A decision support tool for the design, management and evaluation of surface irrigation systems

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Abstract
The adoption of improved surface irrigation design and management practices is inhibited both by a low awareness amongst irrigators of the variables affecting irrigation performance and the difficulty of quantifying the benefits associated with alternative practices. Simulation modelling may be used to address both of these issues. This paper reports on the use of the surface irrigation model SIRMOD to demonstrate the principles of surface irrigation performance and provide quantitative data on the performance of alternative irrigation design and management practices to irrigators and other decision makers. The potential to use this data in economic assessments is also presented.

INTRODUCTION

Surface irrigation uses in excess of 70% of the water used for irrigation in Australia and is the dominant method of irrigating both pastures and crops. While well designed and managed surface irrigation systems may have application efficiencies of up to 90% (Anthony, 1995), many commercial systems have been found to be operating with highly variable efficiencies at significantly lower levels. For example, commercial furrow application efficiencies in the Australian 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, application efficiencies of 30-50% have been found on cotton farms and 40-80% on vineyards (Smith 1988).

The efficiency of surface irrigation is a function of the field design, infiltration characteristic of the soil, and the irrigation management practice. However, the complexity of the parameter interactions within each of these main influences makes it difficult for irrigators to identify optimal design or management practices under commercial conditions. Raine and Bakker (1996) identified a range of methods to improve water application efficiencies in the sugar industry including the use of appropriate furrow lengths, irrigation cut-off times and water application rates. However, one of the main constraints to the improvement of surface irrigation performance has been the inability to provide site specific guidelines without extensive field experimentation. While the value of field research should not be underestimated, it is expensive and time consuming with results limited to the range of conditions investigated.

Another major obstacle to the adoption of improved management practices at the farm level is a recognition by the irrigator of the benefits associated with implementation. Simulation modelling provides an opportunity to identify more efficient practices and assess the benefits for a fraction of the time and cost of field trials. While irrigation earthworks, water diversion, storage and distribution works are routinely designed in Australia using well defined parameters and models, the surface irrigated field is often poorly designed with little use of either field measured or model data. While a wide range of irrigation design and management tools have been developed to assist irrigation researchers and managers investigate irrigation performance at the catchment (Prajamwong *et al*. 1997) and field scales (Strelkoff 1985,; Rayej and Wallender, 1987; Walker and Humphreys, 1983), a survey by Maheshwari and Patto (1990) found that most Australian irrigation designers "guess" the design variables which dominate the performance of surface irrigation. This is of particular concern given the ready availability of simulation software and design manuals. Similarly, few irrigators or extension officers use any form of simulation model or decision support aid to optimise the performance of individual irrigations by selecting flow rates and times to cut-off to maximise performance. This paper provides an introduction to one of the more commonly used surface irrigation models and presents case studies which demonstrate its potential for use as a decision support aid to assist both irrigators and consultants in the design and management of surface irrigation systems.

SIRMOD

The irrigation model SIRMOD (Walker, 1997) simulates the hydraulics of surface irrigation (border, furrow and basin) at the field scale. The principle role of SIRMOD is the evaluation of alternative field layouts (field length and slope) and management practices (water application rates and cut-off times). It was originally developed for research and teaching purposes and has been used successfully at both Utah State University and the University of Southern Queensland in these roles since 1987. It incorporates a hydrodynamic solution to the St Vernant equations using a eulerian integration of space and time, and a numerical solution of the resulting non-linear algebraic equations. The ability of SIRMOD to accurately assess irrigation performance of furrows and borders has been well established by the developers of the model (for example Walker and Humphreys, 1983) and confirmed under Australian conditions by Maheshwari and McMahon (1993a, 1993b) and McClymont *et al.* (1996).

While early versions of SIRMOD were limited in application by a lack of user-friendliness, the latest version (SIRMOD II) has been produced in Windows95 format and equipped with a highly interactive view-editing interface and on-screen graphics. It also incorporates a simplified field design module and a "two point" solution for the calculation of infiltration parameters from irrigation advance data. The package allows the user to specify furrow, border, or basin configurations with free draining or blocked downstream boundary conditions under continuous or surged flow regimes and cutback options. Input data requirements for the simulation component include field length, slope, infiltration characteristics (or advance data), target application depth, water application rate, Manning's resistance and furrow geometry. Output includes a detailed advance-recession trajectory, distribution of infiltrated water, volume balance, run-off hydrograph, depth of water flow at the end of the field, application and requirement efficiencies, and distribution uniformities (Figures 1 and 2).

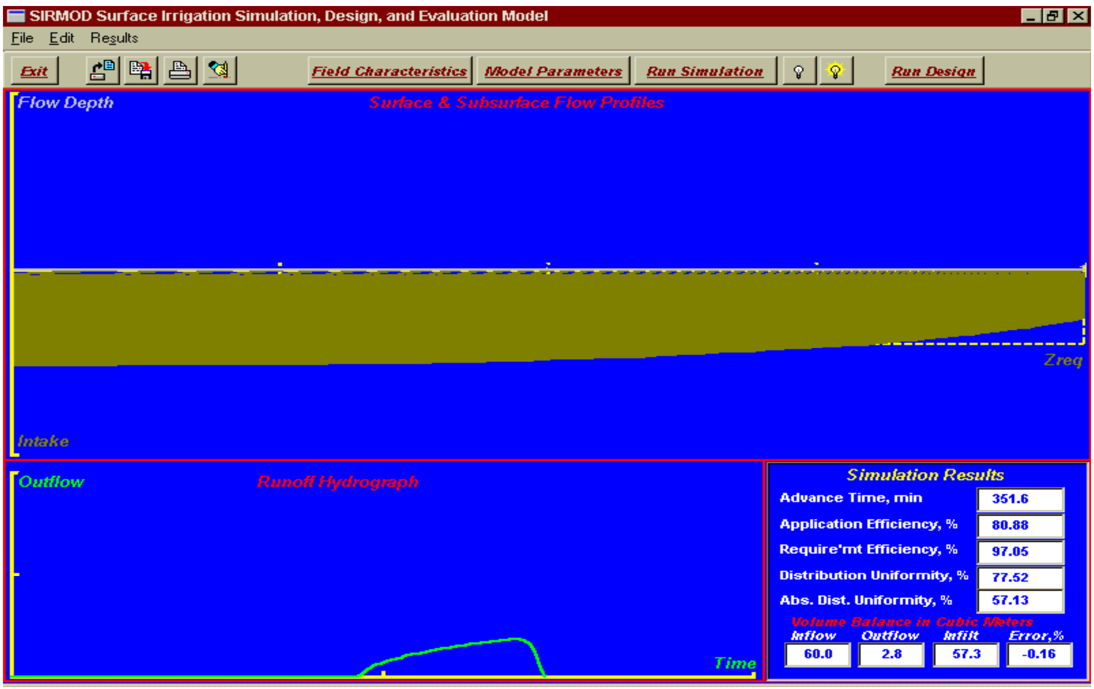

Figure 1 SIRMOD Main output screen

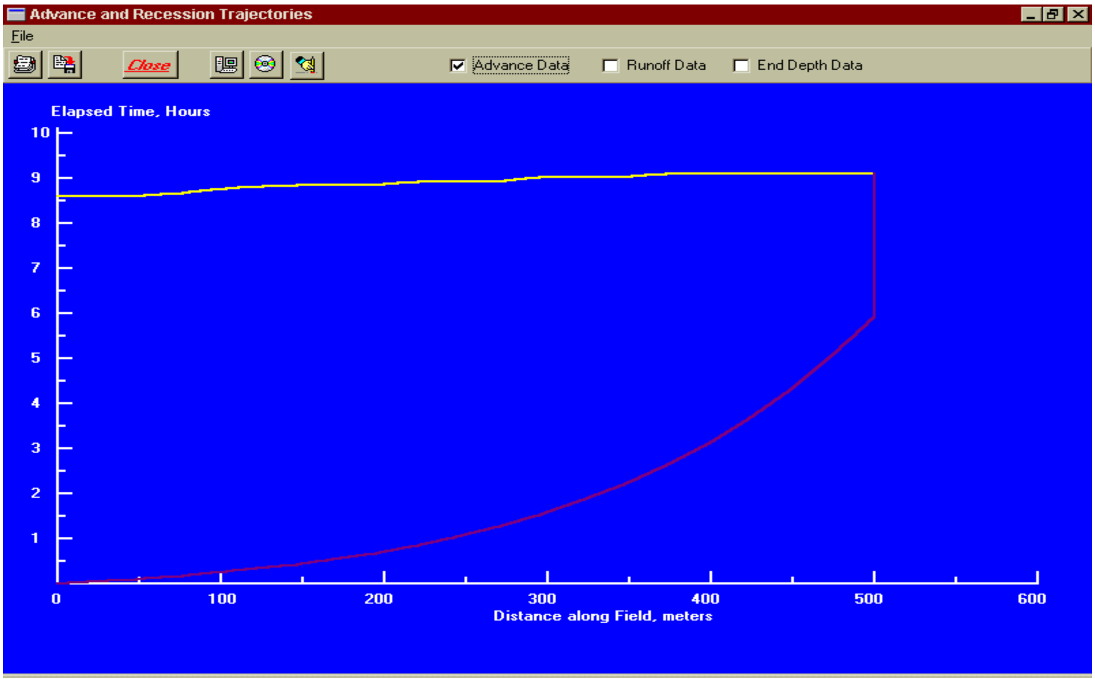

Figure 2. **SIRMOD Advance-Recession Trajectory Output Screen**

IDENTIFYING DESIGN OPTIONS USING SIRMOD

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 inputs are available, simulation modelling provides data on the performance of surface irrigation suitable for the assessment of alternative designs. For example, generic guidelines developed using simulation modelling are used in the current development of irrigation farms in the Burdekin River Irrigation Area (BRIA). However, as the soils and topography of all new irrigation farms in this area are known prior to development, along with the practical limitations associated with water inlet location, inlet capacity and cadastral boundaries, simulation modelling can also be used to provide more accurate and detailed information to assist in assessing specific alternative layouts during field design phase.

For one furrow irrigated farm developed in the BRIA during 1995 (Figure 3), 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, SIRMOD could have been used to identify the effect of the alternative design options (Figure 3) 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 1) 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 1). However, these simulations also highlighted other management considerations. Optimal performance for the preferred

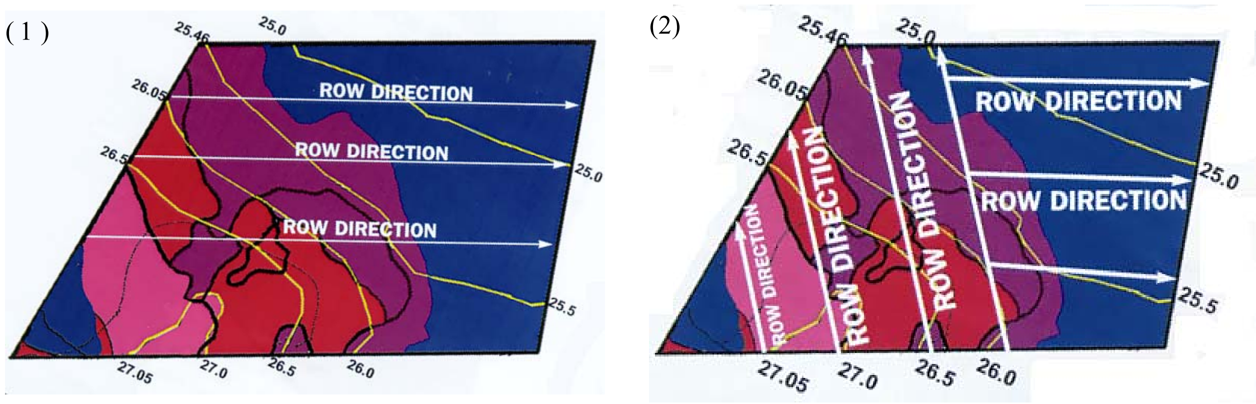

Figure 3. Alternative field layouts of Block 271 in the Burdekin River Irrigation Area
(*after McMahon, 1995*)

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.

Table 1. 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

IDENTIFYING MANAGEMENT OPTIONS USING SIRMOD

The performance of surface irrigation is significantly affected by the management practices adopted. However, commercial irrigators 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). SIRMOD has been used (Raine and Bakker, 1996; Raine *et al.* 1997) to assess the potential improvements in irrigation performance achievable through modification of the water application rate and cut-off time in furrow irrigated sugarcane. However, it has also been used by the authors to demonstrate to irrigators in both Australia and the USA the principles of irrigation management and the options to improve irrigation performance. Prior to one such demonstration to Emerald irrigators during 1997, irrigation design and management practice data had been collected from cotton growers in the "Weemah" irrigation area. This survey identified that 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, SIRMOD predicts that 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 3). 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 most 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 3. 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

The effect of altering water cut-off time and application rate on irrigation performance was investigated for a typical Weemah field (Table 3). Reducing the cut-off time to equal the advance time for the water to reach the end of the field would produce a 16% increase in application efficiency but would only reduce the inundation time to less than 14 hours (Table 3). 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 would reduce the inundation period to approximately 10 hours if the water was allowed to continue to run after reaching the bottom end of the field. However, where the water was turned off immediately the advance reached the field end, the maximum inundation time would be reduced to less than 7 hours. 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.

ECONOMIC EVALUATIONS USING SIRMOD OUTPUT

The irrigation performance output provided by SIRMOD and other simulation models is also 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) SIRMOD input parameters were 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. SIRMOD 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.

Table 2. 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

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 2). 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.

CONCLUSION

Simulation models allow irrigators and water managers to rapidly experiment with design and management variables to investigate irrigation performance. The simulation model SIRMOD has been shown to be a useful tool to investigate the performance of surface irrigation at the field scale during both the initial design and subsequent management phases. It also provides output data that is necessary for the economic evaluation of surface irrigation practices. The user-friendly interface of SIRMOD and the graphical output also provides for easy interpretation of irrigation performance which should make it a useful decision support tool for both irrigation designers and irrigation managers.

REFERENCES

Anthony, D. (1995). On-farm water productivity, current and potential: options, outcomes, costs. *Irrigation Australia* 10, 20-23.

Maheshwari, B.L. and McMahon, T.A. (1993a). Performance evaluation of border irrigation models for south-east Australia: Part 1, Advance and recession characteristics. *Journal of Agricultural Engineering Research* 54, 67-87.

Maheshwari, B.L. and McMahon, T.A. (1993b). Performance evaluation of border irrigation models for south-east Australia: Part 2, Overall suitability for field applications. *Journal of Agricultural Engineering Research* 54, 127-39.

Maheshwari, B.L. and Patto, M.J. (1990). Present status of border irrigation design in Australia. *Conference on Agricultural Engineering, Toowoomba*. Institution of Engineers, Australia. 156-159.

McClymont, D., Raine, S.R. and Smith, R.J. (1996). The prediction of furrow irrigation performance using the surface irrigation model SIRMOD. *Proc. 13th Conference, Irrigation Association of Australia*, 14-16th May, Adelaide. pp10.

McMahon, G.G. (1995). Farm planning: starting from scratch. *Bureau of Sugar Experiment Stations Bulletin* 47, 3-5.

Pramjamwong, S., Merkley, G.P. and Allen R.G. (1997). Decision support model for irrigation water management. *Journal of Irrigation and Drainage Engineering* 123, 106-113.

Raine, S.R. and Bakker, D.M. (1996). Increased furrow irrigation efficiency through better design and management of canefields. *Aust. Soc. Sugar Cane Technologists*, 30 April-3rd May, Mackay, p119-124.

Raine, S.R. and Shannon, E.L. (1996). Improving the efficiency and profitability of furrow irrigation for sugarcane production. In "*Sugarcane: Research Towards Efficient and Sustainable Production* p211-2 (Eds JR Wilson, DM Hogarth, JA Campbell and AL Garside), CSIRO Division of Tropical Crops and Pastures, Brisbane.

Rayej, M. and Wallender, W.W. (1987). Furrow model with specified space intervals. *Journal of the Irrigation and Drainage Division, ASCE* 113, 536-548.

Smith, R.J. (1988). Irrigation in the 90's - Efficient, uniform and effective? *Institution of Engineers Southern Engineering Conference*, DDIAE, Toowoomba.

Strelkoff, T. (1985). *BRDRFLW: A mathematical model of border irrigation*. USDA-ARS. 100p.

Walker, W.R. (1997). *SIRMOD II. Irrigation simulation software*. Utah State University, Logan.

Walker, W.R. and Humphreys, A.S. (1983). Kinematic-wave furrow irrigation model. *ASCE Journal of Irrigation and Drainage Division* 109, 377-392.