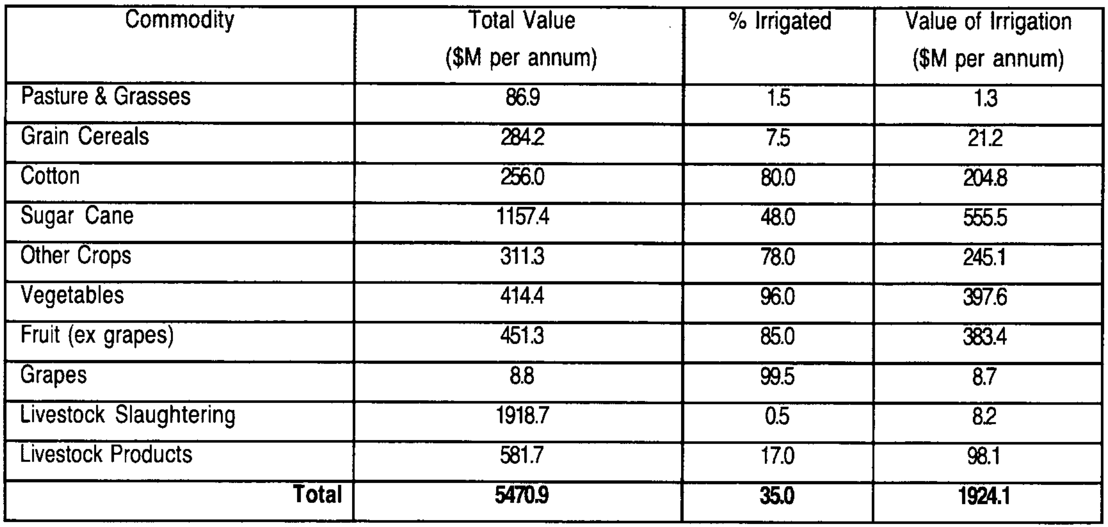
Issues in Farm Design and Water Management for Serious Irrigators

Steven R Raine
National Centre for Engineering in Agriculture,
University of Southern Queensland, Toowoomba

INTRODUCTION

Australia is the second driest continent on earth with a mean annual rainfall of 465 mm per annum (c.f. global average of 700 mm per annum). Hence, many parts of Australia receive inadequate rainfall to sustain cropping without irrigation. Annual water usage in Australia is approximately 14600 GL per annum of which 15% is used for domestic purposes, 10% is used for industrial purposes, and 75% is used for agricultural purposes (Vandeloo, 1997). The total irrigated area in Australia has increased five fold over the last 40 years to approximately 2.5 Mha with 80% of this area located within the Murray-Darling Basin. The sugarcane industry (~172000 ha) is currently the largest irrigated sector in Queensland based on area irrigated (total ~ 404000 ha). However, the horticultural sector provides the largest value of irrigated production (Table 1). Other major irrigation sectors include the cotton and dairy industries.

Table 1: Value of agricultural products produced by irrigation in Queensland.



Commodity	Total Value ($M per annum)	% Irrigated	Value of Irrigation ($M per annum)
Pasture & Grasses	86.9	1.5	1.3
Grain Cereals	284.2	7.5	21.2
Cotton	256.0	80.0	204.8
Sugar Cane	1157.4	48.0	555.5
Other Crops	311.3	78.0	245.1
Vegetables	414.4	96.0	397.6
Fruit (ex grapes)	451.3	85.0	383.4
Grapes	8.8	99.5	8.7
Livestock Slaughtering	1918.7	0.5	8.2
Livestock Products	581.7	17.0	98.1
Total	**5470.9**	**35.0**	**1924.1**

(NSW Irrigator's Council, 1997)

(*Source:* Queensland Irrigation Technology Steering Committee, 1998. p19)

Irrigation in Australia has been variously labelled as either grossly inefficient or amongst the most efficient in the world. Despite the fact that the truth is obviously somewhere between these extremes, there is mounting evidence that irrigation water use efficiency is improving as farmers respond to the economic pressures of diminishing returns and higher input costs. An increasing focus on irrigation efficiency has also occurred due to the relatively low availability and reliability of water supplies during the drought years experienced in the 1990s and a range of external forces including community pressure to increase environmental flows and reduce off-farm irrigation impacts (e.g. pesticide/fertiliser/sediment runoff and groundwater contamination). This paper provides an introduction to irrigation efficiency in commercial agriculture, highlights some of the confusion regarding the terms used in the irrigation efficiency debate, discusses the factors influencing irrigation efficiency and demonstrates the effect of on-farm irrigation design and management practices on water use efficiency.

Are you in the race? Rural Property Conference 2000,
Australian Property Institute. 17-18th March, Toowoomba.

IRRIGATION EFFICIENCY IN CONTEXT

The efficiency of Australian irrigated agriculture was extensively discussed by Smith *et al.* (1983) who concluded that: "O*verall irrigation agriculture operates at about 25% of its theoretical potential and application of current technology could probably raise this to 50%".* While the Smith *et al.* (1983) comment includes inefficiencies within the off-farm water catchment and distribution systems, it also acknowledges that significant inefficiencies commonly occur in the on-farm management component of the system. Perhaps more importantly, particularly in relation to proving or disproving the "myth" of inefficiency they commented that at that time there was *".... a disturbing lack of published studies on these inefficiencies and their cost to the nation."*

Despite these comments in the early 1980s, wide spread investigations of irrigation efficiency at the field and whole farm scale have only recently been advocated and only a small number of detailed studies of individual farms have been conducted in the sugar and cotton industries. Commercial furrow application efficiencies in the Queensland sugar industry have been found to range from 14-90% for single irrigations and from 31-62% for seasonal applications (Raine and Bakker, 1996). Similarly, Cull *et al*. (1986) estimated that whole farm irrigation efficiencies in the cotton industry averaged ~75% while Hearn *et al*. (1997) found whole farm efficiencies as low as 25%. Similarly, Smith (1988) reported that application efficiencies of 30-50% had been found on cotton farms and 40-80% on vineyards. The potential efficiency of micro-irrigation systems is often quoted as greater than 90%. However, Shannon *et al.* (1996) found that drip irrigation application efficiencies for sugarcane under commercial conditions in the Bundaberg area ranged from 30 to 90%. Given the nature of the system, these losses were most likely from over irrigation and deep percolation. Hence, it would appear that commercial irrigation efficiencies in general are highly variable with the ability to achieve high levels of efficiency being more a function of the management of the system rather than some inherent property of the application method.

The effect of low irrigation efficiencies is commonly viewed solely as a loss in the input water costs (ie. principally water/pumping costs). In most cases, the input cost of the irrigation water is a relatively minor component of the overall production costs and irrigators perceive there is little direct economic benefit to investing in improved efficiencies. This has been commonly cited as the reason some irrigators fail to improve efficiencies and is the basic assumption underlying community calls to increase the price of water allocations. However, the real cost of inefficiencies in irrigation water use should be estimated based on the value of lost production opportunities, the costs of associated input wastage (ie. fertiliser/pesticide inefficiencies) and the cost of any external impacts (ie. environmental impacts). For example, where a cotton farm has excess land available for production but is water limited, inefficiencies in water use result in less land being irrigated than would otherwise be possible. In this case, a change in irrigation practice which results in a 10% increase in water use efficiency would enable an ~11% increase in irrigated area with a consequent increase in overall production and returns. Even on farms which are land limited (ie. the whole productive area is already irrigated) increasing water use efficiencies increases the opportunity for more frequent and appropriate irrigation scheduling resulting in increased yields or product quality (particularly important in horticultural crops). As we move towards a tradeable water market, there is also the potential to sell/lease water entitlements which are excess to current needs. Hence, as one of the major input variables in agricultural production, the efficiency of water use has a significant effect on the potential to increase (or decrease) productivity and returns. However, as the efficiency of irrigation water use is most closely associated with management practice these returns may vary greatly depending on the irrigation strategy and management acumen of the operator.

WHAT DO WE MEAN BY IRRIGATION EFFICIENCY?

One of the major communication barriers within the irrigation and water management debate is the inappropriate use of terms and data. A large number of indices for the assessment of irrigation performance have been proposed. Willardson (1972) stated that at least 20 definitions of irrigation efficiency existed at that time. However, this number had increased to more than 30 by the late 1980s (Walker and Skogerboe, 1987). It is difficult (if not impossible) to adequately evaluate irrigation performance using a single parameter. At the system or whole farm level, a range of performance parameters may be appropriate depending on the spatial and temporal boundary conditions established for the evaluation. Similarly, at the field scale, the adequacy of the irrigation is dependent on the water stored within the crop root zone, the water percolating below the roots zone, surface runoff or tailwater, the uniformity of the applied water distribution, and the unused storage capacity of the soil profile following irrigation (Walker and Skogerboe, 1987). Some terms reflect the performance only of the agronomic component of the system while others focus on the engineering component. Data on system performance may include either all of the sources of water to the crop (eg. irrigation + rainfall + soil water) or only the irrigation component (either delivered to the farm gate or applied to the field). In all cases, it is important that the terms used are well defined to remove confusion. If in doubt, ask!

The following water management sub-systems may exist on irrigated farms:

- Supply systems (e.g. harvesting or lifting from river and captured overland flows; pumping groundwater from bores; and/or supply from irrigation scheme dams, channels and/or pipes);
- On-farm storage systems (e.g. ring tank storage cells; buffer holding dams; or catchment dams);
- On-farm distribution systems (e.g. earthen channels; gated pipes; or pressurised enclosed systems);
- Application systems (e.g. surface, spray, micro-systems); and
- Recycling systems (e.g. tail drains and tail water recycling channels and utilising supply harvesting pumps; or catch drains feeding into holding dams).

The efficiency of water use can be defined for each of these sub-systems based on the volumetric water inputs and outputs, or uses and losses (see Table 2). Potential volumetric losses (or inefficiencies) within each of sub-systems must be measured or estimated accurately to quantify whole farm water use efficiency. Volumetric measurements of the water flows into and out of each unit are required and include groundwater and riverine flows, scheme supplies, rainfall, seepage (or percolation), evaporation, overland flows and tailwater recycling.

Table 2: Recommended Irrigation Efficiency Definitions for Australia
(from Barrett Purcell and Associates, 1999)

Term	Definition
Overall Project Efficiency (E_p)	$\frac{\text{Irrigation water available to crop}}{\text{Total inflow into system supply}}$
Conveyance Efficiency (E_c)	$\frac{\text{Total outflow from system supply}}{\text{Total inflow into system supply}}$
Distribution Efficiency (E_d)	$\frac{\text{Water received at field inlets}}{\text{Total outflow from system supply}}$
Field Application Efficiency (E_a)	$\frac{\text{Irrigation water available to crop}}{\text{Water received at field inlet}}$

A major concern with the sole use of volumetric efficiency terms (eg. Table 2) for irrigation evaluation is that they do not provide any assessment of the overall irrigation performance in relation to crop production and economic returns. Terms such as "crop water use efficiency" and "marginal crop water use efficiency", which include both yield and volumetric components, have traditionally been used by many industries (e.g. sugar, cotton, dairy) to set production benchmarks and identify poor returns from irrigation (see Table 3). While these terms are not strictly measures of "efficiency", they are valid performance measures and are valuable in benchmarking system performance. However, the wide range of potential indices available serves to highlight that *an essential component of all irrigation performance evaluations, regardless of the irrigation efficiency term or water use efficiency index used, should be the explicit definition of all terms such that it is clear which values are being measured and reported.* This is important at both the local and international level as there are already too many varying "accepted" definitions to assume that an audience will know which definition is being used.

Table 3: Examples of Water Use Efficiency Indices for the Evaluation of Irrigation Performance
(after Barrett, Purcell and Associates, 1999)

Term	Definition
Gross Production Water Use Index	$\frac{\text{Total Product (kg)}}{\text{Total Water Applied (ML)}}$
Irrigation Water Use Index	$\frac{\text{Total Product (kg)}}{\text{Irrigation Water Applied (ML)}}$
Marginal Irrigation Water Use Index	$\frac{\text{Marginal Production due to irrigation (kg)}}{\text{Irrigation Water Applied (ML)}}$
Crop Water Use Index	$\frac{\text{Production (kg)}}{\text{Evapotranspiration (mm)}}$
Gross Production Economic Water Use Index	$\frac{\text{Economic return (\\$)}}{\text{Total Water Applied (ML)}}$
Irrigation Economic Water Use Index	$\frac{\text{Economic return (\\$)}}{\text{Total Irrigation Water Applied (ML)}}$
Marginal Irrigation Economic Water Use Index	$\frac{\text{Marginal return due to irrigation (\\$)}}{\text{Irrigation Water Applied (ML)}}$
Crop Economic Water Use Index	$\frac{\text{Economic Return (\\$)}}{\text{Evapotranspiration (mm)}}$

FACTORS INFLUENCING IRRIGATION EFFICIENCY

The main objective of irrigation management is to supply a desired amount of water to a crop at a specified time. Hence, effective irrigation management requires some knowledge about how much water to apply (the irrigation volume) and when to apply the water (the irrigation schedule). Adequate prediction of the irrigation volume and schedule requires both the on- and off-farm water managers to have some knowledge of the water availability within the crop root zone and the rate of crop water use.

Irrigation design and management decisions are the result of a complex interaction of many variables which are rarely consistent between individuals. Irrigation management is also often expected to maximise efficiencies and minimise the labour and capital requirements of the particular irrigation system without adversely affecting the growing environment for the plant (Walker and Skogerboe, 1987). Supply volume and rate constraints imposed at the system level may significantly affect the performance and efficiency at the farm and field scales. Hence, irrigation design and management practices are influenced by a wide range of factors including:

- agronomic (e.g. crop responses to climatic and soil moisture variables);
- environmental (e.g. climate, soils, topography);
- social (e.g. experience, education, labour availability);
- economic (e.g. capital availability, operating costs, returns from product);
- historical (e.g. existing infrastructure, previous farming systems);
- hydrological (e.g. river flow regimes, groundwater issues; surface flow harvesting);
- engineering constraints (e.g. hydraulic design limitations on pumps, pipes and storages, supply capacities);
- regulatory policy (e.g. legislation on access to river, surface and groundwater); and
- administrative procedures (e.g. licencing requirements, ordering of water supplies).

Many managerial actions are dependent on the specific type of irrigation application system or design available. Other decisions (e.g. frequency of irrigation, depth of water to be applied) are common to all systems and dependent on the nature of the crop, soil and environmental conditions. However, in all cases, irrigation managers are faced with the need to identify practical and economic answers, in a situation where the system (biological, engineering and economic) is exceedingly complex, its interactions and inter-relationships are complicated or imperfectly understood, the available data is often inadequate, and the specific goal is inadequately defined (e.g maximise marginal or total profit, or biological returns per unit of water/land/other input?). Even at the single field scale, the irrigator requires a wide range of input information (much of which is either inadequate or imperfectly understood) in order to implement an appropriate irrigation management plan. A more detailed review of irrigation and water use efficiency, including a discussion of the design and management options to improve performance from an Queensland focus is given in Raine (1999). A brief summary of the major factors influencing efficiency is provided below.

Factors Influencing the Efficiency of Storage, Distribution and Recycling Systems

The operational efficiency of storage, distribution and recycling structures is influenced by both design and management variables as well as environmental factors. In particular, consideration should be given to:

- evaporative surface area/volume ratio;
- wind velocity/surface protection;
- seepage/drainage rate (function of construction material and head);
- period of storage/distribution;
- dead volumes; and
- capturability of tailwater.

Factors Influencing the Efficiency of Application Systems

The ability of the in-field irrigation system to apply water efficiently and uniformly to the irrigated area is a major factor influencing the agronomic and economic viability of the production system. The performance evaluation of in-field application systems can be divided into the two major components of water losses and uniformity of application. Although both components are influenced by system design and management practices, the losses are predominantly a function of management while the uniformity is predominantly a function of the system design characteristics (Solomon, 1993).

However, the irrigation system is not usually expected to supply all of the moisture required for crop production as some of the crop's water requirements may be met by pre-season moisture stored in the soil profile, rainfall during the growing season, or from shallow groundwater tables. Hence, optimal irrigation management requires not only a knowledge of the characteristics of the application system but an understanding of the environment in which it operates.

The major sources of water loss by in-field application systems are due to evaporation (from either the atmosphere, free water surface or soil surface), deep drainage or by surface run-off. The dominant loss mechanism is closely related to the method of application but in all cases may be substantially reduced by the adoption of appropriate management practices. Typical application efficiencies (Table 4) for the most common irrigation systems indicate that higher efficiencies can normally be expected through the use of micro-irrigation or low pressure overhead spray systems. However, substantial water losses are often found where these systems are being used with inappropriate management practices (e.g. excessive watering periods, irrigating in high wind). In most cases, the potential distribution uniformity in a well designed and maintained application system is greater than 85% (Table 5). Other influences on the efficiency of the application system include:

- infiltration characteristics (soil, wetted area, water quality, compaction);
- application technique;
- field layout;
- application rate and period (continuous, surge/pulse, cut-back); and
- application spatial pattern (bed size, row spacing, emitter spacings).

Table 4: Typical efficiencies for irrigation application systems
(after Solomon, 1993)

Type of system	Application efficiencies (%)
Surface Irrigation	
Basin	80-90
Border	70-85
Furrow	60-75
Sprinkler Irrigation	
Hand move or portable	65-75
Travelling gun	60-70
Centre pivot & Linear move	75-90
Solid set or Permanent	70-80
Micro-irrigation	
With point source emitters	75-90
With line source emitters	70-85

Table 5: Irrigation systems and potential whole field distribution uniformities
(from Burt, 1995)

Irrigation System	Potential Field DU (%)
Permanent under tree sprinkler	94
Linear move	92
Orchard drip	90
Sloping furrows	89
Level furrows	87
Border strip	85
Row crop drip	90
Hand move sprinkler (w alt. sets)	85
Hand move sprinkler (w/o alt. sets)	75

Factors Influencing Crop Water Use Indices

Crops have a variable capacity to extract water from the soil and to convert this water into plant products. Hence, the efficiency of crop water use varies considerably between different crop species. However, there are also considerable differences in crop water use between different varieties (or cultivars) of the same species. Other factors affecting the crop water use include cultural practices (e.g. planting date, spacing, cultivation practice, mulching), irrigation management (e.g. irrigation interval, prior plant stress, water placement) and environmental influences (e.g. nutrition, radiation, temperature, drainage).

IRRIGATION DESIGN AND MANAGEMENT OPTIONS TO IMPROVE WATER USE EFFICIENCY

The strategies to improve water use efficiency revolve around the central themes of reducing losses out of the system (ie. evaporation, deep drainage, run-off), reducing crop evapotranspiration during non-critical periods, and increasing the effectiveness of stored soil moisture and rainfall during the season. The efficiency of storage and distribution systems is influenced most significantly by the system design and construction techniques (influences evaporation/seepage/failure). However, other factors include the use of cell water management, the location of wind breaks, the use of recycling systems to capture run-off and potentially, the use of floating materials to reduce evaporative losses. Water savings at the field scale may be achieved by:

- maximising the pre-season soil moisture storage;
- minimising evaporation losses;
- minimising crop transpiration while maintaining agronomic and economic goals;
- maximising net effective precipitation during the growing season;
- improving the application efficiency of the irrigation application system; and
- reducing deep percolation to only that necessary for leaching.

The specific strategy adopted will be dependent on the individual farm, crop and management constraints. However, some options include:

Surface systems	*Spray systems*	*Micro-systems*
Inflow rate	Larger droplets	Emitter spacing/flow rates
Cut-off time	Cut-off time	Cut-off time
Agronomic practices	Spray spacing/pressures/height	Surface vs sub-surface
Alternate furrow	Don't irrigate in high winds	Deficit irrigation
Surge	Deficit irrigation	

Because of the wide range of factors affecting irrigation efficiency it is necessary to measure the efficiency of the various components to manage the whole of the system effectively. The following examples demonstrate the effect of design and management practices on the nature and efficiency of the in-field application system. While the examples provided are for surface irrigated systems, the same principles and effects are common to all types in-field application systems.

Example of evaluating design options for surface irrigation

Field layout and irrigation design is not normally infinitely variable for any given location. In most cases, the soils, topography, water inlet structures and capacity, location of cadastral boundaries, and agronomic and access considerations impose some limitations on the layout. Hence, irrigation designers are normally interested in comparing the performance of specific alternative layouts. While the capital costs and management benefits associated with alternative layouts may be readily assessable, the costs of inefficient, inadequate or non-uniform water application have been more difficult to ascertain and have been rarely included in design assessments. Where adequate input data is available, simulation modelling provides a means for the assessment of alternative designs and layouts. For example, generic guidelines developed using simulation modelling have been used in the recent development of surface irrigated farms in the Burdekin River Irrigation Area (BRIA). However, as the soils and topography of the new irrigation farms in this area were known prior to development, along with the practical limitations associated with water inlet location, inlet capacity and cadastral boundaries, simulation modelling was also able to be used to provide more accurate and detailed information to assist in assessing specific alternative layouts during the field design phase.

For one furrow irrigated farm developed in the BRIA during 1995 (Figure 1), alternative field designs included field lengths ranging from 500-1700 m and slopes ranging from 0.0009 to 0.002. However, the range of water application rates for the site was restricted to between 0.5 and 2.4 l/s/furrow and due to agronomic considerations the irrigator did not want to apply water to individual furrows for in excess of 36 hours. Using both a first irrigation and average seasonal infiltration characteristic for the dominant soil type, a simulation model could have been used to identify the effect of the alternative design options (Figure 1) on expected irrigation performance. For each field length, the optimal water application rate was selected based on the highest application efficiency that resulted in greater than 95% requirement efficiency and 80% distribution uniformity. The results (Table 6) indicated that the long furrow (1700 m) option was not feasible within the design constraints due to excessive watering periods. However, this option was also found to result in a low application efficiency (43%) and an inadequate distribution uniformity for the first irrigation. The second option was found to achieve better application efficiencies and distribution uniformities than the first option and perform adequately within the design constraints (Table 6). However, these simulations also highlighted other management considerations. Optimal performance for the preferred design option was found to require the application rate to be varied from 2.4 l/s/furrow for the first irrigation to between 0.5 and 0.8 l/s/furrow for later irrigations depending on the field length. Similarly, because of the low infiltration rates at this site, the optimal cut-off times were longer than the advance times resulting in potential improvements of between 4.7 and 28.2% in application efficiency if a recycling system was installed.

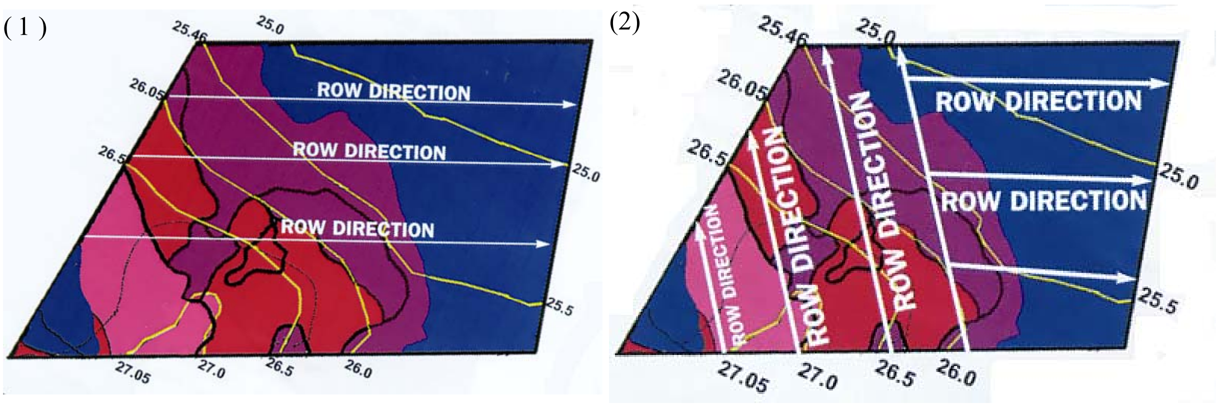

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Figure 1: Alternative field layouts of Block 271 in the Burdekin River Irrigation Area
(*after McMahon, 1995*)

Example of evaluating management options for surface irrigation

The performance of surface irrigation is significantly affected by the management practices adopted. However, commercial irrigators often find it difficult to identify water application rates and cut-off times that optimise irrigation performance. Similarly, many irrigators find it difficult to visualise the effect of various irrigation management practices on the performance parameters (application efficiency, requirement efficiency and distribution uniformity). Field evaluations and computer simulations have been used (e.g. Raine and Bakker, 1996; Raine *et al.* 1997) to assess the potential improvements in irrigation performance achievable through the modification of the water application

Table 6: Irrigation performance of design options for Block 271 in the Burdekin River Irrigation Area

	Option 1 - 1700 m furrows		Option 2 - 1000 m furrows		Option 2 - 500 m furrows	
	First Irrigation	Seasonal Average	First Irrigation	Seasonal Average	First Irrigation	Seasonal Average
Application rate (l/s/furrow)	2.4	1.1	2.4	0.8	2.4	0.5
Advance time (min)	1788	1557	678	907	236	563
Cut-off time (min)	1820	2400	700	1760	279	1630
Application Eff (%)	43.7	72.1	67.0	77.2	81.6	66.8
Requirement Eff (%)	100	99.5	100	96.6	97.5	96.8
Distribution Unif (%)	72.9	83.8	78.6	87.6	88.8	92.2
App. Eff with recycling (%)[a]	46.0	83.1	71.7	94.9	94.5	95.0

[a] assuming 90% recovery

rate and cut-off time in both furrow irrigated cotton and sugarcane. In this example, irrigation design and management practice data were collected from cotton growers in the "Weemah" irrigation area near Emerald during 1997. The majority of cotton in this area is grown on cracking clay soils using a typical field layout approximately 770 m in length and a slope of 0.0021. Water is commonly applied at approximately 2 l/s/furrow and is often continued to be applied after full advance to ensure that it "soaks at the bottom end". Under these management conditions, water will be typically applied for about 15 hours producing a requirement efficiency of 100%, a maximum inundation period in excess of 16 hours and an application efficiency of approximately 70% if the tailwater is not recycled (Table 7). However, this management regime would appear to be less than optimal given that many cotton irrigators believe that inundation in excess of 8 hours is detrimental to crop productivity. Similarly, although some farms in this area have tailwater recycling facilities, it is always better to reduce tailwater losses to a minimum given that it is virtually impossible to get a 100% efficient recycling system and that there is a substantial cost associated with pumping and storing tailwater.

Table 7: Effect of water application rate and cut-off time on irrigation performance for 770m furrows on a cracking clay (Weemah).

	Typical management	Cut-off when reached end	Cut-off one hour before end	Increased application rate	Increased application rate and cut-off when reached end
Application rate (l/s/furrow)	2	2	2	4	4
Cut-off time (min)	918	745	685	552	377
Inundation time (min)	990	810	732	600	396
Application Eff (%)	69.8	85.8	93.1	58.1	84.2
Requirement Eff (%)	100	99.5	98.7	100	98.6
Dist Uniformity (%)	93.3	91.7	90.4	96.8	95.4

Under these conditions, reducing the irrigation water cut-off time to equal the advance time for the water to reach the end of the field was found to produce a 16% increase in application efficiency but would only reduce the inundation time to less than 14 hours (Table 7). By turning the off the water one hour before the water advance reached the end of the furrow application efficiency could be increased to approximately 93% but the inundation time would still be in excess of 12 hours. The most effective method of reducing inundation time by water management is to increase the application rate. In this case, doubling the application rate to 4 l/s/furrow and turning the water off immediately the advance reached the field end would reduce the maximum inundation time to less than 7 hours (Table 7). This management regime would also result in application efficiencies in excess of 80%

without recycling and still maintain a requirement efficiency of greater than 98%. However, for this application rate, turning the water off before the water reached the end of the field is likely to result in a decrease in the requirement efficiency to a level which would be unacceptable to most growers.

Example of an economic evaluation for surface irrigation designs

Irrigation performance evaluation data is important in assessing the costs and benefits of alternative irrigation designs and management practices. As the cost effectiveness of alternative designs are sensitive to the price of the water, application efficiencies and distribution uniformities, it is important that these parameters are accurately quantified in comparative analyses. In an evaluation of irrigation layouts for an existing 12 ha irrigation block growing sugar cane in the Burdekin Delta area (Raine and Shannon 1996), simulation data was obtained from irrigations conducted at the site with the layout choices constrained to either a single 12 ha block with 600 m furrows or two, 6 ha blocks with 300 m furrows. The simulations indicated that decreasing the furrow length from 600 m to 300 m for this site would decrease the volume of irrigation water required to be applied from 1.78 to 1.03 ML/ha/irrigation. The longer furrow length was also found to have lower distribution uniformities. Production losses associated with decreased uniformity were included in the subsequent cost-benefit analysis along with the headworks costs for both permanent and temporary in-field water conveyance systems. Labour, tillage and harvesting costs were not included in the analysis (Table 8). This analysis indicated that the shorter furrows would produce an increased net benefit of up to $210/ha/year when compared to the longer furrows. However, it should also be noted that the economic feasibility of these alternative designs is sensitive to the volume of water saved and the improvements in distribution uniformity. Hence, the accurate quantification of these physical benefits is an important prerequisite to the determination of economic feasibility.

Table 8. The annual costs and benefits associated with converting a 12 ha sugar cane block with 600 m furrow lengths into two, 6 ha blocks with 300 m furrow lengths
(after Raine and Shannon, 1996)

Item	Cost ($)
Benefits	
Water saving	2080
Production gains	2052
Total	4132
Costs (Option 1 - Permanent installation)	
Pipeline ($20250 depreciated at 6.7% p.a.)	1350
Risers ($3000 depreciated at 6.7% p.a.)	200
Fluming and cups ($610 depreciated at 20% p.a.)	122
Headland production (0.2 ha)	868
Total	2540
Costs (Option 2 - Temporary installation)	
Supply fluming ($2100 depreciated at 20% p.a.)	420
Fittings ($1000 depreciated at 20% p.a.)	200
Fluming and cups ($610 depreciated at 20% p.a.)	122
Headland production (0.2 ha)	868
Total	1610

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