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QUEENSLAND, AUSTRALIA

FINAL REPORT
SRDC PROJECT BS90S
INCREASED PRODUCTIVITY THROUGH BETTER DESIGN AND MANAGEMENT OF IRRIGATED CANEFIELDS

by

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SD96008

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Non-Technical Summary

This project has obtained, for the first time, data on the performance and efficiency of furrow irrigated canefields. In particular, it has shown that water application efficiencies on high infiltration soils in the sugar industry are generally low (average approximately 30%) while on low infiltration soils it is generally high (typically >60%). However, furrow irrigation efficiency has also been shown to be closely related to the irrigation design and management practices, with large variations both between sites and throughout the season attributed to management and environmental differences.

During the 1993-1995 irrigation seasons, between 25 and 35 ML ha^{-1} $annum^{-1}$ of irrigation water was applied to some commercial canefields in the Burdekin Delta area. While these volumes are higher than would be expected in average rainfall years, they are still far in excess of the plant water requirements and are indicative of the low water application efficiencies of irrigations in much of this area. It is conservatively estimated that over one-third of the Burdekin Delta area has water application efficiencies of less than 30%. This represents a considerable cost on the production of sugarcane in these areas and arguably raises significant environmental and sustainability concerns. The benefits associated with a modest 10% reduction in water use over one-third of the Burdekin Delta is worth inexcess of \$1.1M $annum^{-1}$ in direct water and pumping costs, and approximately \$13M $annum^{-1}$ in additional potential productivity.

This project has identified a range of irrigation design and management practices that may be used to reduce water use in areas of low application efficiencies. One particular success that has already been widely adopted is the introduction of surface soil compaction by changing furrow shape. This has been shown to reduce water use by up to 47% without loss of productivity on high infiltration soils. Due to the ease and negligible additional cost associated with the implementation of this practice, it has been rapidly adopted within the Burdekin Delta district and is now being practiced or trialed by more than 100 growers (Holden *pers comm*). Other management practices assessed within the project to improve water application efficiencies in high infiltration areas include using herbicides instead of cultivation for weed control, using channel water (low salt content) rather than underground water for some irrigations, and optimising water application rates according to site characteristics. The effect of irrigation design parameters such as furrow length and slope were also shown to significantly affect irrigation efficiency.

The surface irrigation model SIRMOD was evaluated for use as a tool in the development of furrow irrigation design and management guidelines within the sugar industry. This package was found to adequately simulate irrigations where the input data for the individual sites were measured. This package should prove be an effective extension tool for the delineation of design guidelines and assist in demonstrating to growers the effect of various management practices on irrigation efficiency. The model will also provide data to enable quantification of the economic costs and benefits of alternative irrigation designs and management practices. The package should also prove to be a useful tool to reduce the amount of field data required to be measured in similar research studies conducted either in the Burdekin or other areas. However, it should be noted that due to the large variation in soil infiltration properties both across fields and throughout the season, model predictions are only as accurate as the quality of the input data. For this reason, unless the input data is derived from actual irrigations and includes a measure of field variation, the model should only be used to provide indicative

trends. Unfortunately, the model also is not particularly user-friendly in its current form and has no ability to identify optimal irrigation strategies. These two issues will need to be addressed if the package is to be widely accepted as a decision support aid in the development of site specific recommendations for improving irrigation efficiency.

The results of this work have been actively promoted to the grower, industry and research communities through field days, tours, demonstration sites, newspaper and magazine articles, and conference publications. This project has also provided the data necessary to develop the solid scientific basis for the specialist extension programs conducted as part of "Watercheck" (BS127S) and "Increasing the irrigation efficiency of the Australian sugar industry" (BSE2). However, further irrigation research and extension is required to realise the full economic benefit of improved water use efficiency throughout the sugar industry.

1. Background

Furrow irrigation is the most common form of irrigation worldwide. It has a low technology and energy requirement and requires a relatively low capital establishment cost. Approximately 30% of the Australian sugar cane crop is produced using furrow irrigation. The majority of this area is located within the Burdekin region but there is currently substantial expansion occurring in the Mareeba and Proserpine areas. Potentially 100 000 ha of land will be developed for furrow irrigated sugarcane by the end of the decade.

The proper design and management of furrow irrigation systems is necessary to achieve efficient water use and maintain an adequate water supply for all growers or provide water for additional irrigations. It is also necessary to prevent salt accumulation in the root zone and rising water tables in areas irrigated from surface channels. Poor design and management may also lead to poor germination, waterlogging and losses of fertiliser and pesticides out of the root zone. While the general principles involved in the design and management of furrow irrigation systems are known, very little work has been conducted to identify the efficiency of current commercial irrigation practices in the Australian sugar industry. As there have been previously few irrigation design guidelines, and irrigation development is expensive, growers have commonly opted for the least cost design, often without considering water use efficiency or the consequences for long-term viability. As a result, long furrow lengths (>1 000 m) have become common with some furrows in the Burdekin River Irrigation Area (BRIA) inexcess of 2 000 m in length.

The irrigation requirement of sugar cane in the Burdekin region is 9.8 ML ha^{-1} $annum^{-1}$ based on the long term rainfall (Anon, 1991). However, rainfall in the past five years has been less than 500 mm yr^{-1} with evaporation greater than 2 000 mm yr^{-1}. This has increased the irrigation demand and raised the grower awareness of irrigation efficiency, productivity and profitability. Of particular concern to growers during this period has been the reduction in the underground water levels in the Burdekin delta and periodic demand exceeding the capacity of the surface channel system in the BRIA. The increasing irrigation demand in the BRIA resulted in above allocation water being no longer available after 1995 and the possibility of water restrictions being imposed during peak demand periods.

The direct cost of lost productivity and water wastage from inefficient furrow irrigation practices in the Burdekin delta area is been estimated to be approximately $3.5 M annually. However, in many cases, low water application efficiency is limiting production through constraints on the availability of water and the ability of growers to schedule irrigations. Where improvements in application efficiency provide water for additional irrigations or enable irrigation scheduling, production benefits are conservatively estimated to be worth an additional $39M annually in the Burdekin Delta area alone. However, only limited research has previously been conducted to determine the efficiency of current irrigation practices and to determine appropriate irrigation design and management practices for sugar cane production. With this in mind, the primary aim of this project was to "*increase the productivity and sustainability of surface irrigated canefields through improved design and management criteria*".

2. Project Objectives and Operation

This project was conducted from September 1993 to June 1996 and was funded by the Sugar Research and Development Corporation (SRDC), Bureau of Sugar Experiment Stations (BSES) and CSR Ltd (Appendix 1). The project objectives were to:

- Obtain field data on the efficiency of current furrow irrigation practices in the Burdekin
- Identify the most suitable of the irrigation model(s) available for simulating surface irrigation practices, and determine the minimum number of field measurements required to operate the model.
- Obtain infiltration estimates required by the appropriate irrigation model for different initial soil moistures, furrow shapes, water qualities and cultural practices.
- Produce and publicise design guidelines for furrow length and slope for different soil types and cultural practices.

To achieve these objectives within the timeframe and resources available, the project was operated as three concurrent phases with complementary aims:

Phase A	The establishment of field trials and monitoring of commercial irrigation practices to obtain baseline data on irrigation efficiency and identify methods to improve irrigation efficiency;
Phase B	The identification and evaluation of surface irrigation models to assist in the design and management of surface irrigation, and the assessment of the model's requirements for operation; and
Phase C	The dissemination and publication of irrigation design and management guidelines to improve irrigation efficiency.

Each phase addressed a specific requirement within the project but relied heavily on the other phases for input and outputs to achieve the overall project aim. While the phases were operated simultaneously throughout the whole project period, greater emphasis was placed on phase A in the first year of project operation and phase B in the last year of the project. In an effort to ensure farmer involvement in the project and rapid adoption of project outcomes, technology transfer and extension activities (phase C) were conducted throughout the project. In the later years of the project, the results and extension activities arising from this project were also integrated into the activities being undertaken by the specialist extension projects "*Watercheck - Statewide irrigation campaign*" (BS127S) and "*Increasing irrigation efficiency in the Australian sugar industry*" (BSE2). The full list of project staff is given in Table 2.1.

Table 2.1. Project Staff

Name	Function	Affiliation	Contributing period
Dr Steven Raine	Project leader	BSES/USQ	27/9/93-30/6/96
Mr Peter McGuire	Extension Officer	BSES	1/7/93-30/6/96
Mr Anthony Fairfull	Research Assistant	BSES	1/7/93-31/1/95
Mr Rohan Geddes	Research Assistant	BSES	1/2/95-30/6/96
Mr Bob Stewart	Research Officer	CSR	1/7/93-1/11/94
Mr Derk Bakker	Research Officer	CSR	1/11/94-30/6/96
Dr Hugh Barrett	Consultant	Barrett and Assoc.	1/7/93-30/6/96
Prof. Rod Smith	Consultant	USQ	1/7/93-1/11/94

3. Phase A The Monitoring of Commercial Irrigation Practices to Obtain Baseline Data, and the Establishment of Field Trials to Investigate Methods to Improve Irrigation Efficiency

3.1 Introduction

Eight trial sites were established on commercial farms over the three project years to investigate the efficiency of furrow irrigation practices. Data was collected at each site on a wide range of parameters to enable assessment of irrigation efficiency and to enable the operation and evaluation of the computer simulations investigated later (phase B) in the project. In each case, growers were encouraged to conduct their initial irrigations according to their normal operational practices. However, management variables such as the water application rate and period of application were varied for subsequent irrigations to enable data to be collected over a range of conditions. At four of the locations, paired trial sites were established to investigate the effect of furrow shape, alternative furrow irrigation, water quality and trash retention on irrigation efficiency. Separate trials were also conducted on CSR's Kalamia Estate to further investigate alternate furrow irrigation.

3.2 Materials and Methods

3.2.1 *Site Characteristics*

Trial sites were selected to enable data to be collected for the wide range of soils and irrigation management practices used commercially within the Burdekin region (Table 3.1). In each case, trials were monitored throughout as much of the irrigation season as possible.

3.2.2 *Site Measurements*

At each site a variety of parameters were measured to enable the calculation of irrigation efficiency and the application and validation of the irrigation models investigated in phase B. These parameters included both general site characterisation data and data associated with individual irrigations (Table 3.2). At each trial site, water was supplied to head boxes using existing farm water supply facilities. Where possible, the trial plot was located immediately adjacent to an existing head box to reduce water pressure losses and distortions associated with the water delivery system.

Site parameters

The trial site soils were described to a depth of up to 1.6 m from hydraulically driven soil cores (38 mm diameter) and the length of the furrows were measured. The slopes both along and at 90° to the furrow direction were measured using a laser level. Slope measurements were taken every 5 m for the first 30 m from the water inlet, at 50 m and then at 50 m increments thereafter along two furrows at each site. In most cases, these measurements were conducted after the initial watering following final cultivation to provide slopes after slumping of the surface profile. Where trial sites were established later in the season, these measurements were conducted immediately before the initial measured irrigation.

Table 3.1 Trial site characteristics showing the range of locations, soils and furrow lengths studied.

Year Studied	Site	Location	Soil Type	Furrow Length (m)
1993/94	Leichhardt	Block 59	Non-sodic duplex (5Dra)	485
	Jardine	Block 57	Sodic duplex (2Dyb)/non-sodic duplex (6Drb)	1 263
	Mulgrave A	Block 267	Vertisol (2Ugh)	1 630
1994/95	Upper Home Hill	Linton	Sandy clay loam/ Sand clay loam (alluvial)	470
	Jarvisfield	Jones	Sandy clay loam/ Sandy clay (alluvial)	470
	Clare	Oliveri	Clay loam (alluvial)	670
	Rita Island	Searle	Sandy loam/ Sandy clay loam (alluvial)	490
1995/96	Mulgrave B	Block 271	Sodic duplex (2Dyb)	1 000

Table 3.2 Parameters measured at trial sites to obtain data for baseline interpretation and validation of the irrigation models

Site Parameters	Irrigation Parameters
Furrow length Furrow slopes Furrow geometry Soil types	Water application rate Furrow discharge rate Furrow flow depth Water advance/recession times Root zone soil moisture deficit Total Rainfall Initial surface soil moisture Saturated hydraulic conductivity of undisturbed cores

The geometry of the furrows was measured using a profile meter constructed as part of this project and based on the design presented in Walker and Skogerboe (1987). In general, up to three measurements were taken at various locations along the length of several representative furrows after the initial irrigation. At some sites, the measurements were repeated later in the irrigation season to enable comparisons on changes in furrow geometry. Profile measurements were typed directly into a laptop computer in the field. The hydraulic radius and the cross-sectional area of flow required for model operation was calculated using the measured depth of flow and the combined furrow geometry data sets.

Irrigation parameters

Each trial involved between 12 and 20 neighbouring furrows. For the trial sites monitored during the first year of the project, water was supplied to the irrigation plots using a 250 mm fixed PVC pipeline with the height of the water delivery holes in the PVC pipeline adjusted to compensate for pressure head losses along the pipeline length. However, this source of variation in the water application rates was found to be minimal compared to other management variables and subsequent trials used the collapsible layflat fluming as used commercially for furrow irrigation in the Burdekin area. The rate of water application applied to the treatments was controlled using either a standard butterfly valve located in the supply line, a scissor clamp applied to the collapsible fluming or by the insertion of fluming cups with different outlet sizes. The rate of water application and total water applied to the trial plots was measured using a impellor flow sensor (GLI Model F1A12D1) connected to a datalogger. This sensor was mounted in a separate length (1.5 or 3.0 m) of fixed PVC pipeline (200 or 250 mm nominal internal diameter) located between the water supply head tank and the irrigation plot outlet.

Advance and recession times were monitored for each irrigation using float based sensors developed as part of the project. These sensors consist of an 80 mm diameter plastic float within a 90 mm plastic stilling well. The float is connected to a radial arm activating a potentiometer monitored by a datalogger. Sensor accuracy for the depth of water in the furrow was ± 0.7 mm and the datalogger was typically set to record at either 1 or 2 minute intervals. Float sensors were located at appropriate intervals (50-200 m) along the furrow length and were used to provide information on the advance time, depth of furrow flow throughout the irrigation (required for the calculation of Manning's resistance) and recession time.

The furrow discharge rate was determined using either simple cut-throat flumes (Walker and Skogerboe, 1987) or impellor flow meters (GLI Model F1A11A1) mounted in either 38 or 50 mm PVC tubing. In each case, both the rate and total run-off from up to four furrows was measured in each treatment. The adjustable cut-throat flumes (600 mm length) were constructed to provide measurement of flow rates between 1 and 15 L s^{-1} while the flow meters were used to provide greater precision at lower flow rates (0.3-5 L s^{-1}). The flow meters were directly datalogged. However, for the cutthroat flumes, the discharge rate was calculated from the upstream depth of flow recorded using a float as described above. Differences in the measured flume discharge and the predicted discharge calculated using the Walker and Skogerboe (1987) equations resulted in the calibration of individual flumes over the range of expected discharge rates.

The movement of water below the root zone was measured using a neutron moisture meter (NMM). Access tubes were installed to a maximum depth of 1.6 m and were located at intervals of either 100 or 200 m along the entire length of two furrows in each treatment. Tubes were installed in the centre of the furrow except for the paired trial sites where additional tubes were installed in the centre and on the shoulder of the hill. Readings were typically taken both immediately before irrigation and two days after irrigation to calculate the maximum depth of soil-water movement and the distribution uniformity of infiltration along the furrow. The tubes installed in the hill provided data on the wetting patterns and lateral movement of water into the hills and adjacent furrows. Undisturbed soil cores and samples were obtained before selected irrigations to determine the initial gravimetric moisture content and saturated hydraulic conductivity of the surface soil.

3.2.3 *Calculation of application efficiency*

A volume balance approach was used to determine the application efficiency associated with each irrigation event. The basic equation for this approach is:

$$V_a = V_r + V_s + V_d + V_e$$

where: V_a is the volume that has been applied, V_r is the volume of water that has runoff, V_s is the volume of water stored in the root zone, V_d is the volume of water drained below the root zone and V_e is the volume of lost through evapotranspiration during irrigation. In all cases, V_e was assumed to be negligible in the trials conducted. The volume of water stored in the soil profile by the irrigation was assumed to be the root zone storage deficit. This was calculated as the difference in the soil moisture profiles measured both in the hill and furrow before the irrigation and two days following irrigation. All water drained to below the root zone was assumed to be unavailable for plant uptake and no allowance was made for the movement of this moisture back into the root zone through unsaturated flow processes. The application efficiency was calculated as the ratio of the root zone storage deficit and the total irrigation volume applied expressed as a percentage.

3.3 Results and Discussion

The average water application efficiency for all irrigations monitored at each site ranged from 30% on the permeable alluvial soils to 62% on the heavy cracking clay soil (Table 3.3). However, application efficiencies for individual irrigation events ranged from 14 to 90%. Efficiency was found to be closely related to a range of design and management variables. In general, the high infiltration alluvial and non-sodic duplex soils resulted in lower irrigation efficiencies than the sodic duplex and vertisol soils. Except for very short furrows, increasing furrow length resulted in a decrease in the irrigation efficiency. However, this effect was more pronounced for irrigations on high infiltration soils. Tailwater recycling was found to substantially increase irrigation efficiency for irrigations conducted using long furrows and low infiltration soils but of little or no benefit on high infiltration soils. Better control of irrigation cut-off time was found to substantially increase efficiency in nearly all cases with the greatest benefit arising from systems using high infiltration soils with short furrow lengths.

Increasing the water application rate was found to have no effect on the application efficiency for vertisol soils but reduced the application efficiency on high infiltration soils. Reductions in the electrical conductivity of the irrigation water was found to have no effect on the efficiency of irrigations on high infiltration sandy soils but did substantially increase irrigation

Table 3.3 Irrigation efficiencies for commercial sugar cane production in the Burdekin region.

Site	Soil	Average Volume Applied (ML ha^{-1} $irrig^{-1}$)	Average Application Efficiency^{A} (%)
Mulgrave A	cracking clay	1.5	62
Leichhardt	non-sodic duplex	2.1	34
Jardine	non-sodic /sodic duplex	1.5	40
Jarvisfield	alluvial	1.4	42
Rita Island	alluvial	1.6	38
Home Hill	alluvial	2.0	30
Clare	alluvial	1.0	62
Mulgrave B	Sodic duplex	0.9	49

^{A} without tailwater recycling

efficiency on high infiltration clay loam soils. For the high infiltration soils, reducing the amount of cultivation was also found to increase the irrigation efficiency as did the application of surface compaction associated with narrowing of the furrow shape. Trash retention did not substantially affect irrigation efficiency at the site investigated.

3.3.1 *Soil Type, Furrow Length and Tailwater Recycling*

Soil type was found to have a major effect on the efficiency of irrigation (Table 3.4). For all soils, increasing the furrow length reduced furrow irrigation efficiency due to greater deep drainage losses. However, the effect was more dramatic on the high infiltration alluvial and non-sodic duplex soils where increasing the furrow length from 300 to 700 m and 100 to 500 m decreased application efficiency from 73 to 42% and 57 to 34%, respectively. In these cases, the majority of the excess irrigation water was lost as deep drainage and little benefit would be gained from recycling the small amount of tailwater running off these blocks.

Furrow irrigation efficiencies on the low infiltration cracking clay soils were found to be in excess of 70% (Table 3.4). Increasing in furrow length from 400 to 1 200 m on this soil produced only a small decrease in application efficiency. Even with long furrows, deep drainage losses were small and a significant amount of excess irrigation water was lost as surface run-off. Thus, these soils are suited to tailwater recycling with at least 12% of the applied irrigation water able to be recycled from furrows that were shorter than 1 200 m in length.

3.3.2 *Irrigation Cut-Off Time*

Growers in the Burdekin generally continue to irrigate after the water has reached the end of the furrows to ensure that the root zone soil water is completely recharged. However, growers generally have no measure of the period of time required to recharge the soil water deficit, irrigation controllers or timers are not widely used, and the irrigation is often continued until it is convenient to be manually switched off. Thus, under commercial conditions, a significant component of the irrigation water applied may be lost as excessive tailwater (Table 3.5). For the specific irrigation example presented in Table 3.5, 20% of the applied water would have been saved if the irrigation was stopped as soon as the soil water deficit was fully recharged. It is important to note that for this soil, switching off the irrigation at the appropriate time reduced not only the volume of tailwater discharged but also significantly reduced the volume of water lost as deep drainage. This is consistent with other irrigation results for the alluvial soils which show that on average more than 10% of applied water would be saved by more accurate timing of irrigation cut-off.

Table 3.4 Furrow irrigation efficiencies with changes in furrow length for some Burdekin soils.

Soil	Application rate ($L\ s^{-1}$)	Furrow length (m)	Irrigation time (hours)	Water applied ($ML\ ha^{-1}$)	Application efficiency without recycling^{A} (%)	Application efficiency with recycling^{A} (%)
alluvial	2.8	300	3	0.82	73	91
		500	7	0.94	64	70
		700	15	1.44	42	43
non-sodic duplex	2.5	100	2	1.23	57	62
		300	8	1.56	45	47
		500	18	2.09	34	35
cracking clay	2.7	400	7	1.19	76	91
		800	15	1.22	74	87
		1 200	23	1.23	73	85

^{A}Average soil water deficit: alluvial = 0.6 ML ha^{-1}; non-sodic duplex = 0.7 ML ha^{-1}; cracking clay = 0.9 ML ha^{-1}.

Table 3.5 Typical volume balance for a 470 m furrow on an alluvial soil irrigated at 3.4 L s^{-1} furrow $^{-1}$.

Treatment	Application time (hours)	Applied Volume ($ML\ ha^{-1}$)	Soil water deficit ($ML\ ha^{-1}$)	Deep drainage ($ML\ ha^{-1}$)	Tailwater runoff ($ML\ ha^{-1}$)	Application efficiency (%)
Actual	8.5	1.44	0.60	0.56	0.28	42
Optimum cut-off	6.7	1.13	0.60	0.43	0.10	53

3.3.3 *Application Rate*

The effect of water application rate on irrigation efficiency appears to be a function of soil type (Table 3.6). Changing the rate of water application on the cracking clay soils produced no significant difference in the volume of water applied and the application efficiency. This may have been expected as the majority of the infiltration in this soil occurs by filling the

Table 3.6 Effect of water application rate on the efficiency of furrow irrigation

Soil	Furrow length (m)	Application rate (L s^{-1} $furrow^{-1}$)	Volume applied (ML ha^{-1})	Application efficiency[A] (%)
cracking clay	1 647	1.4	1.38	65
		2.8	1.33	68
alluvial	470	1.7	0.92	65
		2.8	1.13	53

[A] Average soil water deficit: alluvial = 0.6 ML ha^{-1}, cracking clay = 0.9 ML ha^{-1}.

crack volume. Thus, a change in the rate of water applied to this soil would not be expected to affect the crack volume, the volume infiltrated nor the irrigation efficiency.

Reducing the rate of water application on the high infiltration alluvial soils resulted in less infiltration and an increased application efficiency (Table 3.6). These soils have no appreciable cracks and infiltration is a function of the soil's saturated hydraulic conductivity. Thus, it seems reasonable to expect that the reduction in intake associated with lower application rates is primarily a function of the reduced wetted perimeter and surface area available for infiltration. However, it should be noted that further reductions in application rate may not produce comparable increases in irrigation efficiency. At very low application rates, the intake rate of the furrow may exceed the rate of water application resulting in irrigations which do not reach the end of the furrows and a reduction in irrigation efficiency.

3.3.4 *Furrow Shape*

The shape of the furrow has a significant effect on infiltration and irrigation efficiency on the alluvial soils of the delta area (Table 3.7). The furrow shape in common usage within the Burdekin sugar industry is a broad based "U" shape normally formed using hill-up boards. A new "V" shape furrow was trialed in an attempt to produce beneficial surface compaction and a smaller wetted perimeter. These furrows were produced by simply tilting the standard hill-up boards forward. The "V" shaped furrows were found to significantly reduce the advance period and increase irrigation efficiency compared to the broad based "U" shaped furrow. The increase in irrigation efficiency was found to be closely associated with a reduction in the infiltration rate of the soil in the "V" shaped furrow. Tests conducted on intact surface cores taken immediately prior to irrigation found a 57-94% reduction in saturated hydraulic conductivity for the "V" shaped furrows compared to the conventional furrow shape (Table 3.7). With lower infiltration rates, the water in the "V" shaped furrows advanced faster typically reducing the irrigation period by up to 40% where the same water application rates were used (Table 3.8). For the Home Hill trial site, the conventional broad based furrows required an average application of 2.01 ML ha^{-1} $irrigation^{-1}$ while the narrow "V" shaped furrows required the application of only 1.06 ML ha^{-1} $irrigation^{-1}$ representing a 47% water saving. This technique has important implications not only for reducing the volume of water applied but also for reducing the time to conduct irrigation cycles and the pumping capacities required and has received wide grower support with many growers already adopting this practice.

Table 3.7 "V" shaped furrows have a lower saturated hydraulic conductivity than conventional "U" shaped furrows

Irrigation Date	Saturated hydraulic conductivity (mm h^{-1})	
	"U" shaped furrows	"V" shaped furrows
12/4/95	1.4	0.6
9/5/95	4.7	0.3
31/5/95	5.8	2.3

Table 3.8 Effect of furrow shape on irrigation efficiency for an alluvial soil.

Furrow shape	Application rate (L s^{-1} furrow^{-1})	Furrow length (m)	Irrigation time (hours)	Water applied (ML ha^{-1})	Application efficiency^A (%)
Broad based "u"	1.7	470	13	1.09	46
Narrow based "v"	1.7	470	8	0.67	75

^{A} Average soil water deficit = 0.6 ML ha^{-1}.

3.3.5 *Cultivation Practices*

Cultivation practices have a significant effect on the infiltration characteristics and irrigation efficiency of alluvial soils (Table 3.9). Normal post-harvest cultivation practices are conducted for weed control, the incorporation of cane trash using inter-row discs or tynes, and the re-forming of furrows using boards. These activities disrupt the soil surface and generally increase infiltration. On highly permeable soils, this may lead to excessive deep drainage losses and reduced irrigation efficiencies. However, repeated wetting and drying cycles associated with subsequent irrigations cause the soil surface to slake and seal reducing infiltration.

Reducing cultivation on these soils and adopting minimum tillage practices was found to reduce the volume of irrigation water applied (Table 3.9). However, irrigation efficiencies under minimum tillage were also low for the first few irrigations after harvest compared to later in the season. Generally, slower advance times and greater depths of flow were measured for the irrigations conducted immediately after harvesting suggesting that the unconsolidated trash acts to impede advance and increase infiltration. Successive irrigations presumably act to consolidate the trash, reducing impedance and increasing the rate of irrigation advance. However, there appears to be no difference in the irrigation efficiencies between the cultivated and minimum till treatments after the first few irrigations.

Table 3.9 The application efficiency of irrigations conducted immediately after cultivation is reduced.

Treatment[A]	Irrigation date	Volume applied (ML ha^{-1})	Application efficiency[B] (%)
cultivated	3/10/94	4.3	14
	18/10/94	1.7	35
	8/11/94	1.5	40
	15/12/94	1.3	46
minimum till	15/9/94	2.0	30
	6/10/94	1.6	38
	21/10/94	1.5	40
	7/11/94	1.4	43

[A] Successive irrigations conducted on an alluvial soil with 470 m furrow length (a) cultivated = after the last cultivation following harvesting and (b) minimum till = immediately after harvesting

[B] Average soil water deficit = 0.6 ML ha^{-1}.

3.3.6 *Trash Retention Systems*

Irrigation of the trash retention treatment advanced more slowly and required an additional 40% more water than the burnt treatment for the first irrigation monitored after harvesting (16/11/94) at the Clare site (Table 3.10). However, there was no significant difference in the irrigation efficiency or advance times between the trash retention and burnt treatments in subsequent irrigations. This suggests that the main effect of trash retention in the initial irrigation may be related to the hydraulic resistance of the trash. The resistance is high in the initial irrigation and hence the advance is slow. This results in difficulties in getting the water to the end of the furrow, large opportunity times for infiltration and low application efficiencies. In subsequent irrigations, loose trash material has either been washed from the furrow or has settled in the base of the furrow resulting in a hydraulic resistance which is much smaller than the initial irrigation but is still significantly larger than found in the burnt treatment. This results in a greater depth of flow in the trash treatment than the burnt for most

Table 3.10 Effect of trash retention on furrow irrigation depth of flow and advance times for selected furrow irrigations at Clare.

Irrigation	**Water application rate (L/s)**	**Burnt**			**Trash Retention**		
		ISSM (%)	**Depth of Flow (mm)**	**Advance time (min)**	**ISSM (%)**	**Depth of Flow (mm)**	**Advance time (min)**
16/11/94	1.4	-	20	650	-	67	920
5/1/95	0.6	-	16	1 160	-	51	1 290
21/2/95	0.9	10.9	37	840	11.9	56	860
4/4/95	1.0	9.1	35	1 070	16.3	46	1 200
13/4/95	1.0	11.4	30	940	19.1	46	1 000
9/5/95	1.0	14.7	34	1 510	20.4	42	1 380

ISSM = initial surface soil moisture

of the irrigation season (Table 3.10). However, towards the end of the season, the depth of flow in each trash treatment decreases as the trash decomposes while the depth of the flow in the burnt treatment increases as cane lodges and natural trash levels from the growing cane increase .

The greater depth of flow in the trash treatment throughout the irrigation season has not resulted in a difference in the advance times (and hence, efficiency) between the trash and burnt treatments. This is because the trash retention treatment had a higher initial moisture content (Table 3.10) and a lower saturated hydraulic conductivity (Table 3.11). The higher initial surface soil moisture would be expected to reduce the initial infiltration rate in the trash treatment while the lower hydraulic conductivity reflects a decreased infiltration rate through the irrigation. Hence, the increased depth of flow in the trash treatment appears to be counteracted by the lower infiltration rates in this treatment producing an irrigation advance similar to the burnt treatment for most irrigations.

Table 3.11 Trash retention systems have a lower saturated hydraulic conductivity than burnt treatments

Irrigation date	Saturated hydraulic conductivity (mm h^{-1})	
	Burnt	Trash
13/4/95	14.1	5.7
9/5/95	15.4	10.1

It should be noted that the rate of water application in all irrigations was low (< 1.1 L/sec) which may have acted to mask the relative effect of flow depth and initial soil moisture on infiltration and advance time. Different soil types would also be expected to respond differently to that reported here and further work is required to be conducted using a range of soils and irrigation management practices to adequately identify the major factors influencing irrigation efficiency under trash retention systems.

3.3.7 *Water Quality*

Water quality is used by many growers in the Burdekin delta to manipulate irrigation performance. However, this technique is applied on an *ad hoc* process to with little attention paid to the success of this practice with different soil properties. Paired trials were conducted at the Rita Island site using underground water (EC = 1.81 dS m^{-1}) and surface water (EC = 0.25 dS m^{-1}) to investigate the effect of water quality on irrigation performance. However, no significant difference in either irrigation advance or irrigation efficiency were found for the five irrigations conducted at this site. This is in contrast to the significant effect of water quality found at other sites not included in this project and is most likely associated with the soil chemical and physical properties found at this site. As a high infiltration soil with a low clay content, the dispersion of the clay by the application of surface water with a low electrical conductivity was clearly not sufficiency to create a surface seal and reduce infiltration. This suggests that some work should be conducted to characterise those soils where water quality will affect irrigation performance and to quantify the benefits/disadvantages of using various water qualities on these soils.

3.3.8 *Alternate Furrow Irrigation*

Alternate furrow or skip-row irrigation is a common practice in many irrigated crops and has been used in the Burdekin by a small number of growers under conditions of limited water availability. However little work has been done to investigate the effect of this practice on irrigation efficiency and crop growth.

Preliminary experiments were conducted on three different blocks (Block 52, 76 and 37) at CSR's Kalamia Estate. Blocks were selected to provide a range of soil types, slopes, lengths and cane variety. The experimental plots were part of larger commercial blocks and the treatment consisted of applying irrigation water to every second furrow within the experimental plot. Irrigation of both Block 52 and 76 were scheduled according to a water deficit of 90 mm, indicated by a mini-evaporation pan. The irrigation of Block 37 was also scheduled using a mini-pan, but deficits of 90 mm and 70 mm were used for the every furrow and the alternate furrow treatments, respectively. This was based on the rationale that the amount of moisture available for the crop was reduced in the alternate furrow treatment compared to the every furrow treatment. Treatments were imposed on Block 52 and 76 at the beginning of November, 1995 and on Block 37 at the beginning of January, 1996.

Stalk elongation measurements were made in October and November 1995 on Blocks 52 and 76 (plant cane), and in January and February 1996 on Block 37 (second ratoon cane). The soil type in Block 52 varied substantially from a loamy clay at the top end of the block to a clay at the bottom end of the block. Hence, stalk elongation was measured at both the top and the bottom end of this block. For the treatments in Blocks 52 (Figure 3.1) and 76 (Figure 3.2), 20 plants were initially selected for measurement immediately after initiation of the treatment. However, an additional set of 20 measurements was also taken within each treatment after the first 12 days. Stalk elongation measurements of Block 37 (Figure 3.2) were averaged over three sites within the block, each containing 20 plants.

Increase in stalk height was found to be closely related to water stress with the crops in Blocks 52 and 76 both suffering water stress about 10 days after the initial treatment irrigation (Figures 3.1 and 3.2). However, the onset of water stress in the alternate furrow (AF) treatment occurred earlier than in the every furrow (EF) treatment where both treatments were irrigated using the same mini-pan deficit of 90 mm. A similar stress occurred during subsequent irrigation cycles progressively increasing the difference in stalk height between the two treatments. There was up to 30 cm difference in stalk height between the treatments after 40 days. This resulted in a 13% decrease in cane yield and a 12% decrease in the CCS produced by the alternate furrow treatment compared to the every furrow treatment on Block 52 (Table 3.12). No yield data was available for the treatments in Block 72.

Differences in the yield (Table 3.12) and stalk height (Figure 3.1) observed between the every furrow and the alternate furrow treatment where the treatments were irrigated at the same soil moisture deficit are due to moisture stress. The soil moisture stress applied in each of these treatments is illustrated by the changes in soil moisture content from the wettest profile during the season (ie. the profile which had the most moisture stored in the entire profile) in Block 52 (Figure 3.3). Although there had been significant differences in the crop growth rates measured after day 10, it was only after day 40 that the soil moisture differences recorded by the NMM between the treatments became obvious (Figure 3.3). After this time, the alternate furrow (AF) treatments started to dry out to a greater extent between irrigations compared to the every furrow (EF) treatment. This suggests that the crops in the AF treatment were accessing water from a smaller volume of soil than the EF treatment. Hence, to maintain the same water uptake (and growth rate) the crops in the AF treatment are required to extract water at higher suctions than the EF irrigated crops.

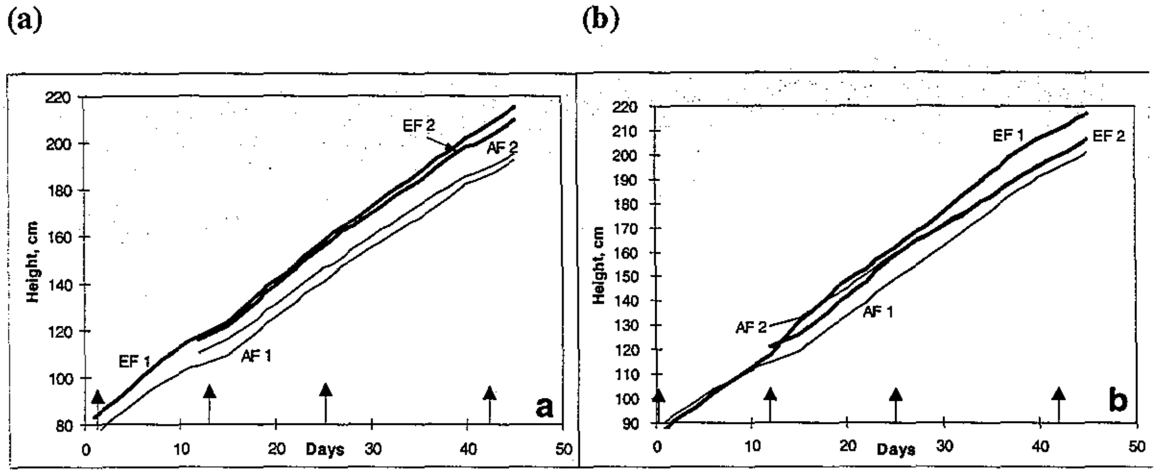

Figure 3.1 **Stalk height for plant cane growing in the (a) loamy clay and (b) clay section of Block 52. Irrigations scheduled using 90 mm mini-pan evaporation.** (Arrows indicate irrigations)

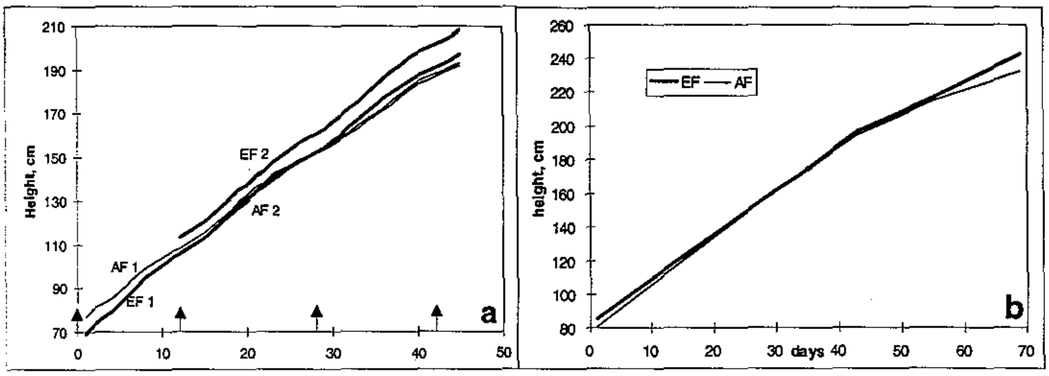

Figure 3.2 **Stalk height for (a) plant cane growing in Block 76 and scheduled using a 90 mm mini-pan deficit and (b) ratoon cane growing in Block 37 and scheduled using mini-pan deficits of 90 mm (every furrow) and 70 mm (alternate furrow)** (Arrows indicate irrigations)

Table 3.12 Yield of sugarcane irrigated using the every furrow and alternate furrow techniques where both treatments were scheduled using a mini-pan deficit of 90 mm.

Irrigation Treatment	Yield	
	t_{cane}/ha	CCS
Every furrow	164 (± 11)	12.5 (±0.4)
Alternate furrow	142 (± 4)	11.4 (±0.6)

Where a 70 mm mini-pan deficit was maintained for the AF treatment and compared to the EF irrigations conducted using a 90 mm mini-pan deficit, there was no significant difference in stalk growth over a seventy day period (Figure 3.2(b)) and no significant difference ($P<0.05$) in the final yield of these two treatments (Table 3.13). The limited soil moisture content data set for Block 37 (Figure 3.4) indicates that the fluctuations in the moisture content during the irrigation cycle for these treatments were much less extreme than where the same soil moisture deficit was maintained for both the EF and AF treatments (Figure 3.3). This confirms that where the AF treatment is conducted using a smaller mini-pan deficit than the EF treatment, water stress on the crops is significantly reduced and yields similar to the EF treatments can be achieved.

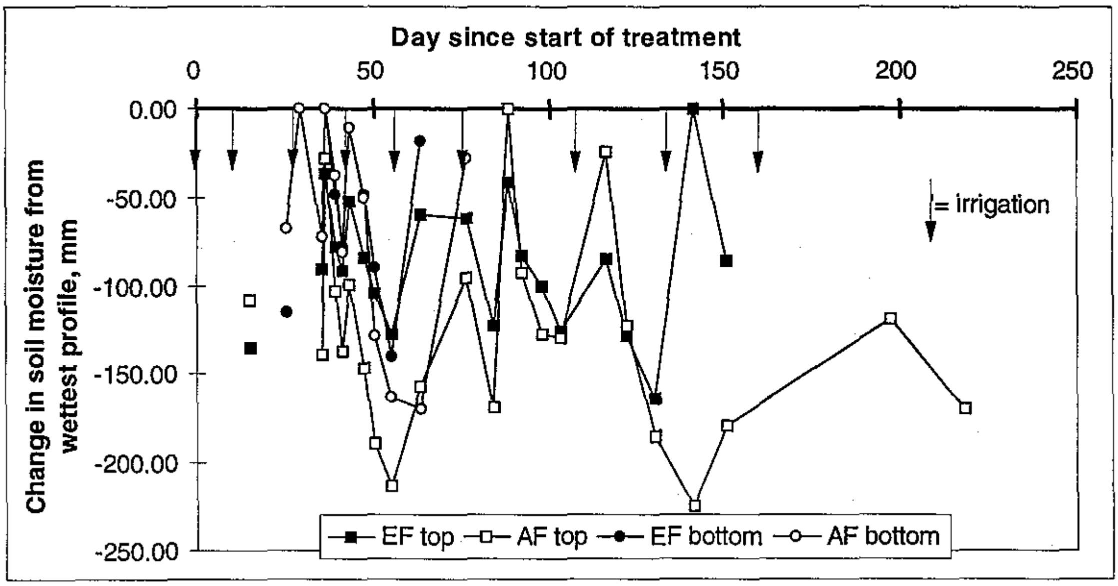

Figure 3.3 Changes in soil moisture content in the plant row for the every furrow (EF) and the alternate furrow (AF) treatments. (Arrows indicate irrigations)

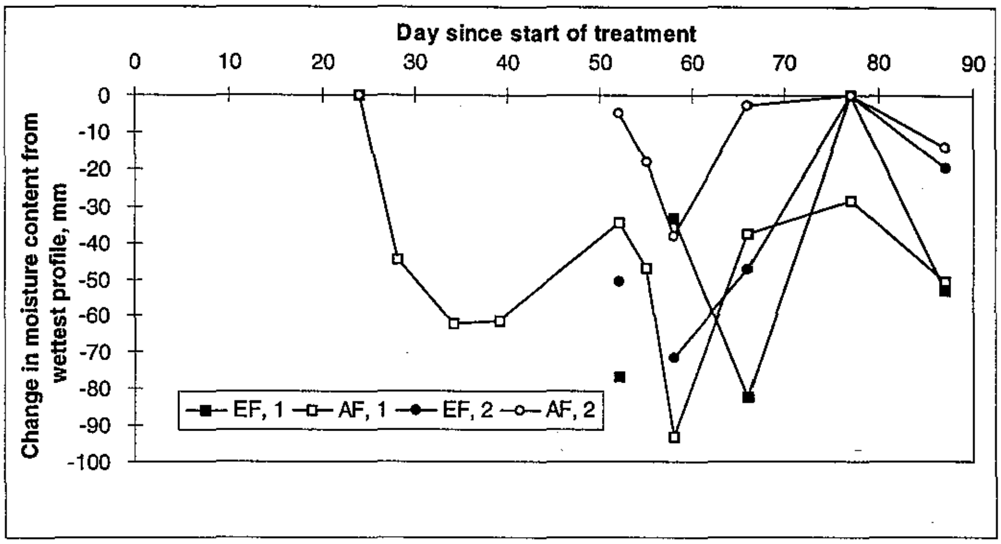

Figure 3.4 **Changes in soil moisture content in Block 37 for two different treatments, every furrow (EF) and alternate furrows (AF).**

Table 3.13 **Yield of sugarcane irrigated using the every furrow and alternate furrow techniques where the treatments were scheduled using mini-pan deficits of 90 mm and 70 mm respectively.**

Irrigation Treatment	**Yield**	
	t_{cane}/ha	**CCS**
Every furrow	**140 (± 3)**	**15.2 (± 0.1)**
Alternate furrow	**132 (± 7)**	**15.5 (± 0.3)**

Alternate furrow irrigation usually requires an extended period of irrigation per furrow due to longer advance times. However, this is dependent on the soil infiltration characteristic and the amount of lateral soil-water movement. In both low infiltration soils and the high infiltration loamy clay soils, lateral movement is minimal and there is little should be little difference in the advance time of every and alternately irrigated furrows. However, from preliminary trials conducted at the Mulgrave A site on cracking clay soils, substantial lateral water movement through the crack volume was observed. This resulted in the advance time of the alternately irrigated furrows being twice as long as for every furrow irrigations.

The amount of lateral soil-water movement also has an effect on the amount of water stored in the soil profile. As the advance times were not different for the alternate furrow irrigation treatment compared to the every furrow treatment in Blocks 52 and 76, about half the total amount of water was applied in each alternate furrow irrigation compared to the every furrow irrigations. As the irrigations in each treatment were scheduled at the same time, this translated to a 50% saving in the volume of water applied to the alternate furrows. However, where water meters were installed in Block 37 to directly measure the volume of water applied to the treatments scheduled at different deficits, there were no substantial water savings using the alternate furrow irrigation technique (Table 3.14). This implies that under alternate furrow irrigation either (a) substantial lateral movement occurs (ie. the entire soil profile is wetted up), (b) deep drainage losses have been increased, (c) the inflow into the furrow was substantially different between the AF and EF treatment or (d) the irrigation periods were inconsistent. However, to identify the precise mechanisms affecting the results would require detailed irrigation observations such as inflow per furrow, advance rates and lateral moisture distribution.

Table 3.14 Volume of irrigation water applied to the treatments in Block 37.

Every Furrow		Alternate Furrow	
Irrigation Date	**Volume (ML ha^{-1})**	**Irrigation Date**	**Volume (ML ha^{-1})**
4/04/96	2.79	28/03/96	0.85
26/04/96	1.43	9/04/96	1.07
20/05/96	2.08	24/04/96	1.55
5/06/96	1.16	14/05/96	1.19
10/07/96	0.97	31/05/96	1.53
02/08/96	1.79	1/07/96	1.36
		22/07/96	1.10
Total	10.22	**Total**	8.65

This work indicates that if alternate furrow irrigation is applied without allowing for a reduced irrigation water deficit substantial yield losses can occur. However, where a smaller irrigation deficit is maintained for the alternately irrigated furrows, other factors might eliminate some of the advantages of alternate furrow irrigation. This contrasts the outcome of work carried out by CENICAÑA in Colombia (Torres *et al.* 1996) where substantial water savings were obtained without a reduction in yield. However, the climatic conditions and soil types found in Colombia are very different compared to the Burdekin with different rainfall patterns resulting in fewer irrigations (3-4) compared to the Burdekin (15-18). Lower average yields across all treatments and some questionable interpretations of the Colombian results may also explain some of differences in these findings. Further work is required to adequately define the conditions for successful alternate furrow irrigation in the Australian sugar industry.

4. Phase B The Identification and Evaluation of a Suitable Surface Irrigation Model, and the Assessment of the Model's Requirements for Operation

4.1 Introduction

The need for a tool in surface irrigation design arises from the difficulties in efficiently applying the desired quantity of water evenly across a field. Water losses in the form of runoff and deep drainage are likely to occur as a result of improper design and management practices. With the increasing need to conserve water, such a tool may not only increase the economic return for the user but reduce the environmental impacts of low water use efficiency.

Various software tools are available for irrigation design and management. This phase of the project involved a preliminary evaluation of three of these tools for use in irrigation design and management. The models identified prior to project initiation for evaluation were KINCON (Connolly and Barton 1990), SIRMOD (Walker, 1993) and KIM/ZIM (Ross, 1986). The preliminary evaluation identified that KINCON was inappropriate for the irrigation design and management tasks required. KINCON is an event based hydraulic model designed to simulate runoff under rainfed conditions to assist in the design of contour banks and waterways. However, both SIRMOD and KIM/ZIM were identified as suitable for further investigation. SIRMOD uses a hydrodynamic model to simulate the hydraulics of surface irrigation (furrow, border check and surge) and gives the user a choice of three solution techniques (full hydrodynamic solution, zero inertia approximation and kinematic wave approximation). KIM/ZIM is similar to SIRMOD but only provides the operator with the option of the kinematic wave or zero inertia approximate solutions. In the preliminary evaluations, the solutions obtained using KIM/ZIM were found to be numerically similar to those obtained using the kinematic wave and zero inertia options in SIRMOD. However, SIRMOD was found to be far easier to operate than KIM/ZIM with SIRMOD providing "user friendly" data input screens, greater control over data output including graphics representations, and more comprehensive documentation. As there were no other models readily available for evaluation, it was decided to focus on SIRMOD throughout the rest of this project.

SIRMOD was developed principally as a tool for the evaluation of alternative field designs (furrow lengths and slopes) and management practices (flow rates and times to cut-off). However, its use in selecting optimal values of the above parameters is limited by the need to apply a trial and error approach. In a comparison of a variety of surface irrigation models, Maheshwari and McMahon (1993a & 1993b) concluded that the SIRMOD hydrodynamic and zero inertia solutions gave accurate predictions of the advance and an acceptable overall prediction of irrigation performance. However, one of the perceived disadvantages of SIRMOD is its requirement for a substantial amount of measured data. This includes information on furrow profile shape and roughness, field size and slope, soil infiltration characteristics, irrigation inflow rates and event time. In practice this level of data tends to be difficult, time consuming and expensive to obtain. This has led to uncertainty regarding the effort required or justified in data collection for this model to be used in the development of irrigation design and management guidelines. Thus, a study was conducted to determine (i) the ability of SIRMOD to accurately simulate the physical irrigation event if all of the input data is available (model validation); and (ii) the usefulness of the model if some of the data is inaccurate or missing (sensitivity analysis of the model's input parameters).

4.2 Materials and Methods

Data collected during the 1994-5 irrigation season was used to evaluate the simulation accuracy of SIRMOD. To reduce errors due to non-uniformities in furrow shape, the furrow geometries were measured using a profile meter at up to six locations within the trial site. This data was averaged and the program PCSv1.42 (Raine, *unpub*) used to produce the empirically fitted profile parameters $\rho 1$, $\rho 2$, $\sigma 1$, $\sigma 2$, $\gamma 1$, and $\gamma 2$ which were used as input on the SIRMOD "Page 3" screen to describe the surface water storage. These values were also used in the calculation of the Manning *n*.

SIRMOD uses the Kostiakov-Lewis equation to described the infiltration process:

$$I = kt^a + f_o t$$

where I is the cumulative infiltration, a and k are fitted parameters, f_o is the final infiltration rate, and t is the opportunity time for infiltration. The average hydraulic area of the furrow was calculated within PCSv1.42 and used to calculate the infiltration parameters a and k using a modified version of the two point method (Elliott and Walker, 1982). If, as occasionally occurred, the value of the parameter a was calculated as a negative number using the two-point method, it was set to equal to zero and k was recalculated. This implies a linear infiltration curve predominantly influenced by a high final infiltration rate.

The sensitivity analysis was undertaken using data from three irrigations at each of the Home Hill, Rita Island and Jarvisfield sites. The analysis was conducted by progressively changing the measured input parameters individually to produce an input variable that was larger than could be realistically be encountered in practice. These changed parameters were then used as input into SIRMOD and the output volume balance for the changed condition calculated. Except where otherwise stated, all other parameters were maintained at their measured value. The full hydrodynamic solution option was used preferentially when undertaking the SIRMOD simulation. However, where this solution was unable to complete the simulation due to either programming constraints or mathematical non-viability, the zero inertia model and kinematic wave model options were used.

The program INFILTv3.01 (McClymont & Smith, 1995 and 1996) was also used to generate alternative values of the three infiltration parameters (a, k, f_o) and the cross-sectional area of flow from the measured advance data. The program does this by calculating all four parameters in a single optimisation process. The empirical profile parameters were matched to the area parameter value generated from INFILTv3.01 using the profile program PCSv1.42. These results were then used as input into SIRMOD and the output compared with field measurements to determine the necessity of directly measuring the infiltration parameters. The effect of variation in the infiltration function of successive irrigations on the cumulative infiltration was also investigated.

4.3 Results

4.3.1 *Model Validation*

To test the model's validity, the results for predicted advance, and runoff and infiltration volumes, were compared against the measured quantities for over 70 sets of irrigation data. The relationship between the measured advance times and those predicted by SIRMOD (Figure 4.1) shows a high correlation (r^2=0.83) with the slope (0.91) of the regression indicating that SIRMOD slightly underpredicts the advance times.

A significant correlation (r^2=0.63) was found between the measured and predicted infiltrated volumes with a regression coefficient of 0.8 (Figure 4.2). This suggests that the model generally underpredicts the total infiltration during the irrigation. However, the average deviation was 16.9% of the measured infiltrated volume (or less than 10% of the total volume applied). Because of the direct relationship between the infiltrated and runoff volumes, an underprediction in infiltration resulted in an overprediction in runoff (Figure 4.2). In this case the slope of the regression between the measured and predicted runoff was 1.2 and the correlation coefficient 0.2. This poor correlation coefficient reflects the proportionally small runoff volumes obtained in the trials at these sites.

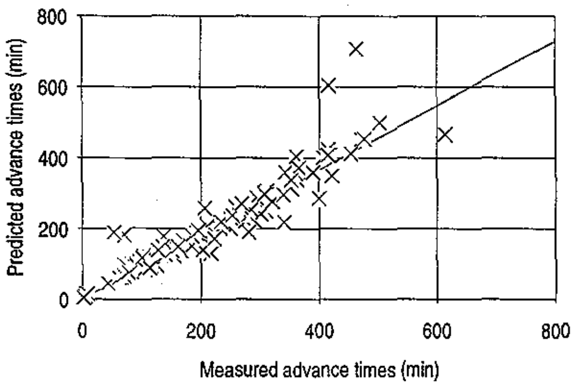

Figure 4.1 Comparison of measured and predicted advance times

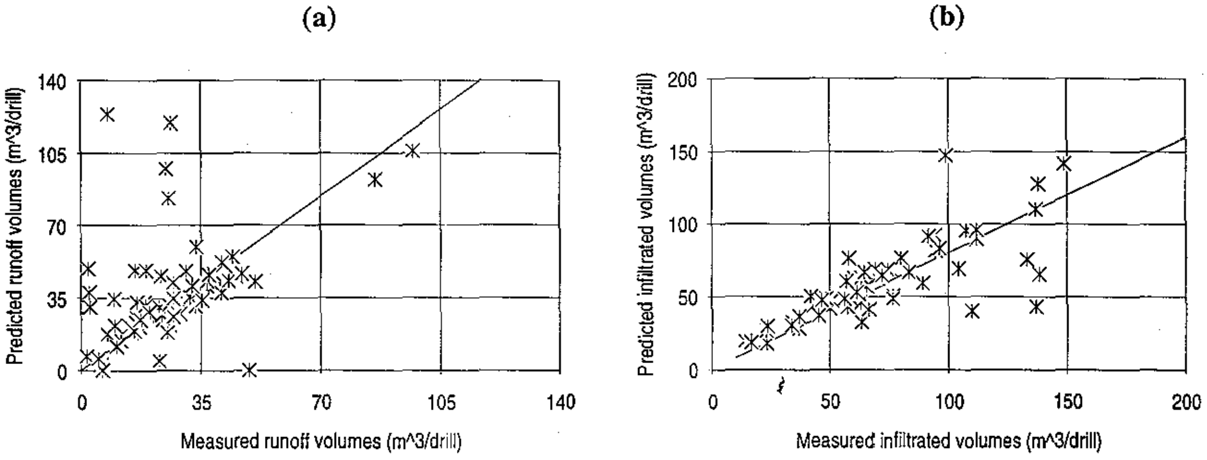

Figure 4.2 Comparison of measured and predicted (a) runoff volumes and (b) infiltrated volumes.

The average deviation from the measured runoff volumes appears high at 151% although again it is less than 10% of the total volume applied. The deviations from the measured runoff volumes remained under 40% for the majority of tests. The 16.9% average deviation between measured and predicated infiltration volumes provides some reassurance that the model simulates the physical process with some reliability. However, this is for the case where all of the input parameters have been measured.

4.3.2 *Sensitivity Analysis*

Manning's n

The Manning's *n* was varied from 50% to 250% of the measured value to demonstrate the effect of changes in the Manning's *n* on the SIRMOD output (Figure 4.3). These graphs indicate that increasing the Manning's *n* increases the simulated infiltrated volume. This was expected as increases in Manning's *n* reflect an increase in furrow roughness; slowing the advance and allowing more time for infiltration. However, increases of up to 250% of the measured Manning's *n* produced an error of less than 4% in the measured infiltrated volume. The maximum volume balance error was only 2.9% of the total volume applied.

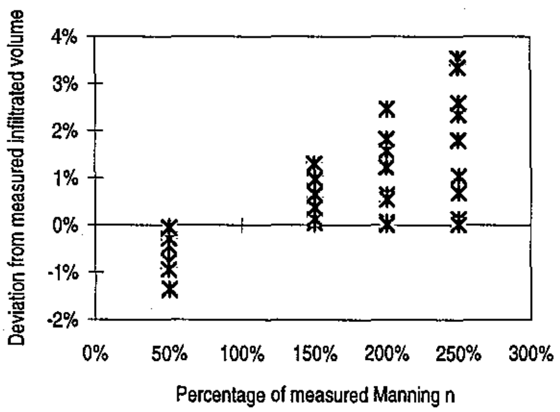

Figure 4.3 Effect of changes in Manning *n* on the infiltrated volumes.

Field Slope

The field slope parameter in SIRMOD was varied in this analysis from 40% to 200% of the measured value. Increases in the field slope parameter effectively act to increase the runoff and decrease the infiltrated volume due to a faster advance. The maximum error induced in the irrigation performance produced by altering the measured slope was less than 3% of the infiltrated volume (Figure 4.4). This equates to an error of 2.2% of the total volume applied. Interestingly, errors in the volume balance were larger where the slope parameter underestimated the true slope compared to where the parameter overestimated the slope. This suggests that where field slope is not measured accurately, it is better to overestimate than underestimate this parameter.

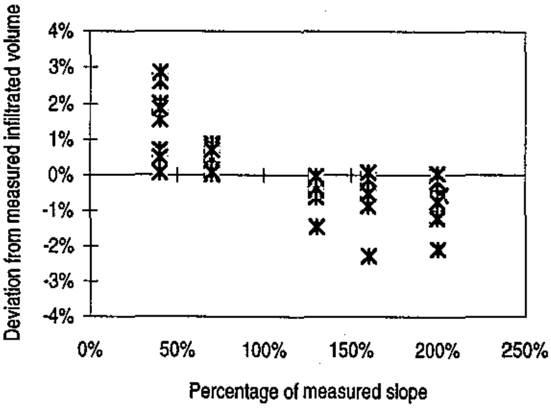

Figure 4.4 Effect of changes in field slope parameter on calculated infiltrated volumes.

Inflow rate
Water application (inflow) rates ranging from 70% to 160% of the measured values were used as input to SIRMOD. However, this trial was conducted in two parts as the water application rate is also used in the calculation of the Kostiakov-Lewis infiltration parameters (*a* and *k*) required by SIRMOD. In the first part, the infiltration parameters and time to cutoff were entered as their measured values to represent a situation which would occur if the infiltration parameters were determined either from a previous event or from a separate measurement. In the second part of this trial, the infiltration parameters were recalculated using the altered water application rate to simulate the situation where these parameters were determined from the irrigation event being modelled.

Changes in the water application rate have little effect on infiltration into the soil, which is dominated by the soil properties.

Where inaccurate measurements of the inflow rate which were not used to calculate the infiltration parameters were used in the model, they were found to produce a significant error in the calculated infiltration volume (Figure 4.5a). In this case, the error was generally less than 20% of the measured infiltration volume. However, where the inflow rates were 40% of the measured value, the calculated infiltrated volume was underestimated by up to 60%. The larger errors occurring at these lower inflow values arise due to a combination of the cut-off time not being increased with the decreasing inflow value and hence, the total volume of water applied has also decreased. In these cases, although the simulated advance may not reach the end of the field (and hence, there is no run-off) the total volume applied is significantly less than that measured as infiltrated. However, it should be noted that any reasonable estimate of inflow rate would be expected to be less than 20% from the actual inflow rate and that under these conditions the error in volume infiltrated would also be expected to be considerably less than 20%.

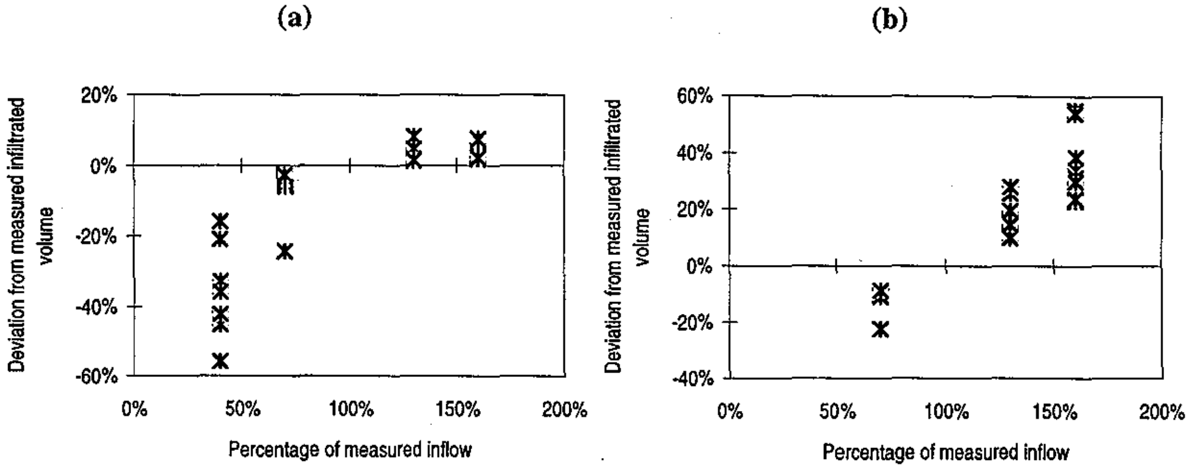

Figure 4.5 Effect of changes in inflow on (a) infiltrated volume with constant infiltration parameters and (b) infiltrated volume with recalculated infiltration parameters.

Where the inflow rate was used to recalculate the infiltration parameters prior to use in the model, significant errors in the calculated infiltrated volume were also found (Figure 4.5b). In this case, the errors were typically less than 20% although errors of up to 60% in the infiltrated volume were found where inflow was overestimated by 60%. It should also be noted that it was mathematically impossible to recalculate the infiltration parameters for an inflow rate that was 40% of the measured value. However, this is not unrealistic as in practice it is unlikely that such a low inflow rate would produce such a fast advance rate.

This work indicates that the accuracy of the model volume balance determinations is closely related to the accuracy of the water application measurement. The general trend is that where the water application rate is overestimated, the infiltrated volume will also be overestimated whether or not the infiltration parameters are recalculated. Similarly, where the application rate is underestimated, the infiltration volume will also be underestimated by the model. However, in both cases, where the water application rate is used to recalculate the infiltration parameters, the errors propagate to produce larger errors in the volume balance.

Final Infiltration Rate

The final infiltration rate (f_o) parameter was varied from 0-200% of the measured value and the Kostiakov-Lewis infiltration parameters (a and k) recalculated and the volume balance determined using the model. For some very high f_o values it was not always mathematically possible to calculate a and k values given the irrigation advance data. In general, overestimations in the final infiltration rate were found to lead to a reduction in runoff volume and overestimation of the infiltrated volume. Errors in the calculated infiltrated volume were typically less than 30% but ranged up to 50% when the f_o values were assumed to equal zero (Figure 4.5). This suggests that the model operation is sensitive to errors in f_o and that this variable should be measured as accurately as possible in the field.

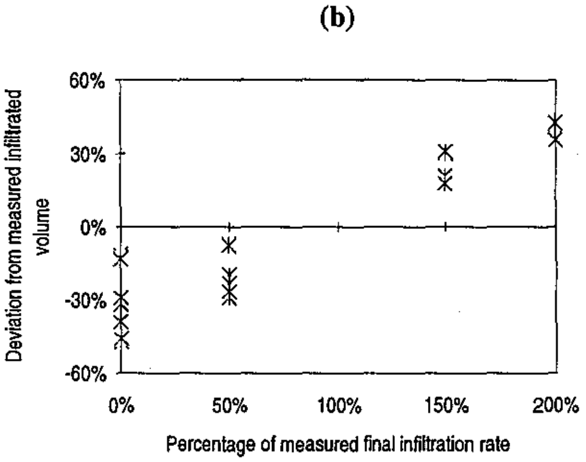

Figure 4.6 Effect of final infiltration rate on the calculated infiltration volume.

Cross Sectional Area Of Flow

The effect of changes in the cross sectional area of flow parameter on the output volumes were determined where the infiltration parameters were not recalculated using the new cross-sectional area of flow and the situation where the infiltration parameters were recalculated using the new area (Figure 4.7). Where the infiltration parameters were not recalculated, there was a negligible effect of cross-sectional area parameters on the infiltrated volume calculated by the model. In this case, the greatest infiltration error was less than 1.2% in infiltrated volume (Figure 4.7a), corresponding to an error of 0.62% of the total volume applied. The scatter in the graph is indicative of numerical rounding errors.

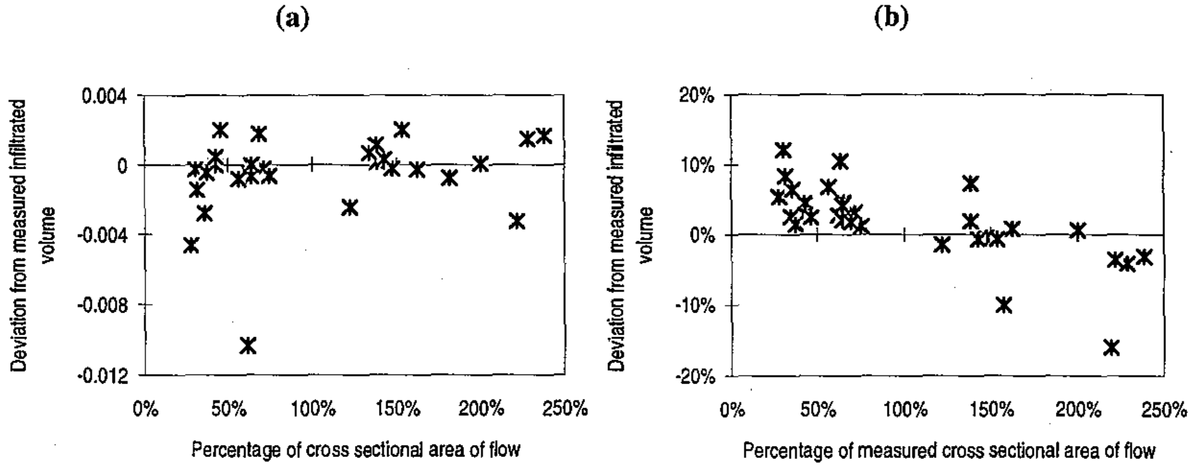

Figure 4.7 Effect of changes in cross-sectional area of flow on (a) infiltrated volume with constant infiltration parameters and (b) infiltrated volume with recalculated infiltration parameters.

Where the infiltration parameters were recalculated (Figure 4.7b), the cross-sectional area error was magnified on propagation and the maximum infiltrated volume error increased to 15%. The general trend of this graph indicates that an increase in cross-sectional area of flow increases the calculated runoff and reduces the calculated infiltration volume. This essentially demonstrates the effect of changes in the cross sectional area parameters on the Kostiakov-Lewis infiltration parameters.

4.3.3 *Empirically Fitted Infiltration Parameters*

Figure 4.8 shows the magnitude of the volume errors incurred through using the output of INFILTv3.01 as input into SIRMOD. Five of the tests showed fairly good agreement with the measured infiltration volumes with deviations of less than 12%. However, the three sets of data from the Jarvisfield site (j37, j74, j104) and one set of data from the Rita Island site (sh74) showed a poor correlation between measured and predicted infiltration volumes. The maximum volume balance error was for the event "j104" at 33.8% of the maximum inflow volume.

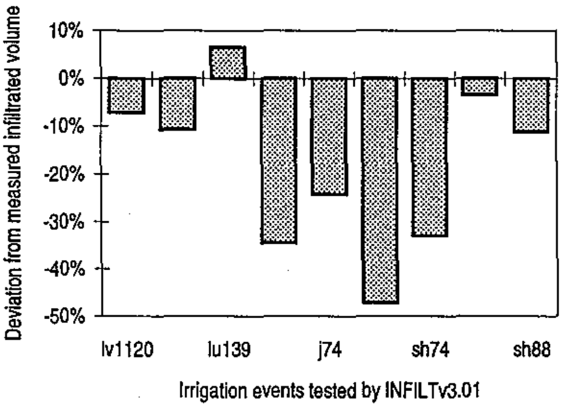

Figure 4.8 Results from SIRMOD using infiltration parameters from INFILTv3.01 showing effect on infiltrated volumes.

In all cases but one, the empirically fitted infiltration parameter based model underpredicted infiltration. However, Figure 4.2(b) demonstrated that SIRMOD generally underpredicts infiltration, so this result may not wholly be attributed to the empirically fitted infiltration parameters. The optimisation undertaken in the INFILTv3.01 model is in effect a curve fitting exercise through the irrigation advance points. Therefore the quality of the advance data has an effect on the output parameter values. Table 4.1 shows the coefficients of variation for the simple power curve regressions of the advance data for the nine irrigations analysed. This shows that the irrigation data sets which produced poor correlations in the predicted volume balance (Figure 4.8) also had high coefficients of variation and confirms that empirically fitted infiltration parameters are less reliable for "noisy" advance data. This suggests that where the irrigation advance data is accurately measured, the infiltration parameters may be adequately determined directly from the advance data without additional field measurements. However, further research is required to confirm this work and determine the limits of applicability.

Table 4.1 Coefficients of variation (%) for power curve regressions of the nine irrigation events.

	lv1120	lu56	lu139	j37	j74	j104	sh74	sh84	sh88
coefficient of variation	0.01	0.12	3.42	2.33	2.22	2.66	3.33	0.29	0.20

4.3.4 *Temporal Variation of Infiltration*

Infiltration was measured for each irrigation at each of the sites. In all cases, these measurements showed the substantial variation with time which results from a range of factors such as changes in antecedent moisture content of the soils, soil compaction and changes in vegetative cover. To illustrate the errors which may occur where a single infiltration measurement from one irrigation is used to predict irrigation performance on subsequent irrigations (as is sometimes attempted in modelling work) the cumulative depths of infiltration (corresponding to an opportunity time of 500 mins) were calculated from measurements taken over a nine month period at the Jarvisfield site. In this case, the infiltrated volume ranged from 0.13 m to 0.24 m which represented an 85% increase over the period (Figure 4.9). However, the trend was not even consistent with infiltration rate (and hence infiltrated volume) decreasing in the March-April period for no obvious reason. Considering the results from the previous sensitivity analysis and the sensitivity of irrigation performance to small variations in the infiltration function, this highlights the difficulty associated with the use of an assumed single estimate of infiltration in irrigation assessments.

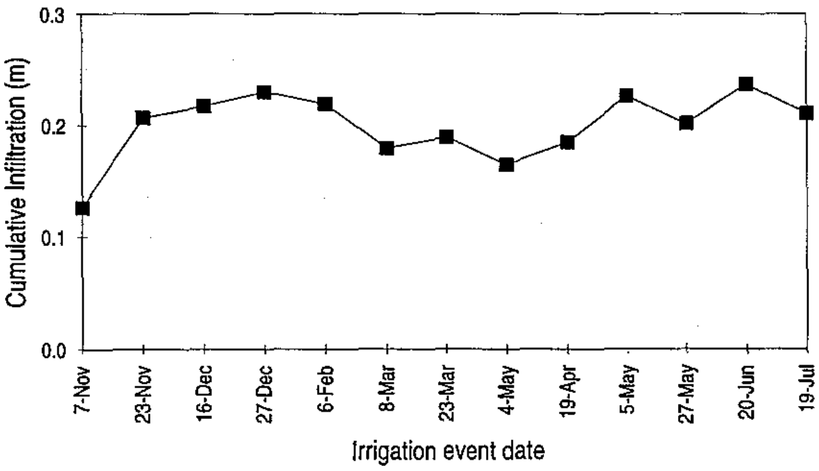

Figure 4.9 Comparison of cumulative infiltration results over a nine month period at the Jarvisfield site for a nominal opportunity time of 500 mins.

4.4 Discussion

The first part of this analysis showed that SIRMOD is able to simulate the surface irrigation process adequately when sufficient data are available. However, when using all the data SIRMOD still showed a tendency to underpredict both the rate of advance and the volume infiltrated. This underprediction by SIRMOD of the volumes infiltrated was also observed by Maheshwari and McMahon (1993b), a fact which they attributed to an uncertainty in the values they used for the infiltration parameters. Given that the same result occurred in the present study, this suggests that there is a systematic error in SIRMOD which might be removed by an appropriate calibration procedure. Here calibration is defined as the process whereby the value of a parameter is adjusted until the predicted result matches the measured result. The infiltration parameters and the Manning's *n* are the only data input to SIRMOD which are not measured directly and which therefore provide an opportunity for calibration. In other applications of similar hydrodynamic models (e.g. in modelling river flows), the Manning's *n* is used as the calibration factor. One outcome of this is that it often results in unrealistically high values for *n*. A useful extension of the present study would be to explore the efficacy of attempting to calibrate SIRMOD against measured data prior to its use in the optimisation of irrigation applications.

Models are most useful if they can be used with confidence in a predictive role. The sensitivity analysis conducted in this work has shown that for prediction of irrigation performance to be successful, an accurate estimate of the infiltration characteristic of the soil is a necessity as it was the infiltration parameters which had the far greater effect on the model results. However, it is also the infiltration parameters which are the most difficult to measure or estimate. An extensive number of point measurements are expensive and may not account well for the spatial and temporal variation in the soil properties, while techniques based on the irrigation advance cannot be applied prior to the first irrigation and in any case are variable from one irrigation to the next (Figure 4.9). Hence, where possible, event based methods using data from the irrigation being investigated should be employed while infiltration characteristics measured at a point source or from previous irrigations may be used where the temporal variation has been taken in account.

This work has also shown that the model SIRMOD was relatively insensitive to changes or errors in the field slope, Manning's *n* and the cross-sectional profile of the furrow. However, where the water application rate is not measured reasonably accurately, significant errors in the volume balance determinations do occur. SIRMOD has already been successfully used to identify the benefits associated with various irrigation management strategies (Raine and Shannon, 1996) and can be used with confidence to provide recommendations and guidelines for the improvement of irrigation efficiency. It should also prove to be useful in reducing the amount of field work necessary for evaluation of furrow irrigation performance in future studies. However, it should be noted that SIRMOD is not a particularly user-friendly package due to the nature of the interface and that the package does not have an optimisation ability. Thus, to identify improved irrigation practices and to develop guidelines for individual farms, it is necessary to conduct a series of iterative simulations and to compare the results manually. When attempting to optimise for several irrigation variables,(eg. furrow length, water application rate and management practices that influence the infiltration characteristic) this can be a tedious and time consuming process. For this package to be widely used in an extension role, it will be necessary to redevelop and simplify the interface and to incorporate an optimisation routine to assist in the identification of optimal practices for a range of specified conditions.

5. Phase C The Dissemination and Publication of Irrigation Design and Management Guidelines to Improve Irrigation Efficiency

This phase of the project was conducted actively throughout the project period. Extension activities were targeted specifically at the farm, local industry, and research levels (Table 5.1). While the major extension effort was directed towards ensuring the adoption of improved management practices by local growers, results were also promoted to the broader sugar producing and irrigation communities. To ensure that each group was targeted appropriately, a wide range of extension activities were undertaken. For the local growers, this involved conducting on-farm trials, demonstration site tours and field day displays. During the latter part of the project operation, a substantial effort was also directed towards working closely with the participatory action learning program for growers being undertaken as part of the extension project *"Increasing irrigation efficiency in the Australian sugar industry"* (BSE2). Newspaper articles were used to create an awareness regarding the project and disseminate project information to the broader local community. Presentations were conducted throughout the project to local industry groups to ensure growers and industry workers were aware of the results and implications of the project findings. These groups variously included local representatives of the Cane, Pest and Productivity Boards, irrigation supply and design companies, CANEGROWERS, CSR Burdekin Mills, the Queensland Irrigators Council and the local Mill Supplier's Committees. Industry magazine articles and ASSCT conference presentations were used promote the project results more widely within the broader sugar producing community. However, project results applicable to the broader research communities were also presented at the national conferences of both the Australian Society of Soil Science Inc. and the Irrigation Association of Australia. Fifteen industry and conference publications have been produced from this project to date (Appendix 2).

The results of this project have been instrumental in providing a sound scientific basis for the irrigation extension programs *"Watercheck"* (BS127S) and *"Increasing irrigation efficiency in the Australian sugar industry"*(BSE2). The data obtained through this project provided much of the material initially presented to raise the awareness of the grower groups established as part of these programs. In addition, many of the furrow irrigation management practices currently being promoted by these extension programs to improve water application efficiency were identified and developed as part of this project. Data from this project has also provided a knowledge base for providing recommendations regarding irrigation strategies both as part of these formal extension projects and within the normal reactive extension activities conducted by BSES.

Table 5.1. Major extension activities undertaken as part of BS90S

DATE	ACTIVITY	AUDIENCE
December 1993	Newspaper article "The Advocate"	Burdekin community/growers
February 1994	Meeting presentation	Growers/millers/local industry representatives
April 1994	ASSCT presentation	Growers/researchers/industry
May 1994	BSES Field day	Growers/local industry
July 1994	Newspaper article "NQ Register"	North Queensland growers/industry
October 1994	Tour field sites	Proserpine growers
December 1994	Irrigation seminar	Industry/Government representatives
February 1995	BSES Information meetings	Sarina growers Proserpine growers Burdekin growers
February 1995	Industry presentation	Growers/millers/local industry representatives
February 1995	Meeting presentation	Invicta Mill Suppliers Committee
February-April 1995	Grower cell group meetings/workshops	Burdekin growers
March 1995	Magazine Articles (2) "BSES Bulletin"	Growers/industry
April 1995	Tour field sites	Growers (Herbert River and Far North Queensland)
April 1995	BSES Technical Report	Researchers/industry
May/June 1995	CSR Shed Meetings	Local growers
May 1995	ASSCT Presentations	Growers/researchers/industry
May 1995	BSES Field day	Growers/local industry
June 1995	Magazine Article "Canegrower"	Growers/industry
June 1995	Information pamphlets produced	Growers
August 1995	BSES Technical Report	Researchers/industry
September 1995	Meeting presentation	Inkerman Mill Suppliers Committee
September 1995	Irrigation course	BSES and CPPB extension officers/local irrigation industry
October 1995	Grower cell group meetings/workshops	Burdekin growers
February 1996	Grower cell group meetings/workshops	Burdekin growers
May/June 1996	CSR Shed Meetings	Local growers
May 1996	ASSCT Presentations	Growers/researchers/industry representatives
May 1996	BSES Field day	Growers and local industry

6. Recommendations for Further Research and Development

This project has provided baseline data for a range of furrow irrigated conditions and has identified the importance of specific farm design and management practices on irrigation efficiency. While substantial gains have been made to improve irrigation efficiency on the high infiltration soils of the Burdekin delta, this project has only provided a limited introduction to the identification of more efficient (both in water/labour and capital requirements) practices applicable to other areas. Similarly, there were a number of important irrigation practices that were unable to be investigated within this project due to time and resource constraints. In addition, several of the management practices that have been investigated by this project require additional research and development to adequately identify the conditions under which these practices might be adopted commercially. In most cases, gross effects and general trends associated with the introduction of these practices have been identified but additional work is required to formalise recommendations. The development of an optimisation routine to improve the user friendliness of SIRMOD and enable the demonstration to growers of improvements in irrigation performance associated with changes in management practices should be considered as a high priority. This development would enable the package to be readily used by extension officers in an advisory role to assist with the provision of site specific irrigation management and design guidelines.

The formal extension programs being conducted as part of the continuing irrigation extension projects BSE2 and BS127S have provided a framework for the adoption of irrigation management practices identified as part of this project. However, these associated projects are directed towards participatory action learning which aims to raise grower awareness and change community attitudes. It should be noted that these extension projects are not capable of undertaking the detailed scientific investigations required to identify, evaluate and develop innovative irrigation management practices for implementation. These extension programs undertake observational studies of irrigation practices constrained by current commercial conditions and do not have the resources nor the expertise to undertake a systematic study to identify the mechanisms and processes operating under various conditions. Only by understanding of these processes will innovative irrigation practices to reduce inefficiencies be identified. Specific areas of furrow irrigation research and development which require further detailed investigation include the:

- development of soil specific guidelines for increasing surface soil bulk densities to reduce deep drainage on high infiltration soils without producing subsoil compaction or water entry problems

- development of appropriate farm design and management guidelines for successful furrow irrigation of trash retention systems, particularly on the low infiltration and low slope soils of the Burdekin River Irrigation Area

- identification of benefits and the development of guidelines for the adoption of alternate (skip-row) irrigation

- evaluation of the benefits and constraints associated with using various water qualities to reduce water wastage during post-cultivation irrigations.

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Appendix 1 BS90S Project Funding

Year	SRDC Contribution	BSES Contribution	CSR Contribution	Total Funding
1992-93	$43 340	-	-	$43 340
1993-94	$29 780	$29 100	$5 210	$64 090
1994-95	$69 900	$34 100	$3 720	$107 720
1995-96	$49 570	$25 470	$8 930	$83 970
Total	$192 590	$88 670	$17 860	$299 120

Appendix 2 Industry and conference publications arising from BS90S

Shannon, E.L. and Raine, S.R. (1995) Increasing the productivity and efficiency of irrigation in the Burdekin. *BSES Information Meeting, Burdekin. BSES Publication* **748**, 19-23.

Shannon, E.L. and Raine, S.R. (1995) Irrigation - a statewide perspective. *BSES Information Meeting, Mackay. BSES Publication* **746**, 18-20.

Shannon, E.L. and Raine, S.R. (1995) What benefit is irrigation in the Sarina region? *BSES Information Meeting, Sarina. BSES Publication* **747**, 19-23.

Shannon, E.L. and Raine S.R. (1995) Canegrowers strive to get best results with available water. *Australian Canegrower* **17(6)**, 20-21.

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Raine, S.R. and Bakker, D.M. (1995) Calibration equations for soil moisture measurement using the neutron moisture meter. *BSES Technical Report* TE95006. pp15.

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