A design and management tool to improve surface irrigation efficiency

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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%, many commercial systems have been found to be operating with highly variable efficiencies at significantly lower levels. 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 interactions makes it difficult for irrigators to identify optimal design or management practices under commercial conditions. 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.

Simulation modelling provides an opportunity to identify more efficient irrigation 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. A survey in 1990 found that most Australian irrigation designers “guess” the design variables which dominate the performance of surface irrigation. Similarly, few irrigators or extension officers currently 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 article 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 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. The ability of SIRMOD to accurately assess irrigation performance of furrows and borders has been well established by the developers of the model and confirmed under Australian conditions.

SIRMOD has been produced in Windows95 format and is equipped with on-screen graphics and a highly interactive view-editing interface. 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).

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. 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 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.

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 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 2). 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.

The effect of altering water cut-off time and application rate on irrigation performance was investigated for the “typical” Weemah field (Table 2). Turning the water off when the advance reached the end of the field would produce a 16% increase in application efficiency and reduce the inundation time to less than 14 hours (Table 2). Turning the water off one hour before the advance reached the end of the furrow could increase application efficiency to approximately 93% but the inundation time would still be in excess of 12 hours. One of the most effective methods of reducing inundation time is to increase the application rate so long as it does not produce erosion. For the “typical” Weemah field, increasing 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 (Table 2). 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, turning the water off before the water reached the end of the field at this application rate would be likely to result in a decrease in the requirement efficiency that would be unacceptable to most growers.

CONCLUSION

SIRMOD allows irrigators and water managers to rapidly experiment with design and management variables to investigate irrigation performance. This can be a useful tool to investigate the performance of surface irrigation without the time and cost associated with field experiments. For further information contact Dr Steven Raine on telephone (07) 4631 1691 or facsimile (07) 4631 2526.

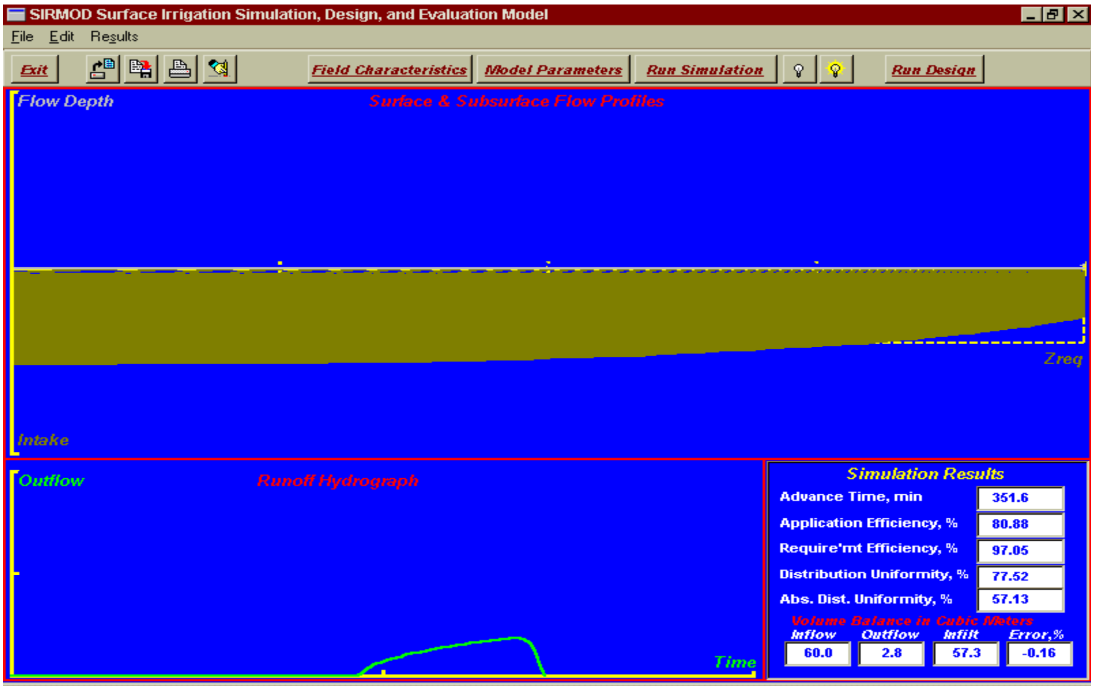

Figure 1 SIRMOD Main output screen

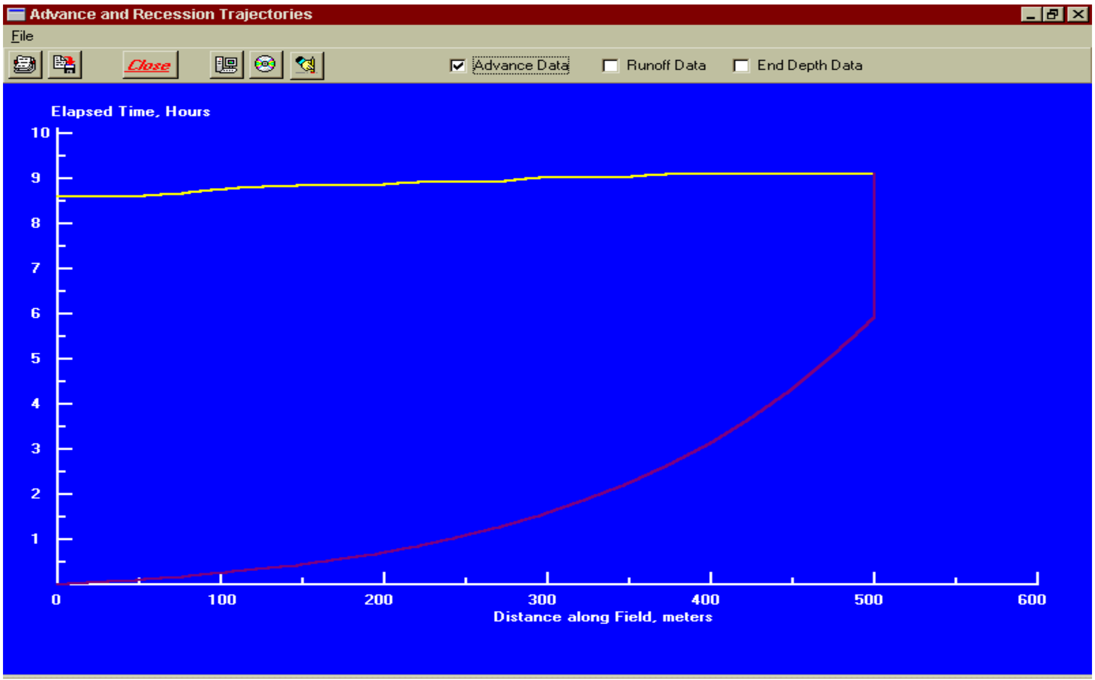

Figure 2. SIRMOD Advance-Recession Trajectory Output Screen

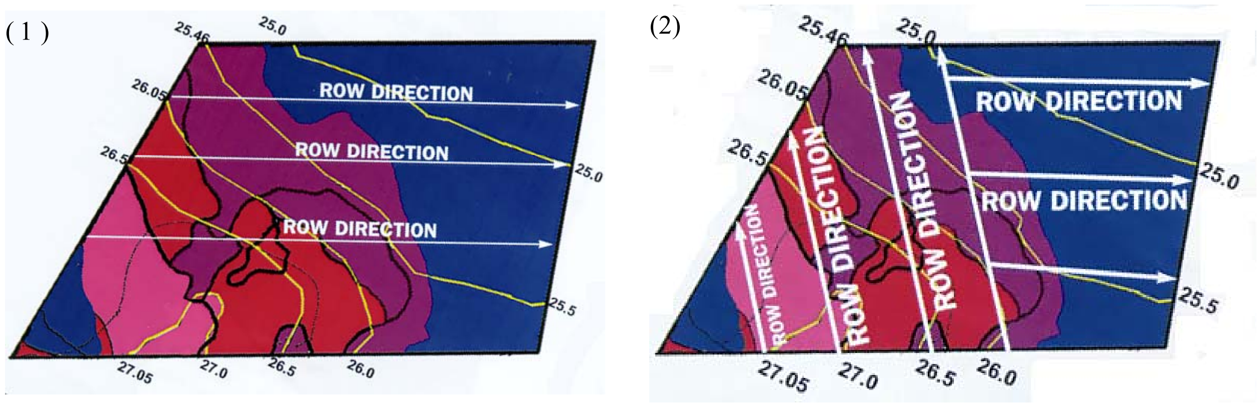

Figure 3. Alternative field layouts for a new farm in the Burdekin River Irrigation Area
(*after McMahon, 1994*)

Table 1. Irrigation performance of field design options

Management Option	Option 1 - 1700 m furrows First Irrigation	Option 1 - 1700 m furrows Seasonal Average	Option 2 - 1000 m furrows First Irrigation	Option 2 - 1000 m furrows Seasonal Average	Option 2 - 500 m furrows First Irrigation	Option 2 - 500 m furrows 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

Table 2. Effect of water application rate and cut-off time on irrigation performance for 770m furrows on a cracking clay (Weemah).

Management Option	Typical management	Cut-off when reached end	Cut-off one hour before end	Higher application rate	Higher 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 Efficiency (%) [a]	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

[a] not including recycling