001-2002 season



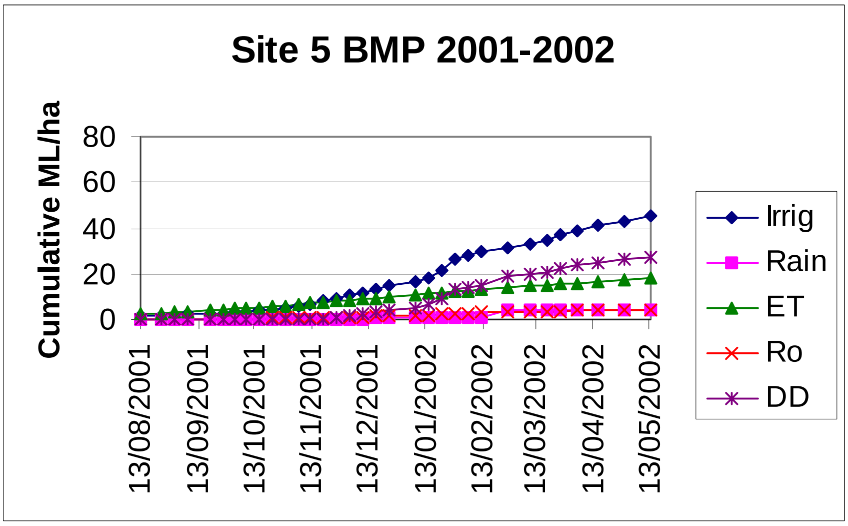
(o) Cumulative components of the mass-balance equation at site 4 conventional treatment during the 2002-2003 season



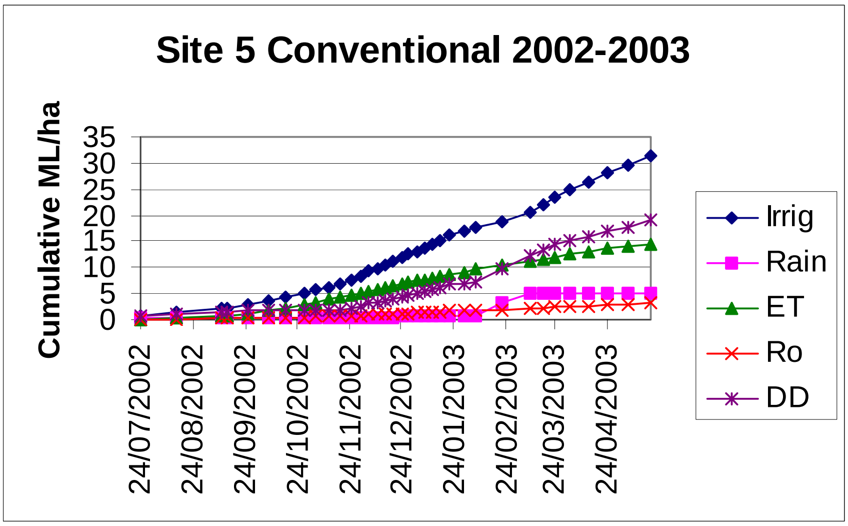
(p) Cumulative components of the mass-balance equation at site 4 BMP treatment during the 2002-2003 season



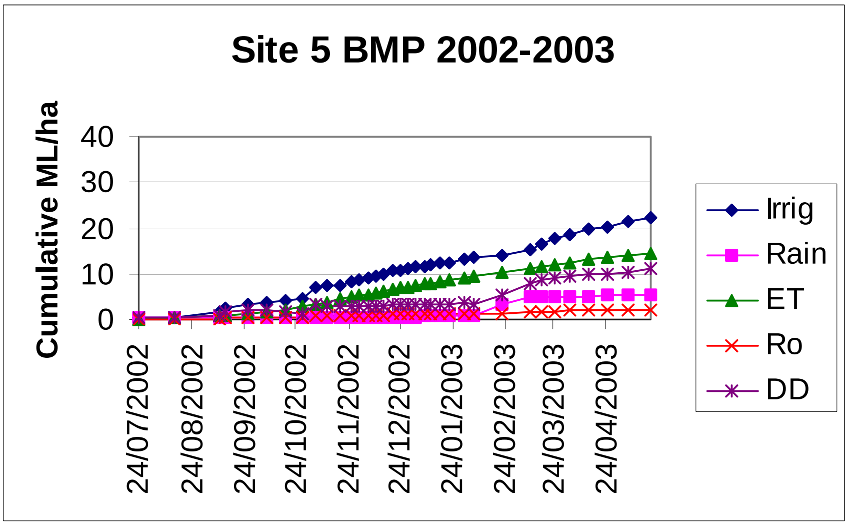
(q) Cumulative components of the mass-balance equation at site 5 conventional treatment during the 2001-2002 season



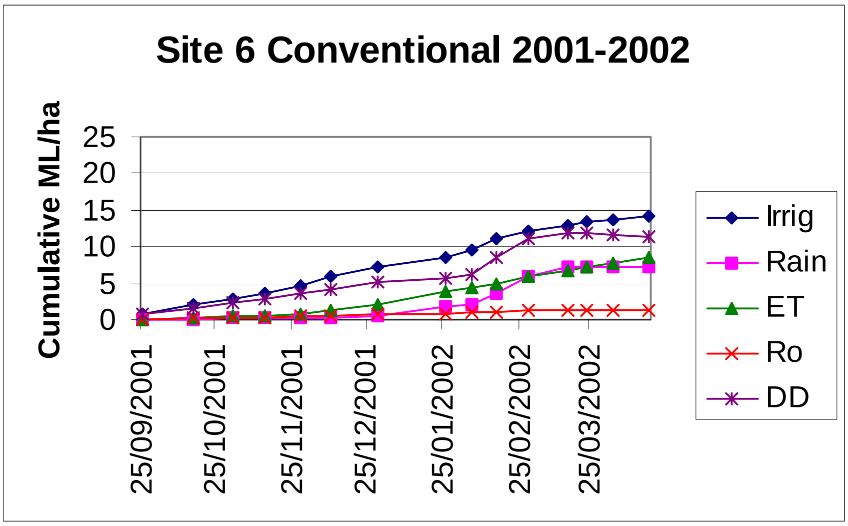
(r) Cumulative components of the mass-balance equation at site 5 BMP treatment during the 2001-2002 season



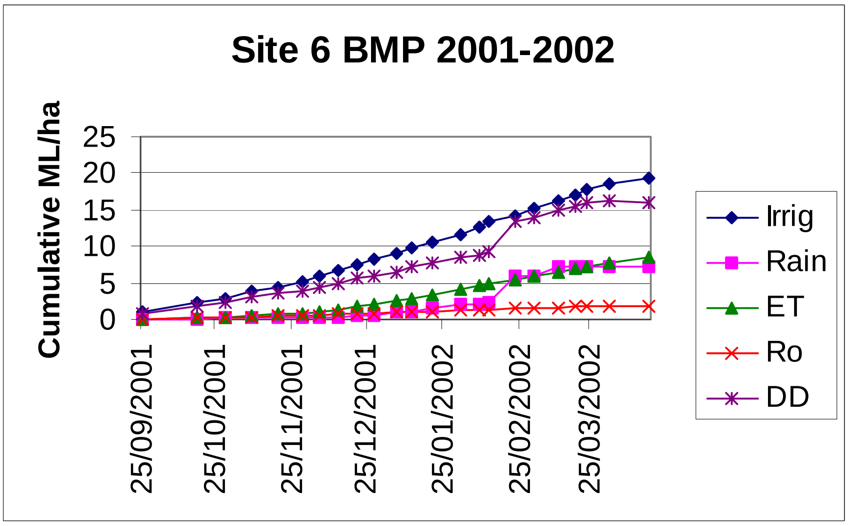
(s) Cumulative components of the mass-balance equation at site 5 conventional treatment during the 2002-2003 season



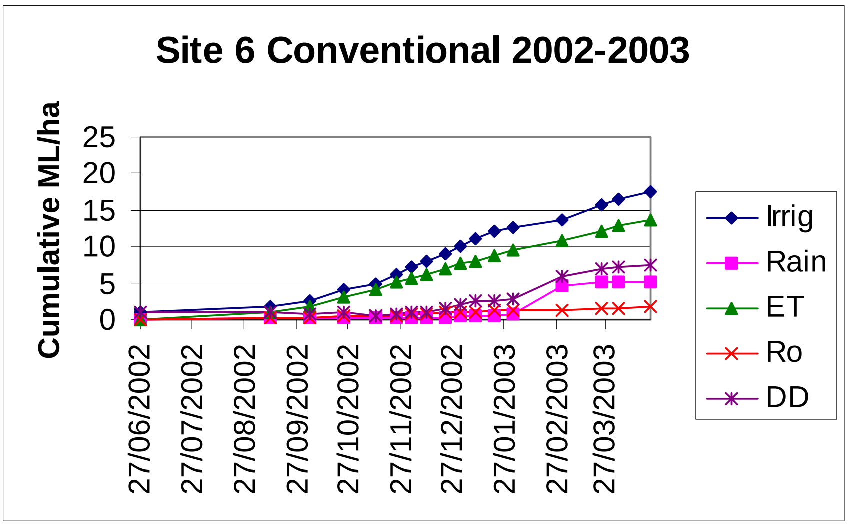
(t) Cumulative components of the mass-balance equation at site 5 BMP treatment during the 2002-2003 season



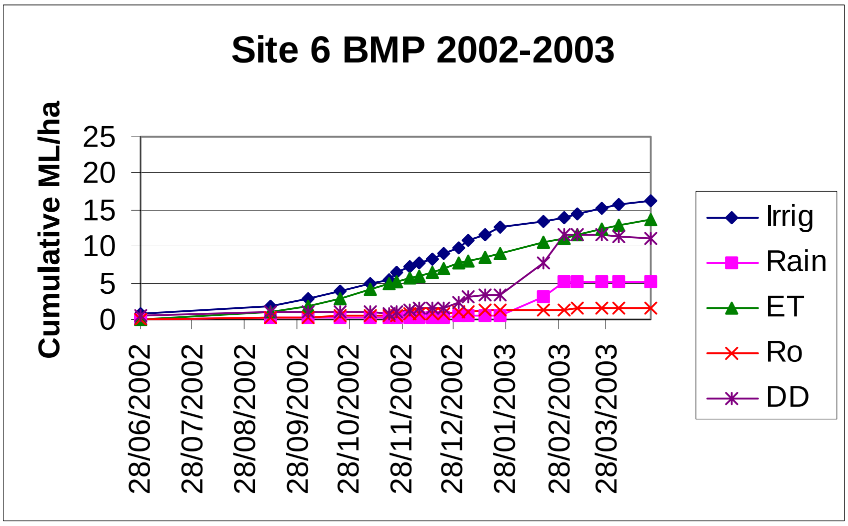
(u) Cumulative components of the mass-balance equation at site 6 conventional treatment during the 2001-2002 season



(v) Cumulative components of the mass-balance equation at site 6 BMP treatment during the 2001-2002 season

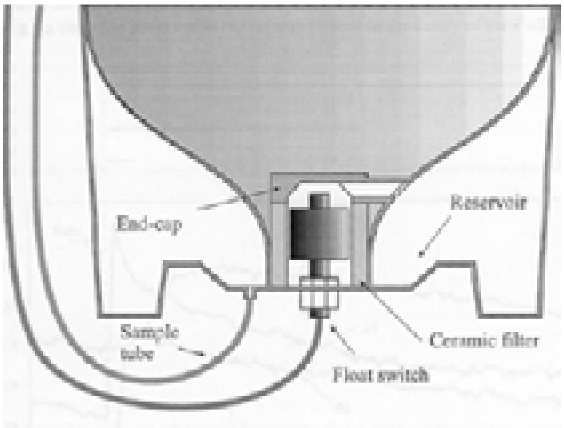


(w) Cumulative components of the mass-balance equation at site 6 conventional treatment during the 2002-2003 season

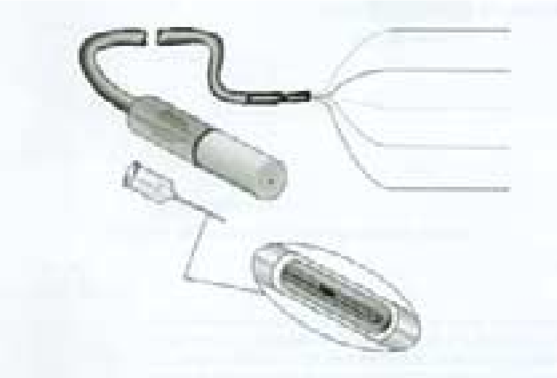


(x) Cumulative components of the mass-balance equation at site 6 BMP treatment during the 2002-2003 season

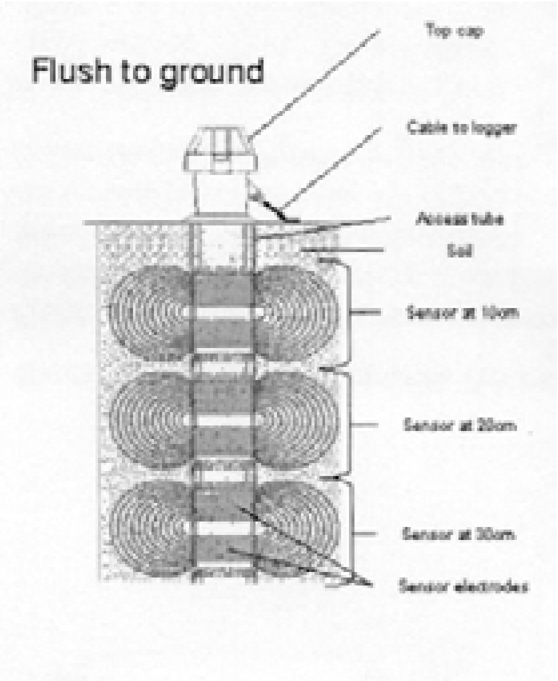
APPENDIX 8 Soil-moisture monitoring equipment



(a) FullStop®

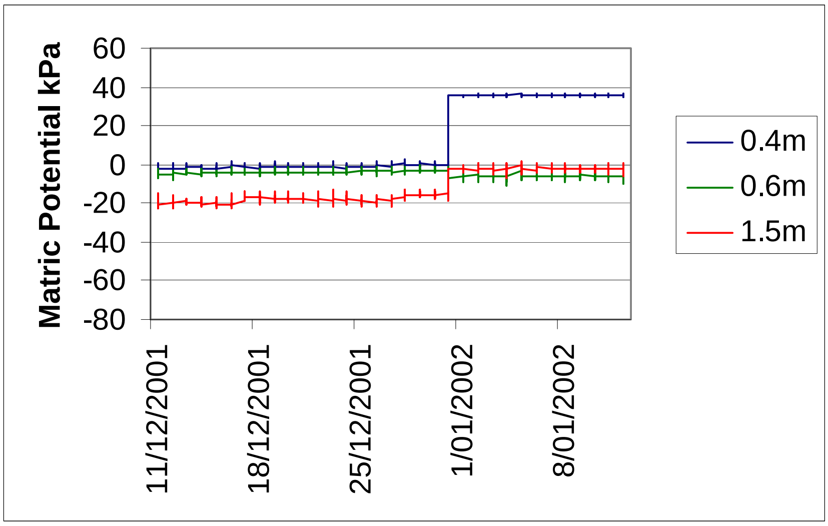


(b) Campbell Scientific 229

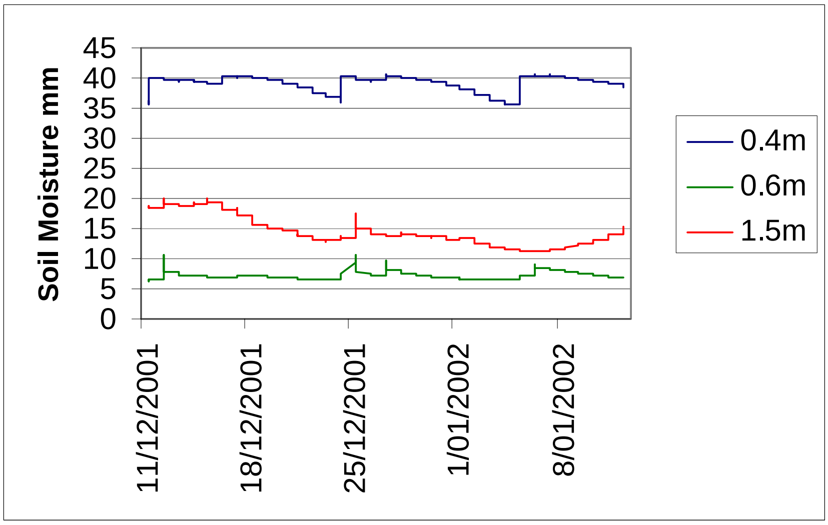


(c) EnviroSCAN®

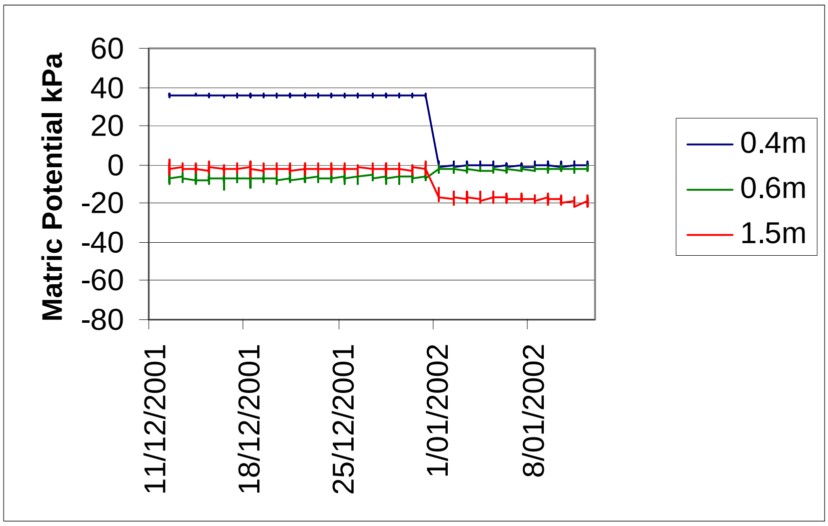
APPENDIX 9 Data from 229 sensors and FullStop®



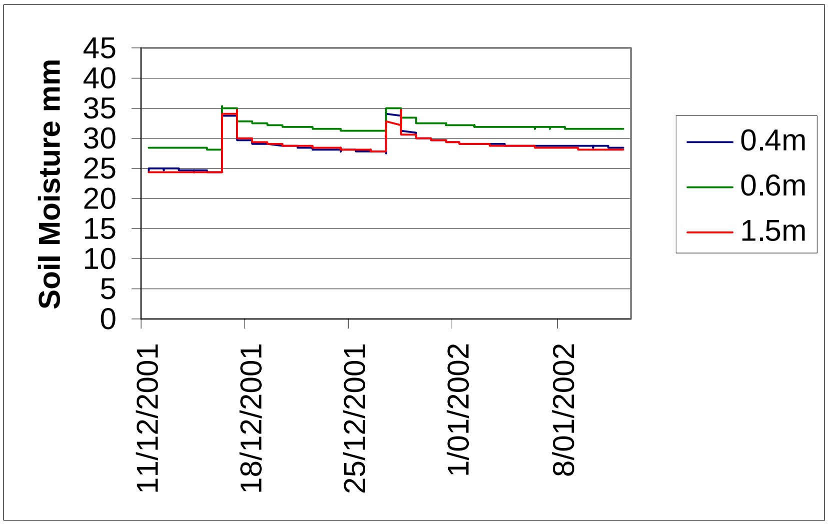
(a) 229 sensor data from site 1 BMP treatment



(b) EnviroSCAN data from site 1 BMP treatment



(c) 229 sensor data from site 4 BMP treatment



(d) EnviroSCAN data from site 4 BMP treatment

(e) Partial data from site 3 BMP treatment FullStop®

Code	Year	Day	Time	Code	Year	Day	Time
1	2001	270	957	2	2001	271	1805
1	2001	270	1001	2	2001	273	1248
1	2001	270	1014	2	2001	273	2116
1	2001	270	1019	2	2001	274	453
1	2001	273	1111	2	2001	274	601
1	2001	273	1437	2	2001	274	1005
1	2001	274	435	2	2001	296	1727
1	2001	274	525	2	2001	297	119
1	2001	274	947	2	2001	297	130
1	2001	274	1354	2	2001	297	913
1	2001	297	100	2	2001	297	925
1	2001	297	129	2	2001	297	934
1	2001	297	859	2	2001	297	938
1	2001	297	921	2	2001	297	946
1	2001	297	933	2	2001	297	952
1	2001	297	936	2	2001	297	1002
1	2001	297	942	2	2001	297	1051
1	2001	297	947	2	2001	297	1127
1	2001	297	955	2	2001	297	1149
1	2001	297	1036	2	2001	297	1222
1	2001	297	1110	2	2001	297	1335
1	2001	297	1131	2	2001	297	1355
1	2001	297	1212	2	2001	297	1411
1	2001	297	1334	2	2001	297	1415
1	2001	297	1354	2	2001	297	1536
1	2001	297	1357	2	2001	274	1005
1	2001	297	1413	2	2001	296	1727
1	2001	297	1452	2	2001	297	119
1	2001	274	947	2	2001	297	130
1	2001	274	1354	2	2001	297	913
1	2001	297	100	2	2001	297	2055
1	2001	297	129	2	2001	298	1338
1	2001	297	859	2	2001	298	1428

(f) Partial data from site 6 BMP treatment FullStop®

Code	Year	Day	Time	Code	Year	Day	Time
1	2001	267	926				
1	2001	267	1032	2	2001	267	926
1	2001	267	1032	2	2001	267	1032
1	2001	290	2326	2	2001	290	2119
1	2001	303	516	2	2001	302	2326
1	2001	334	712	2	2001	334	155
1	2001	341	321	2	2001	341	45
1	2001	355	1708	2	2001	355	819
1	2001	362	1757	2	2001	362	853
1	2002	5	1557	2	2002	5	1427
1	2002	6	711	2	2002	6	514
1	2002	6	1155	2	2002	6	951
1	2002	13	243	2	2002	12	1711
1	2002	18	51	2	2002	17	2210
1	2002	23	1407	2	2002	23	402
1	2002	25	818	2	2002	25	334
1	2002	33	1016	2	2002	32	2008
1	2002	34	1842	2	2002	34	1537
1	2002	40	926	2	2002	39	1833
1	2002	45	2220	2	2002	45	449
1	2002	47	1120	2	2002	45	2357
1	2002	49	210	2	2002	48	2102
1	2002	55	733	2	2002	54	1919
1	2002	61	1343	2	2002	60	2038
1	2002	63	544	2	2002	62	151
1	2002	64	933	2	2002	63	1742