Deep Drainage Potential of Surface Irrigated Sugarcane in the Arriga Flats of Far North Queensland

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JAMES COOK UNIVERSITY AUSTRALIA

NATIONAL PROGRAM FOR Sustainable Irrigation

SRDC Investing in sugarcane industry innovation

BSES Sugarcane for the future

Abstract
The National Program for Sustainable Irrigation provided funds to undertake an 8-week research study on-farm during the 2010-2011 summer. The initial approach to this study sought to investigate and improve irrigation application efficiency of furrow irrigated sugarcane in the Arriga Flats of Far North Queensland, using the surface irrigation model SIRMOD. Due to above average summer rainfall preventing growers from irrigating during the whole study period, an alternative approach had to be developed. Seeking to identify areas of irrigation inefficiency on a fine spatial scale over one furrow-irrigated sugarcane block, I related bulk soil electrical conductivity (EC_a) measurements, obtained from an EM38 survey, to deep drainage (DD) estimates as calculated by the model SALFPREDICT, using analytical data from 8 selected soil profiles. Using simple linear regression analysis, the study found that in this area (with soils that are variably sodic but not saline), the EC_a was a poor predictor of estimated DD (r^2=0.12). The study also found estimated DD to vary considerably (40-254mm/year) within the block, even though it was mapped as having one soil type. Appropriate identification of areas of irrigation inefficiency and the management of areas most susceptible to DD losses therefore requires a fine scale quantification of soil properties which influence DD.

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1. Introduction

1.1 Background to Study

In late 2010, I received a university scholarship offered by the National Program for Sustainable Irrigation (NPSI). The scholarship was for a short (8 week) research study on-farm during the 2010-2011 summer period. The primary objective of the scholarship was to provide direct partnerships between the irrigation industry, irrigation researchers and university students. The following report will outline my approaches to the study and detail my major findings.

1.2 Need for Research

Surface irrigation accounts for 70-80% of irrigation water use in Australia (Raine and Walker, 1998), and is the most widely used system for sugarcane in Queensland (Qureshi et al., 2001). Despite its widespread use, the efficiency of surface irrigation practices is often low and highly variable (Raine and Walker, 1998).

Raine and Bakker (1996) and Dalton et al. (2001) identified deep drainage (DD) below the root-zone as a major contributor to poor irrigation efficiency. DD is described as the amount of infiltration which exceeds the soil moisture deficit (Smith et al., 2005). If recharge through DD exceeds discharge, the water table may rise to within or close to the crop root zone, with subsequent problems of waterlogging and soil salinisation (Triantafilis et al., 2003).

In the Mareeba Dimbulah Water Supply Scheme (MDWSS, formerly known as the Mareeba–Dimbulah Irrigation Area) in Far North Queensland, rising saline groundwater has been a concern since the 1980's (Jensen et al., 1996; Rose et al., 1996; Lait, 1998; Webb et al., 2005). The Department of Natural Resources, Mines and Water identified a specific risk of salinity arising from irrigation for the Cattle Creek catchment. The catchment comprises ≈5000 ha of irrigated land, mostly under furrow irrigated sugarcane (Webb et al., 2005). To assess the significance of rising saline groundwater, ≈100 groundwater monitoring bores were installed between 1988 and 1995 (Nelson et al., 2010). The monitoring results caused serious concern when groundwater levels were found to be rising significantly. For example, Lait (1992) reported that water tables were rising up to 0.5 m/year in some parts of the catchment, and the rise continued until 2008 (Nelson et al. 2010).

In a recent study of the salinity risks of the Cattle Creek Catchment, Webb et al. (2005) reported approximately 466 ha of the catchment has a depth to water table of less than 4m with a moderate (10-20kg Cl/m^2) or high (>20kg Cl/m^2) salt load. The Arriga Flats were highlighted as an area of major concern. The Arriga Flats are a relict floodplain of dominantly clay soils, but which also has bands of sandier soils with higher permeability (Webb et al., 2005). Webb et al. (2005) suggested if the water table continues to rise, parts of the Arriga Flats are likely to become waterlogged and eventually saline. There is concern of major degradation of natural resources with impact on primary production, downstream water quality and ecosystem health. A need for further research into recharge under different soils and crop irrigation practices in the Arriga Flats was evident.

The ultimate objective of this study was to investigate surface irrigation practices on the Arriga Flats with a view to improving water use efficiency and reducing DD to the aquifer. However, due to a number of unforeseen circumstances, several different approaches had to be developed and implemented.

1.3 Approaches to Study

The intended approach was to use the surface irrigation model SIRMOD (Walker, 1993), to characterise and quantify furrow irrigation practices across sugarcane cropping on the major soils of the Arriga Flats and to estimate DD. To become proficient in the use of the SIRMOD computer model, I undertook a week's training at BSES (Burdekin Branch).

SIRMOD simulates the hydraulics of surface irrigation at the field level. This allows surface irrigators and water managers to experiment with design and management variables, to investigate and improve surface irrigation application efficiency, and minimise DD losses to groundwater (Hornbuckle et al., 2005). Unfortunately, sustained above-average rainfall meant that growers did not need to irrigate their crops and therefore no data was able to be collected. This led to the development of an alternative approach.

Given the need for more detailed soil mapping and measurement of soil attributes relevant to DD in the Arriga Flats (Webb et al., 2005), the alternative approach sought to provide a detailed examination of the physical and chemical properties of the major soils. For example, measurements of saturated hydraulic conductivity using Guelph Permeameters (Soil Moisture Corporation, 1991), and a wide-scale estimation of topsoil properties such as texture and composition, clay, and pH using the GR320 portable gamma-ray spectrometer (Exploranium Radiation Detection Systems, Canada) were trialled. Detailed soil sampling and analysis were also planned. Unfortunately, the soil was far too wet to obtain reliable measurements of hydraulic conductivity, and technical problems precluded use of the gamma-ray spectrometer. Consequently, a third approach was developed.

The third and final approach, which is the focus of the remainder of this report, sought to relate bulk soil electrical conductivity (EC_a) measurements, obtained from an EM38 (Geonics, Canada) survey, to DD estimates as calculated by the salt and leaching fraction model SALFPREDICT (Carlin and Brebber, 1993), for a furrow- irrigated block, on a major soil type of the Arriga Flats.

1.4 Scope of Study

Traditional methods of measuring DD such as lysimetry (e.g. Kitching et al., 1980; Moss et al., 2001), and environmental tracers such as chloride profiles (Willis and Black, 1996; Radford et al., 2009; Slavich and Yang, 1990) are often time consuming and site specific (Gee and Hillel, 1988; Allison et al., 1994). These methods therefore often fail to account for the spatial variability of soil properties which influence DD, and are too costly to be undertaken over large areas (Triantafilis et al., 2003). As a result, inefficiencies in irrigation management and the accurate identification of areas most susceptible to DD losses often result. It is increasingly recognized that there can be significant variation in rates of local recharge over a few meters (Sharma and Hughes, 1985; Johnston, 1987).

Electromagnetic induction (EMI) instruments such as the EM38, afford an alternative, robust and less expensive means of determining the spatial variability of soil properties which directly influence hydraulic characteristics, and hence DD of soil (Triantafilis et al., 2003). The EM38 measures bulk soil electrical conductivity (EC_a) which is a function of salinity, clay content and mineralogy, porosity, soil moisture, and soil temperature (McNeill, 1980b). EMI instruments have been used extensively in the measurement and mapping of the properties that influence DD (e.g. Sudduth et al., 2005; Slavich and Petterson, 1990; Triantafilis and Lesch, 2005). In the cotton growing district of Gwydir valley, northern New South Wales, Triantafilis et al. (2003), established a relationship between EC_a measurements, obtained by an EM38, to DD estimated by SALFPREDICT

The empirically based SALFPREDICT model, described and developed by Shaw and Thorburn (1985a; 1985b), can be used to estimate the rate of DD at steady state using various amounts of irrigation water. The basis of the SALFPREDICT is detailed in Shaw and Thorburn (1985a) and Shaw and Thorburn (1985b), while limitations of the model are discussed in Carlin and Truong (1999).

SALFPREDICT is based on the assumption that soil leaching (or proportion of input water draining below the active root zone) is related to the soil hydraulic conductivity, which in turn is influenced by clay content, clay mineralogy (defined by CEC/clay content or CCR), exchangeable sodium percentage (ESP) at 0.9m (nominal bottom of the root zone), cation exchange capacity (CEC), and air dry soil moisture content (ADMC). The depth (mm) and electrical conductivity of irrigation water applied annually and the annual rainfall (mm) are also important factors (SalCon, 1997).

In this study, I examined the applicability of the methodology described by Triantafilis et al., (2003) to a surface irrigated, sugar cane block on the Arriga Flats.

2. Aims

- Relate DD estimates to EC_a data.
- Map estimated DD across the studied block (using the EC_a map) and discuss implications for rising saline groundwater in the Arriga Flats.

3. Outcomes

This study will provide a greater understanding of DD on a major soil type of the Arriga Flats leading to improved irrigation practices and management.

4. Materials and Methods

4.1 Site Description

The Arriga Flats are located in Far North Queensland, approximately 15km southwest of Mareeba (Figure 1). The main irrigated crop is sugar cane, which is predominantly furrow irrigated. The climate is monsoonal dry tropical with a marked summer wet season and long dry season. Average annual rainfall is 754 mm while average annual evaporation is 1970 mm (Webb et al., 2005).

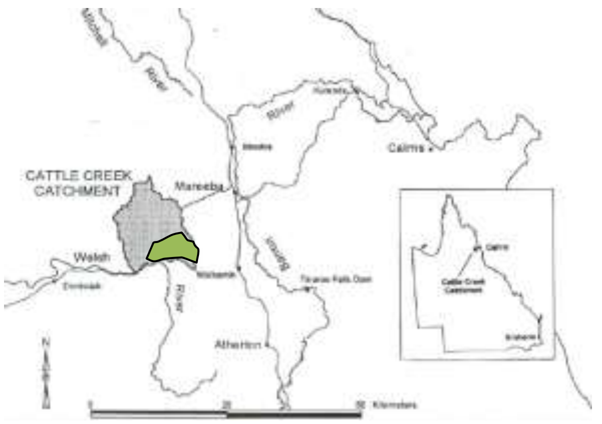


Figure 1: Location of the Cattle Creek Catchment with the Arriga Flats shaded green. Adapted from Webb et al. (2005).

The area selected for detailed study is Block 2 (-17.108418°, 145.323443°) and 3 (-17.110056°, 145.327594°) (hereafter referred to as 'the Block') on a property owned by Bundaberg Sugar. The Block was selected due to the availability of EM38 data, and because it is furrow irrigated. The soil is mapped as a Penman (Pm) which are deep gradational to uniform soils with cohesive silty clay loams to silty light clays grading to mottled grey to yellow-brown pedal light to medium clays; alkaline reaction trend, sodic; occasionally acid, nodular and fine gravelly in places (Enderlin et al., 1997). Irrigation water is applied almost continuously throughout the dry season; however no groundwater is used for irrigation (Nelson et al., 2010).

4.2 EM38 Data Collection and Data Clean Up in ArcGIS

A survey using the non-contacting electromagnetic induction instrument (EM38-MK2) was undertaken by Trevor Parker of *Northern Gulf Resource Management Group (NGRMG)* in June of 2010. The EM38-MK2 and a global positioning system (*Ag*GPS RTK) were mounted on a wooden sled and dragged approximately 6 m behind a 4WD travelling at ~12 km/hr. The EM38 was used in the vertical (EMV) and horizontal (EMH) mode of operation and was positioned 0.15m above the soil surface. In this configuration the maximum depth of exploration was approximately 1.5m (McNeill, 1980b). Measurements of EC_a were taken every second along 44 transects, spaced at 10m intervals, with a total of ≈7000 measurements made.

The EM38 survey data was imported into ArcGIS v9.0 and any irregular values were removed from the dataset. The EM38 layer was clipped to a pre-existing field boundary layer, to eliminate readings not part of survey area (e.g. turnaround points).

4.3 Sampling Design

The ESAP-RSSD (Lesch et al., 2000) program was used to generate an optimal soil sampling design from the conductivity survey information. For a detailed description of the methodology, consult Lesch et al. (2000). The EMV conductivity survey data was read into ESAP-RSSD using the "Grid" file format. The ESAP-RSSD program uses a statistical technique known as a response surface sampling design to select the sample sites. In order to facilitate this design, all conductivity survey data was first centred, scaled, and decorrelated. A by-product of this decorrelation analysis is that outlier survey readings (>4.5 standard deviation units from mean) are removed (signal data validation). The spatial response surface sampling site selection tool was invoked and 6 soil sampling locations were identified.

4.4 Soil and Water Sampling

A Garmin eTREX H high sensitivity GPS was used to locate sampling locations. At the time of sampling the sugarcane was ¾ grown, making it difficult to accurately locate sampling sites. All sampling sites were within 4.5m of the prescribed sampling location, with the exception of one sample site where it was physically impossible to get closer than 12.2 m. See Appendix 1 for the distances between actual and prescribed sampling sites. While in the field, an additional 2 sites were sampled. At each site, samples were recovered from 4 depths (0.015-0.15 m, 0.25-0.35 m, 0.55-0.65 m, 0.85-0.95 m, hereafter referred to as 0.1 m, 0.3 m, 0.6 m, 0.9 m respectively).

The decorellated EMV data and the sampling information was entered into ArcGIS. The EMV data was interpolated using a simple kriging technique, employing a spherical semiovariogram model with a radius of 5 m. This produced a map of EMV EC_a over the Block. The map also showed the location of sample sites (Figure 2).

4.5 Soil and Water Analysis

The soil samples were air-dried and ground to pass a 2 mm sieve. pH and electrical conductivity (EC) were determined using 1:5 soil:water suspension. Exchangeable cation contents, cation exchange capacity (CEC, calculated as the sum of exchangeable cations) and exchangeable sodium percentage (ESP) of each sample was determined using method 15A1 (exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) – 1M ammonium chloride at pH 7.0, no pretreatment for soluble salts) as outlined by Rayment and Higginson (1992). Clay content was determined using the hydrometer method. The EC of water from the supply channel and a water recycling dam was determined using an Aqua-CP/A handheld EC/pH meter. Refer to Appendix 2 for complete data set of soil and water analyses. Onsite rainfall and irrigation records from 1998-2010 were retrieved from the grower. Refer to Appendix 3 for rainfall records and irrigation data.

4.6 SALFPREDICT

The soil data and water quality and quantity information for the 8 sample points were entered into SALFPREDICT in order to estimate DD at each location. The average annual rainfall at the Block was ≈850 mm (Appendix 2). An important assumption of SALFPREDICT is that runoff under rainfall for most situations is small and can be neglected (Shaw, 1988). However personal observations and discussions with the grower indicated that because rain events are often short and intense, some water is lost as runoff. Although there was no available data to quantify this loss, an approximation of 250 mm annual loss was used for this study. Based on irrigation records from 1998 to 2009 (Appendix 3), average irrigation application was found to be ≈800 mm; this value was used for all locations. To determine the effect of increasing irrigation input, while rainfall remained constant, simulations of 800 mm, 1000 mm and 1200 mm irrigation per annum were carried out.

4.7 Correlation matrices and regression analyses

To identify relationships between measured soil properties, DD estimates and EC_a data, a number of correlation matrices were produced (Tables 4-8). Significant or interesting correlation results were investigated further using simple linear regression analysis in Excel (Figure 5-6).

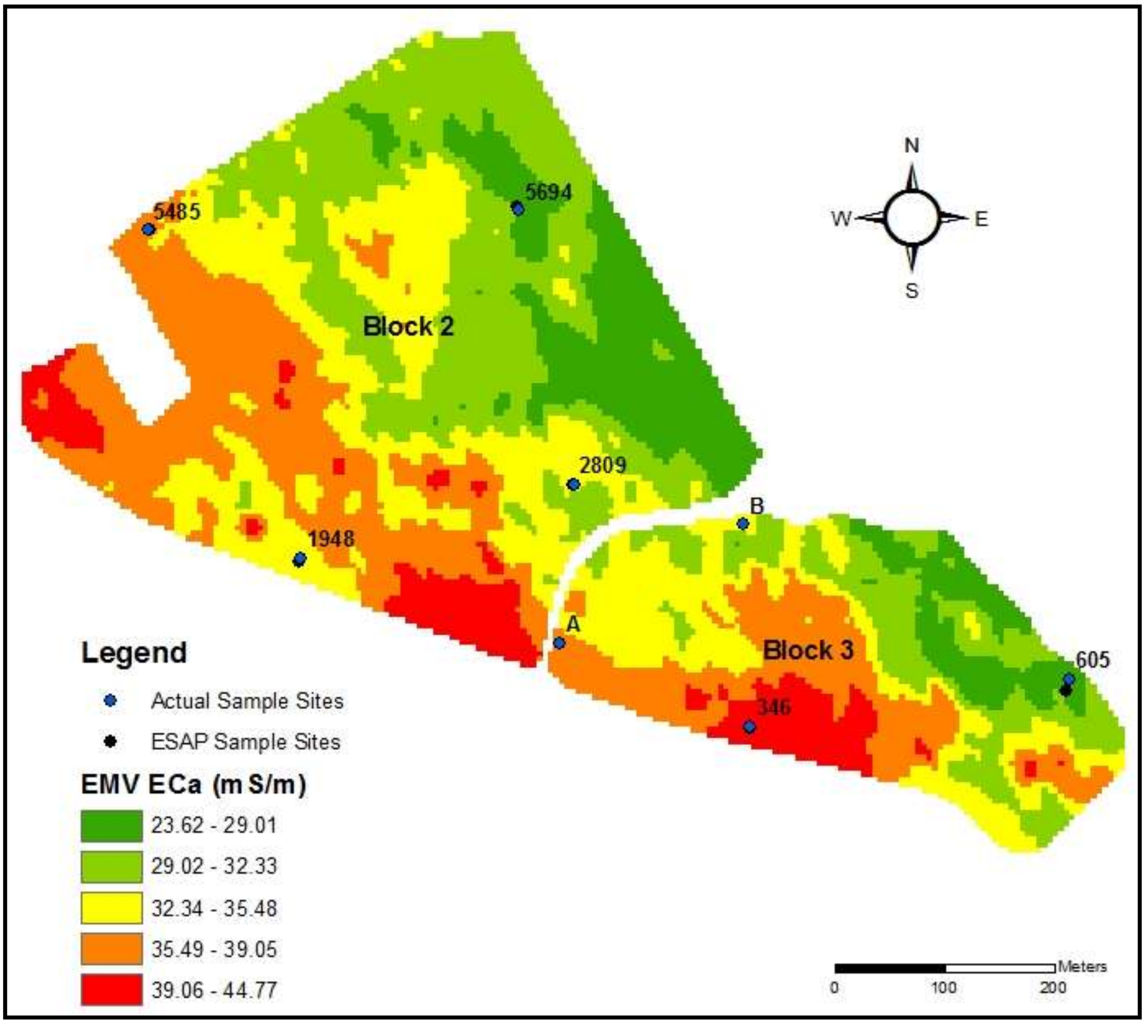


Figure 2: EMV EC_a Variations over the Block with Sample Site Locations
*EC_a data obtained from Trevor Parker of NGRMG

5. Results

5.1 EM38 readings (Table 1 and 2)

EMV EC_a readings were closely related to EMH EC_a readings. EMV EC_a readings only are discussed, as the instrument in this mode measures EC_a within agriculturally significant portion of the root zone (McNeill, 1990). Across the Block, 6523 EC_a measurements were obtained. The EC_a data exhibited an approximately normal distribution, centred upon a mean of 33.5 mS/m, with a minimum of 23.2 mS/m and a maximum of 47.0mS/m.

5.2 Soil properties (Table 3, Figure 4)

Clay content ranged from 9.9 to 49.9%. pH ranged from 5.87 to 7.63. EC ranged from 0.02 to 0.15 dS/m. CEC ranged from 0.86 to 9.19 cmol(+)/kg. CCR ranged from 0.06 to 0.21. ESP ranged from <1.4 to 57.2%. Three sites had clay contents that varied little or decreased slightly with depth. The other 5 sites had clay contents of 10-25% in the top 20 cm, increasing to 20-50% at depth. ESP generally increased with depth, with a sharp increase in ESP at 0.6m. Site 5694 was the most sodic site, with a maximum ESP of 57.2% at 0.6 m. However, clay content was low at this site (12.6 % at 0.6 m).

5.3 Relationships between EC_a, soil properties and DD (Table 4-8, Figures 5-9)

There appeared to be a weak correlation ($p= 0.13$) between DD and EC_a, and linear regression gave an r^2 of 0.12. EC_a was closely correlated ($p<0.05$) with mean profile clay content, however no significant correlation was observed for individual depths. Linear regression analysis found EC_a to be a reasonably good predictor of mean profile clay content ($r^2= 0.58$). EC_a was closely correlated ($p<0.05$) with mean profile CCR, with linear regression analysis revealing EC_a to be a reasonably good predictor of mean profile CCR ($r^2= 0.51$). EC_a was closely correlated ($p<0.05$) with mean profile CEC (linear regression $r^2=0.65$), primarily due to a significant correlation at 0.6 m depth. There appeared to be no correlation between ESP at 0.9 m depth and EC_a, with linear regression giving an r^2 of 0.01. EC_a was well correlated with pH at 0.3m.

Despite no significant correlation being observed between DD and mean clay content, a strong negative correlation ($r=-0.7$, $p<0.01$) between DD and clay content was evident at 0.9 m. Further, linear regression analysis found mean profile clay content to be a reasonably good predictor of DD ($r^2 =0.56$). DD was positively correlated ($p<0.05$) with ESP at 0.1m, which was unexpected. However, only weak correlations were observed for mean profile ESP, and all other depths. Linear regression analysis revealed no relationship between DD and ESP at 0.9m ($r^2 =0.02$). DD was positively correlated ($p<0.05$) with mean profile EC. This again appears strange, but it should be noted that none of the soils could be considered saline.

CEC was strongly correlated with clay content at all depths. Mean CCR and mean CEC were strongly correlated with each other. The strength of the correlation between CCR and CEC appeared to increase with depth; a strong correlation was found at 0.9 m. A very strong correlation occurred between ESP and EC at 0.3 m and again at the 0.9 m depth.

5.4 Estimated DD and depth of irrigation (Table 4)

Increasing the depth of irrigation in SALFPREDICT resulted in increased DD. The minimum estimated DD (with 600 mm/year rainfall, 800mm/year irrigation) was 40 mm/year whereas the maximum estimated DD (with 600 mm/year rainfall, 1200mm/year irrigation) was 377mm/year. For the 'typical' irrigation scenario (600 mm/year rainfall, 800mm/year irrigation) estimated DD ranged from 40 mm/year to 254 mm/year.

Table 1: Linear regression parameters for EM38 EC_a readings (mS/m) in the horizontal mode (EMH) as a function of readings in the vertical mode (EMV)

n	Coefficient	Constant	r^2
6524	1.8106	-36.079	0.9827

Table 2: Signal statistics of decorellated EMV EC_a (mS/m) readings

n	Mean	Std. Dev.	Max.	Min.	Deleted Sites
6523	33.46	4.12	46.99	23.16	1

Table 3: Minimum and maximum values of soil properties across all sampling locations

	Clay (%)		pH		EC (dS/m)		CEC (cmol(+)/kg)		CCR		ESP	
Depth (m)	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
0.015-0.15	15.3	23.9	5.09	6.76	0.02	0.07	1.75	4.61	0.11	0.21	<1.4	20.3
0.25-0.35	11.9	27.9	6.02	7.29	0.02	0.05	1.57	3.77	0.09	0.18	4.3	33.5
0.55-0.65	12.6	49.9	6.18	6.93	0.02	0.06	0.86	6.28	0.06	0.14	6.5	57.2
0.85-0.95	9.9	43.3	5.87	7.63	0.02	0.15	0.92	9.19	0.06	0.21	9.2	40.2

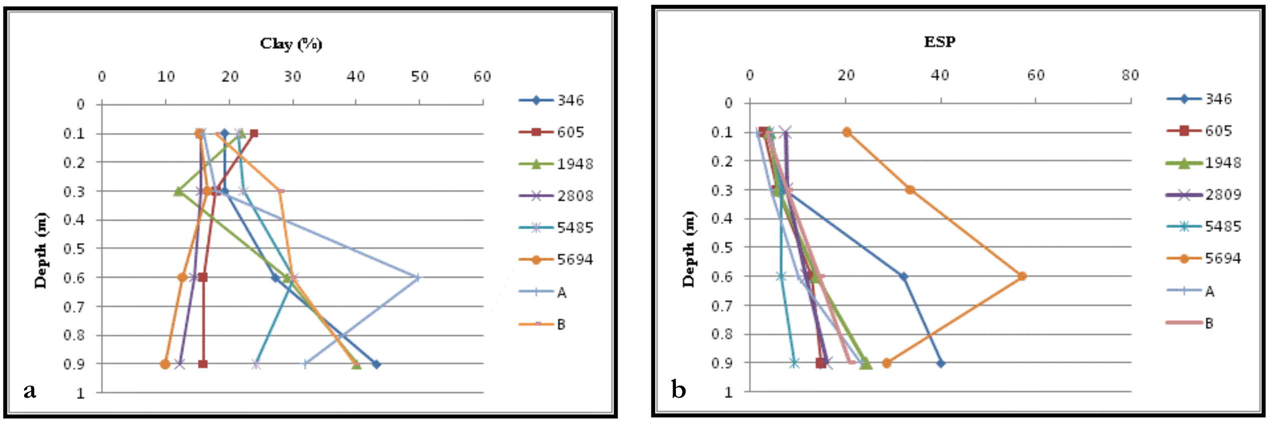


Figure 4: (a) Clay content with depth, (b) Exchangeable sodium percentage (ESP) with depth.

Table 4: Mean profile soil properties correlation matrix (Pearson correlation coefficient)

	Clay %	pH	EC	CEC	CCR	ESP	DD	EC_a
Clay %	1.000							
pH	-0.459	1.000						
EC	0.437	-0.019	1.000					
CEC	0.947	-0.539	0.640	1.000				
CCR	0.551	-0.655	0.706	0.779	1.000			
ESP	-0.363	0.589	0.364	-0.307	-0.267	1.000		
DD	0.184	0.169	0.815	0.321	0.319	0.670	1.000	
EC_a	0.760	-0.514	0.491	0.806	0.712	-0.320	0.130	1.000

Table 5: Correlation matrix for soil properties at 0.1 m depth (Pearson correlation coefficient)

	Clay %	pH	EC	CEC	CCR	ESP	DD	EC_a
Clay %	1.000							
pH	0.329	1.000						
EC	0.301	-0.554	1.000					
CEC	0.916	0.403	0.326	1.000				
CCR	-0.135	-0.734	0.410	-0.190	1.000			
ESP	-0.443	0.565	-0.609	-0.379	-0.567	1.000		
DD	-0.516	0.131	-0.328	-0.530	-0.420	0.766	1.000	
EC_a	-0.083	-0.444	0.080	0.055	0.712	-0.538	-0.517	1.000

Table 6: Correlation matrix for soil properties at 0.3 m depth (Pearson correlation coefficient)

	Clay %	pH	EC	CEC	CCR	ESP	DD	EC_a
Clay %	1.000							
pH	0.075	1.000						
EC	0.130	0.260	1.000					
CEC	0.861	0.024	-0.264	1.000				
CCR	0.500	-0.570	-0.470	0.461	1.000			
ESP	-0.128	0.280	0.953	-0.530	-0.542	1.000		
DD	-0.289	-0.008	0.572	-0.531	-0.420	0.634	1.000	
EC_a	0.401	-0.753	-0.348	0.501	0.712	-0.495	-0.517	1.000

Table 7: Correlation matrix for soil properties at 0.6 m depth (Pearson correlation coefficient)

	Clay %	pH	EC	CEC	CCR	ESP	DD	EC_a
Clay %	1.000							
pH	0.176	1.000						
EC	0.386	0.718	1.000					
CEC	0.970	0.086	0.449	1.000				
CCR	0.361	-0.047	0.365	0.488	1.000			
ESP	-0.453	0.571	0.562	-0.418	-0.270	1.000		
DD	-0.699	-0.025	-0.255	-0.658	-0.420	0.406	1.000	
EC_a	0.702	0.144	0.402	0.717	0.712	-0.364	-0.517	1.000

Table 8: Correlation matrix for soil properties at 0.9 m depth (Pearson correlation coefficient)

	Clay %	pH	Ec	CEC	CCR	ESP	DD	EC_a
Clay %	1.000							
pH	-0.337	1.000						
EC	0.653	0.277	1.000					
CEC	0.766	0.099	0.974	1.000				
CCR	0.549	0.035	0.790	0.841	1.000			
ESP	0.454	0.337	0.776	0.677	0.319	1.000		
DD	-0.868	0.235	-0.503	-0.602	-0.420	-0.221	1.000	
EC_a	0.622	0.027	0.550	0.669	0.712	0.130	-0.517	1.000

Correlation is significant at the 0.001 level (2-tailed)	(red)
Correlation is significant at the 0.01 level (2-tailed)	(orange)
Correlation is significant at the 0.05 level (2-tailed)	(yellow)

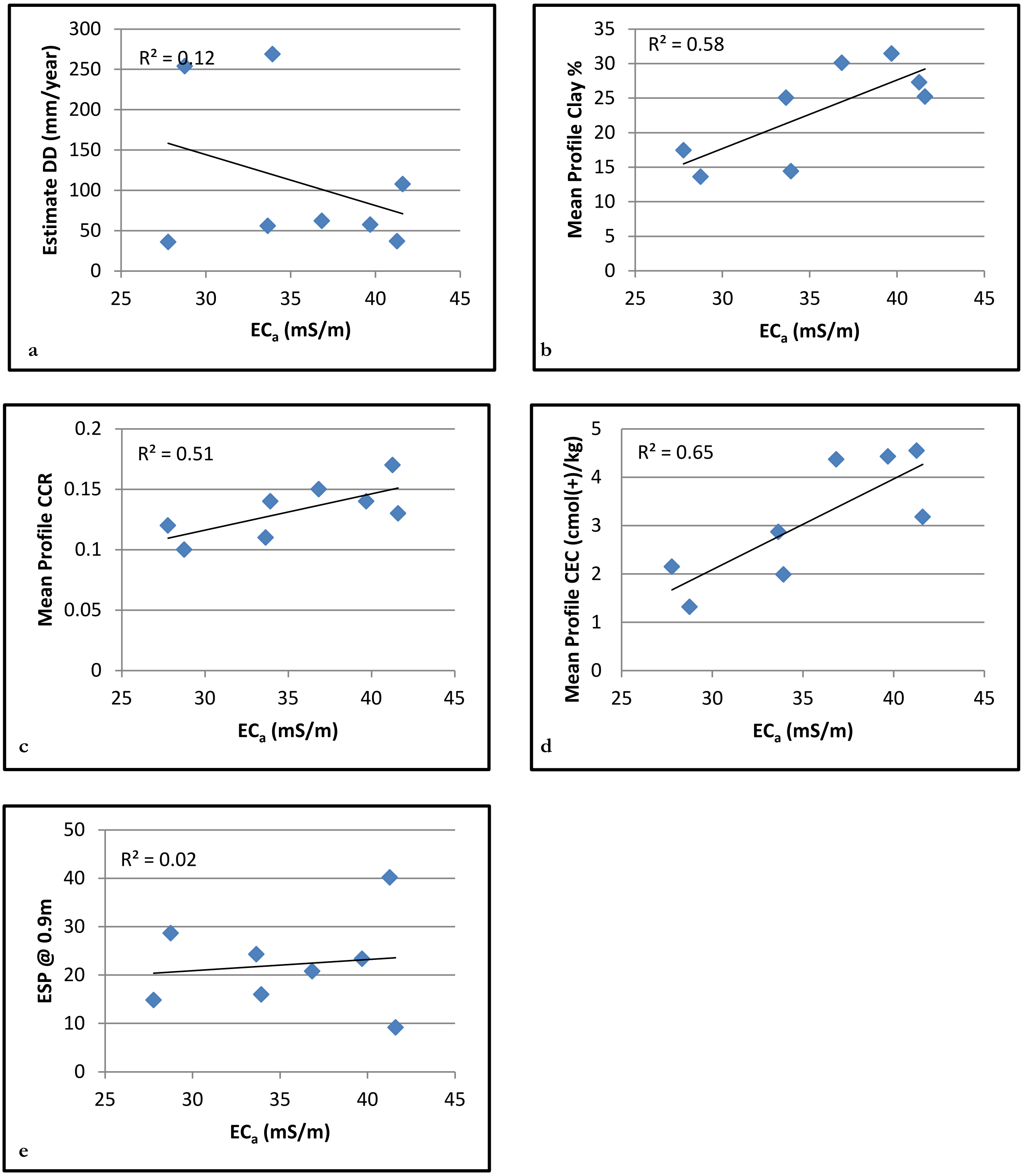
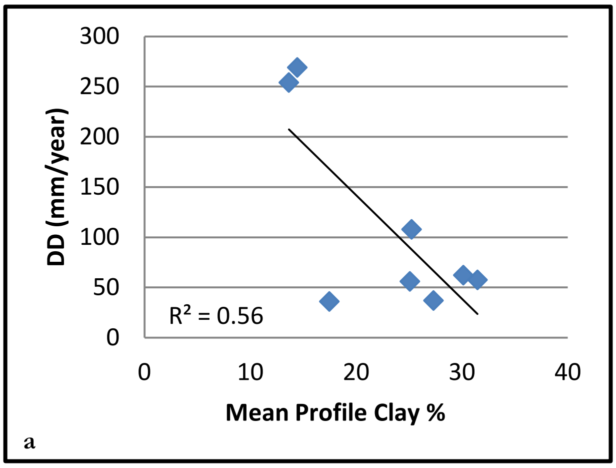


Figure 5: Linear regression of (a) DD, (b) mean profile clay content, (c) mean profile CCR (d) mean profile CEC, and (e) ESP at 0.9m as a function of EC$_a$.



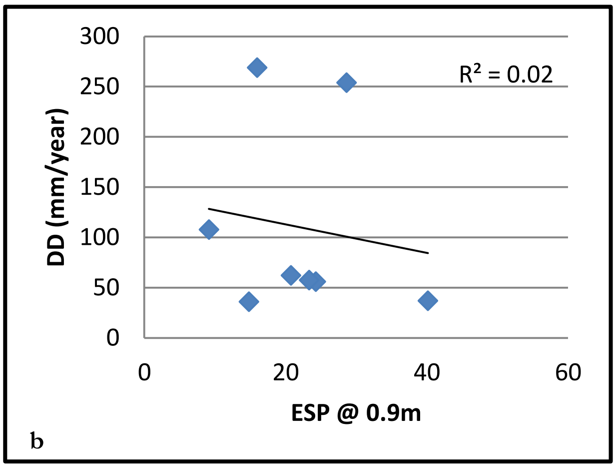


Figure 6: Linear regression analysis of (a) mean profile clay content and (b) ESP at 0.9m as a function of DD.

Table 9: Estimated DD at various irrigation inputs (all with average annual rainfall of 600 mm/year)

Site	**346**	**605**	**1948**	**2809**	**5485**	**5694**	**A**	**B**
800 mm/year Average Annual Irrigation	40	104	56	269	108	254	58	62
1000 mm/year Average Annual Irrigation	52	132	72	321	139	304	74	80
1200 mm/year Average Annual Irrigation	65	164	91	377	174	356	93	101

6. Discussion

6.1 EC_a and DD

A major objective of this study was to determine the relationship between estimates of DD as predicted by SALFPREDICT and EC_a data from an EM38 survey. Unlike similar studies, (e.g. Triantafilis et al., 2003), there was only a weak relationship between the two parameters at this site (Figure 5a).

Due to time and resource constraints, it was possible to sample 8 sites only. The robustness of this sample size to adequately represent the total population of EC_a readings may explain the poor relationship observed. However, the range of EC_a values across the study area was narrow (23.2-47.0 mS/m, Table 2) and was captured well by the sampling scheme. Comparatively, Triantafilis et al. (2003) observed a much wider range of EC_a readings (25 - 190 mS/m), and sampled at 81 locations.

Mean clay content, mean clay mineralogy (CCR) and ESP at 0.9m are the main soil properties which influence SALFPREDICT's estimate of DD. In this study, the EM38 was found to reasonably predict mean profile clay content (Figure 5b) and mean CCR (Figure 5c), but not ESP at 0.9m (Figure 5e). Although EC_a is related to clay content and mineralogy, it is not directly related to ESP (McNeill, 1980a). Numerous studies have however documented a good correlation between sodicity and salinity (e.g. Shaw et al., 1998). Therefore in areas where the soils are both sodic and saline; EC_a has been found to correlate well with ESP (e.g. Nelson et al., 2002). However, Nelson et al. (2002) found that ESP, which ranged from 0 to 84 % (at 0.5-0.75 m depth) was not well correlated with EC_a (EMH 11-140 mS/m, n=17) in the Mareeba-Dimbulah Irrigation Area.

The majority of Triantafilis et al. (2003) sample points were in the high EC_a range (>100 mS/m). In contrast, EC_a values across the Block were low (<50 mS/m), corresponding with low EC values (Table 3). Furthermore, all sample sites had sodic subsoils, with ESP at 0.9m ranging from 9.2% to 40.2% (Table 3). As the soils in this study were variably sodic, but not saline, the EM38 was unable to detect variation in ESP. Therefore for this study site, EC_a was a poor predictor of DD.

6.2 Spatial Variability of DD Estimates and Implications for Irrigation Management

Estimated DD varied considerably within the block, which was mapped as having the same soil type. For the 'typical' irrigation scenario (600 mm/year rainfall, 800mm/year irrigation) estimated DD ranged from 40 mm/year to 254 mm/year (Table 9). Clay content was found to be the dominant soil property influencing this variation (Figure 6a). The considerable variation in DD estimates across the block highlight that irrigation efficiency can be very variable at this scale. Broad scale estimates of DD such as those provided in Webb et al. (2005) cannot be used to guide management decisions at the farm scale. This poses a significant problem for irrigators and water managers, as fine scale quantification of soil properties over large areas is very costly.

In areas where the soils are saline, the EM38 has been found to provide a relatively inexpensive and efficient means of quantifying the soil properties influencing DD at a fine spatial scale (e.g. Triantafilis et al., 2003; Triantafilis et al., 2004). However, this study found such an approach is not appropriate for areas where the soils have variable clay content and ESP, but uniformly low salinity. Therefore identifying irrigation inefficiencies in areas at risk of salinisation, but not already saline, remains a challenge.

6.3 Future Research

This study has formed a strong basis upon which further research can be developed. Given more time and resources, future research may extend this study into parts of the Arriga Flats where the soil is known to be saline; to determine if a better relationship between the EC_a and SALFPREDICT's estimate of DD could be obtained. If a good relationship is found, the study could be undertaken on a much broader scale, encompassing the major soil types, land uses and irrigation systems of the Arriga flats. Furthermore, on furrow-irrigated properties, SIRMOD could be used to investigate and improve surface irrigation application efficiency, and minimise DD losses to groundwater. It would also be of value to irrigators and water managers to investigate other means (in addition to the EM38) of mapping soil properties at finer scales than the existing soil maps. For example, gamma radiation may be useful, as aerial surveys of the area have shown variations in emissions. Point measurements of hydraulic conductivity would also complement this data. Finally, carrying these measurements out at sites with continual monitoring of soil water content will allow the DD estimates to be checked against water balance models.

7. Conclusion

The ultimate objective of this study was to investigate surface irrigation practices on the Arriga Flats of Far North Queensland with a view to improving water use efficiency and reducing DD to the aquifer. Due to a number of unforeseen circumstances, in particular the above average summer rainfall; several different approaches were implemented. The approach upon which this report was focused, sought to relate apparent soil electrical conductivity (EC_a) measurements, obtained from an EM38 survey, to DD estimates as calculated by the salt and leaching fraction model SALFPREDICT, for a furrow-irrigated block on a major soil type of the Arriga Flats. Unlike similar studies, e.g. Triantafilis et al. (2003), there was only a weak relationship between the two parameters. As the soils in the study area were variably sodic, but not saline, the EM38 was unable to detect variations in ESP. ESP is one of the main soil properties which influence SALFPREDICT's estimate of deep drainage. Therefore, EM38 readings were a poor predictor of DD at this study site. Estimated DD varied considerably within the study site, which was mapped as having the same soil type. It was concluded that fine-scale quantification of soil properties influencing DD is required for appropriate identification of areas of irrigation inefficiency and for management of areas most susceptible to DD losses. Future research may look at undertaking this study in an area of the Arriga Flats where the soil is known to be saline. Further, SIRMOD evaluations, wide-scale mapping of topsoil properties, and point measurements of saturated hydraulic conductivity may also be investigated. This data would provide essential information for future groundwater and salinity risk modelling and the matching of irrigation practices to soil properties to improve irrigation efficiency.

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10. Appendices

Appendix 1: Distance error between actual and prescribed sample sites

Sample site	Distance (m)
346	1.3
605	12.2
1948	4.5
2809	1.3
5484	2.0
5694	3.7

Appendix 2: Soil and water analyses

Appendix 2a: Results of soil analyses

Site	Depth (m)	Sand (%)	Silt (%)	Clay (%)	Texture Classification	pH	Ec (dS/m)	Air Dry Mositure Content (%)	Ca (cmol(+)/kg)	K (cmol(+)/kg)	Mg (cmol(+)/kg)	Na (cmol(+)/kg)	CEC (cmol(+)/kg)	CCR	ESP	EMV EC_a (mS/m)
346	0.015-0.15	66.1	14.6	19.3	Loam	5.40	0.047	8.82	2.41	<0.1	0.67	0.10	3.19	0.17	3.26	41.27
346	0.25-0.35	64.7	16.0	19.3	Loam	6.08	0.021	6.00	1.45	<0.1	0.71	0.16	2.33	0.12	6.90	41.27
346	0.55-0.65	60.7	12.0	27.3	Clay Loam	6.93	0.065	1.39	0.33	<0.1	1.93	1.08	3.35	0.12	32.30	41.27
346	0.85-0.95	50.7	6.0	43.3	Clay	7.63	0.145	8.19	0.33	0.11	5.05	3.69	9.19	0.21	40.16	41.27
605	0.015-0.15	60.1	16.0	23.9	Loam	6.00	0.065	23.00	3.81	<0.1	0.62	0.12	4.55	0.19	2.74	27.77
605	0.25-0.35	64.1	18.0	17.9	Loam	7.29	0.019	3.06	1.96	0.12	0.29	0.14	2.50	0.14	5.63	27.77
605	0.55-0.65	70.1	14.0	15.9	Loam	6.55	0.016	6.48	0.70	<0.1	0.18	0.13	0.98	0.08	12.74	27.77
605	0.85-0.95	72.1	12.0	15.9	Loam	7.17	0.020	4.58	0.81	<0.1	0.52	0.20	1.33	0.08	14.82	27.77
1948	0.015-0.15	60.1	18.0	21.9	Loam	6.45	0.024	4.31	2.54	<0.1	1.04	0.15	3.72	0.17	4.08	33.65
1948	0.25-0.35	82.1	6.0	11.9	Sandy Loam	6.54	0.020	0.54	1.25	<0.1	0.75	0.12	2.12	0.18	5.82	33.65
1948	0.55-0.65	43.1	27.7	29.2	Silty Clay Loam	6.50	0.034	5.61	1.05	<0.1	1.71	0.44	3.21	0.11	13.80	33.65
1948	0.85-0.95	40.1	19.7	40.2	Clay	6.64	0.027	5.26	0.21	<0.1	1.74	0.62	2.57	0.06	24.29	33.65
2809	0.015-0.15	74.1	10.4	15.5	Sandy Loam	5.18	0.040	16.18	1.32	<0.1	0.30	0.13	1.75	0.11	7.35	33.93
2809	0.25-0.35	76.1	8.4	15.5	Sandy Loam	6.02	0.022	8.43	1.58	<0.1	0.35	0.16	2.09	0.13	7.63	33.93
2809	0.55-0.65	78.1	7.4	14.5	Sandy Loam	6.36	0.023	6.25	1.18	<0.1	0.33	0.20	1.72	0.12	11.67	33.93
2809	0.85-0.95	84.1	3.7	12.2	Sandy Loam	7.17	0.021	5.75	0.87	<0.1	0.54	0.27	1.68	0.14	15.98	33.93
5485	0.015-0.15	64.8	13.7	21.5	Clay Loam	6.29	0.042	1.64	3.26	<0.1	1.16	0.19	4.61	0.21	4.10	41.60
5485	0.25-0.35	61.8	16.0	22.2	Clay Loam	6.30	0.027	1.46	1.38	<0.1	1.62	0.21	3.21	0.14	6.55	41.60
5485	0.55-0.65	51.5	18.3	30.2	Clay Loam	6.61	0.025	2.33	0.60	<0.1	2.09	0.19	2.88	0.10	6.47	41.60
5485	0.85-0.95	65.5	10.3	24.2	Clay Loam	7.01	0.021	1.93	0.29	<0.1	2.08	0.24	2.62	0.11	9.16	41.60
5694	0.015-0.15	64.7	20.0	15.3	Loam	6.76	0.026	2.64	1.63	0.18	0.19	0.51	2.51	0.16	20.30	28.75
5694	0.25-0.35	68.7	14.7	16.6	Loam	6.82	0.050	2.44	0.88	<0.1	0.16	0.52	1.57	0.09	33.48	28.75
5694	0.55-0.65	76.4	11.0	12.6	Sandy Loam	6.92	0.050	0.42	0.18	<0.1	0.19	0.49	0.86	0.07	57.23	28.75
5694	0.85-0.95	82.4	7.7	9.9	Sandy Loam	7.33	0.017	0.29	0.11	<0.1	0.55	0.26	0.92	0.09	28.65	28.75
A	0.015-0.15	68.1	16.0	15.9	Loam	5.09	0.054	12.13	2.23	<0.1	0.57	<0.039	2.81	0.18	-	39.69
A	0.25-0.35	72.1	10.0	17.9	Loamy Sand	6.22	0.020	7.96	1.74	<0.1	0.72	0.11	2.57	0.14	4.33	39.69
A	0.55-0.65	18.1	32.0	49.9	Silty Clay	6.87	0.053	13.17	2.06	<0.1	3.59	0.63	6.28	0.13	9.99	39.69
A	0.85-0.95	48.1	20.0	31.9	Silty Loam	7.36	0.044	7.01	0.70	<0.1	1.85	0.78	3.33	0.10	23.35	39.69
B	0.015-0.15	66.1	16.0	17.9	Loam	6.00	0.042	10.71	2.14	<0.1	0.64	0.10	2.88	0.16	3.42	36.84
B	0.25-0.35	44.1	28.0	27.9	Silty Clay Loam	6.70	0.029	10.06	2.58	<0.1	0.90	0.29	3.77	0.14	7.62	36.84
B	0.55-0.65	44.1	26.0	29.9	Silty Clay Loam	6.18	0.035	10.39	1.47	<0.1	2.03	0.58	4.09	0.14	14.31	36.84
B	0.85-0.95	44.1	16.0	39.9	Clay	5.87	0.050	7.94	1.60	<0.1	2.12	0.98	4.69	0.12	20.78	36.84

Appendix 2b: EC of irrigation water

	EC (dS/m)
Supply Channel	0.19
Recycling Dam	0.15

Appendix 3: Irrigation and rainfall data for Bundaberg Sugar Property

Year	Block 2 Irrigation (mm)	Block 3 Irrigation (mm)	Annual Rainfall (mm)
1998	568	1140	857
1999	496	1140	1154
2000	355	880	*missing*
2001	386	850	*missing*
2002	*0*	*0*	595
2003	468	1280	589
2004	514	1360	890
2005	491	1110	574
2006	491	1120	794
2007	355	910	671
2008	0	0	1237
2009	700	1760	1201
2010	609	1470	*incomplete*
Average (mm)	494	1184	856
Average 'Block' (mm)	839		

Note:
Irrigation data – Year 2002 and 2008 no irrigation took place as block was fallow.
– Approximately 70% of irrigation input is derived from water supply channel.
– Approximately 30% of irrigation is derived from recycled water dams.