Use of SIRMOD as a Quasi Real Time Surface Irrigation Decision Support System

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EXTENDED ABSTRACT

Surface irrigation currently accounts for 70-80% of irrigation water use in Australia and surface application is by far the dominant irrigation method applied throughout the world. However, water use efficiencies with surface irrigation methods tend to be low. In recent years a number of surface irrigation simulation models for assessing surface irrigation system performance have been developed. One of the most commonly used models SIRMOD, developed by Utah State University, has seen wide use and evaluation throughout the world particularly by researchers and has been shown to offer potential for increasing surface irrigation water use efficiencies.

Considerable efforts are now being undertaken to move use of the model from the realm of a research domain to the farmer domain. Maximum benefit from the use of such models will only occur when farmers have the ability to use Decision Support Systems (DSS) such as SIRMOD in a near real time environment i.e. for individual irrigations.

An extensive field investigation of the model was undertaken on a range of irrigation layouts and two different soil types commonly found in south eastern Australia. The regression analysis of measured infiltrated volumes showed a strong correlation with modeled results (Figure 1 r^2 = 0.9474).

The SIRMOD simulation model was found to adequately predict furrow irrigation characteristics on irrigation layouts and soil conditions typically found in the Murrumbidgee Irrigation Area (MIA). Comparisons of infiltrated volumes predicted by SIRMOD with measured infiltrated volumes gave a strong relationship providing confidence that SIRMOD was able to adequately model furrow irrigation systems typically used in the MIA.

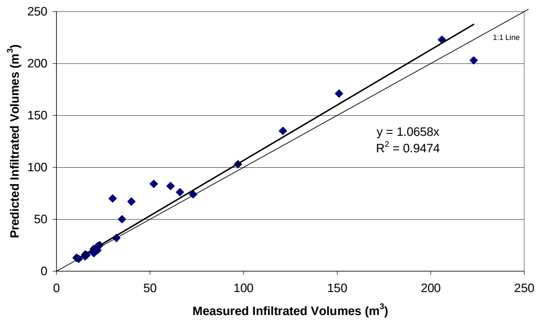

Figure 1. Relationship between predicted and measured infiltrated volumes.

This paper presents the results from field testing and evaluation of the model directly with irrigation farmers and user experiences with using SIRMOD as a quasi real time decision support tool.

Four areas have the potential to dictate the uptake of the SIRMOD model as DSS:

1. Ease of gathering input data for the DSS
2. Platform delivery of the DSS
3. Relating model outputs to end user needs
4. Level of irrigation water availability and the cost:benefit ratio of using the DSS

The use of the SIRMOD model as a management tool for improving irrigation efficiencies was found to be a valuable aid. Adoption of the model in use as a DSS has great potential. Future directions in research should focus on providing a streamlined solution which delivers an integrated system and addresses the four points outlined above. This will ensure irrigation farmers harness the benefit of the model.

1. INTRODUCTION

Surface irrigation methods within Australia are currently responsible for greater than 70% of the total volume of water used for irrigation and hence make up the dominant method of irrigating both crops and pastures. Although well designed and managed furrow-irrigated systems have the potential to operate at application efficiencies above 90% (Faulkner et al. 1998), many furrow systems operate at significantly lower efficiencies.

One of the major constraints to the improvement of furrow irrigation performance has been the difficultly in assessing the many variables associated with furrow irrigation systems and their interactions, and to utilize these in irrigation management.

One potential for improving the efficiency and performance of furrow irrigation systems lies in the use of simulation models to predict furrow irrigation performance and assess changes in management variables, which can lead to improvements in irrigation efficiency. A number of such models have been developed which aim to simulate surface irrigation systems. A few of these models have also been developed into user-friendly computer programs with the ultimate aim of being used by irrigation practitioners as DSS. These include the SRFR model (USDA, 1997), SURDEV (Jurriens *et al.* 2000) and the SIRMOD model (Walker, 1998).

2. THE SIRMOD MODEL

The SIRMOD model (Walker, 1998) simulates the hydraulics of surface irrigation (border, basin and furrow) at the field level. The simulation routine used in SIRMOD is based on the numerical solution of the Saint-Venant equations for conservation of mass and momentum as described by Walker and Skogerboe (1987).

Inputs required for the model to simulate an irrigation event include the infiltration characteristic, hydraulic resistance (Manning's n), furrow geometry, furrow slope, furrow length, inflow rate and advance cut-off time. Of these required inputs, the most difficult to determine adequately are the infiltration characteristics and the furrow inflows which often require either relatively expensive equipment or significant periods of time and skilled operators. These inputs have also been found to be the most sensitive in the SIRMOD model (McClymont *et al.* 1996).

Infiltration characteristics of a furrow are represented in the SIRMOD model with the Kostiakov-Lewis infiltration equation, which is given by:

$$Z = kt^a + f_0 t \qquad (1)$$

where Z is cumulative infiltration (m^3/m furow); t is the time (min) that water is available for infiltration; a, k are fitted parameters; and f_0 (m^3/min/m furrow) is the steady or final infiltration rate (Walker and Skogerboe, 1987)

Infiltration characteristics can be determined from the furrow advance rate as described by McClymont and Smith (1996). The remaining input parameters, furrow geometry, furrow slope and furrow length can be easily measured and the Manning's n coefficient is generally used as a 'calibrating' parameter.

The output from the model includes the advance and recession characteristics, ultimate distribution of infiltrated water and parameters related to water application, storage, efficiencies and runoff hydrographs.

3. EXPERIMENTAL SITES

To validate the model, monitoring was undertaken at three commercial furrow irrigated farms in the MIA. A description of each of the farms is given below:

Kooba (Kooba) Site: The Kooba irrigation data was collected on a self-mulching Wunnamurra Clay soil (Hornbuckle and Christen, 1999). The soil was a heavy clay with a strongly developed blocky structure of self-mulching character with little variation in structure or clay content with depth. The furrow irrigation system used at this site consisted of 443m long furrows with a slope of 0.0005 and spacing of 1.93m between furrows. Maize was irrigated at the site during the experimental period. The water table at this site was deeper than 4m from the soil surface.

Whitton (Whit) Site: The Whitton site was also situated on a Wunnamurra Clay soil with similar properties to the Kooba site. The main difference was that the watertable was within 1m of the soil surface. The furrows were 418m long with a slope of 0.0005 and spacing of 1.9m. Sunflowers were grown during the experimental monitoring period.

Merungle Hill (MH) Site: The Merungle Hill sites consisted of a number of small irrigation farms growing wine grapes and citrus. Soil type at the sites was classified as Merungle loam (Taylor and

Hooper, 1938) and consists of a loam A horizon of 0.2m depth and a clay loam B horizon to a depth of 1.8m. Furrow length for the systems ranged from 90-280m and spacing of 3.7-6.9m. Furrow slopes were varied, but they were typically steeper than the other sites and averaged 0.003. Subsurface drainage was also present at these sites.

For a detailed description of each of the sites see Hornbuckle (1999).

4. MODEL VALIDATION AND TESTING AS A QUASI REAL TIME MANAGEMENT TOOL

4.1 Model Validation

In order to validate the SIRMOD model 25 individual furrows were monitored. Furrow inflows and outflows were monitored using both Venturi and RBC flumes (Clemmens *et al.* 1984) situated at the entrance or head of the furrow and at the outlet of the furrow. Advance characteristics were measured at 100 to 200m intervals depending on the furrow length with 6-8 advance points measured per furrow. Field length, slope and furrow geometry were measured manually or taken from field layout plans.

4.2 Testing as a Quasi Real Time Management Tool

Testing of the SIRMOD model as a management tool was undertaken on a broadacre farming enterprise at Hillston, NSW and a commercial vineyard in Hanwood, NSW. Descriptions of the two sites are given below.

Broadacre Farming Enterprise: The soil was a self-mulching grey clay. Furrow length was 600m and winter wheat was grown on 1m spaced raised beds.

Vineyard: The soil was a Jondaryan loam (Taylor and Hooper, 1938). Furrow length was 628m and furrow spacing 3.8m. Subsurface drainage was present at the site and was parallel to the irrigation furrows.

The greatest potential for improving furrow irrigation using SIRMOD is through the use of the model directly by irrigators. This involves measuring the furrow inflow and advance characteristics to determine the infiltration parameters and undertaking simulation runs with SIRMOD to determine optimal management regimes. In order for this approach to be undertaken, cost effective and relatively simple methods for determination of the furrow inflows and advance need to be available.

A simple device was developed for the measurement of furrow inflows based on the circular flume described by Samani and Herrera, (1996). The flumes can be constructed easily with basic hand tools and are made from commonly available PolyVinyl Chloride (PVC) pipe. Flow rates are determined from upstream water heights measured with a graduated scale. The flumes can be produced at low cost (<$20AUD) and provide acceptable accuracy for the intended purpose. A photograph of the flumes being used in field experiments is shown in Figure 2.

Figure 2. Circular flume used for furrow inflow determination, note hydraulic jump in the bottom picture.

Figure 3. GPS for measuring advance distance to calculate infiltration characteristics and portable circular flumes.

Advance measurements can be taken manually using markers at known distances, however this method is often time consuming. An alternative is the use of a hand held GPS unit, which can easily be used to measure advance distance (Figure 3).

5. RESULTS OF MODEL VALIDATION

A total of 25 individual furrows were monitored at the Kooba, Whitton, and Merungle Hill sites with inflow, advance and run-off data collected. The relationship between the measured infiltrated and outflow volumes and those predicted by the SIRMOD model are shown in Figure 4 and Figure 5.

The regression analysis of infiltrated volumes showed a strong correlation (r^2 = 0.9474) with slope of the trend line (1.066) indicating that the SIRMOD model provided good predictions of the total infiltrated volume of water for the furrow irrigation events monitored. However, there was a slight tendency for the model to over predict the volume infiltrated. The outflow volumes, because of the direct relationship between infiltrated and runoff volumes (Inflow = Infiltration + Outflow), showed a tendency to under predict the outflow volume, shown in Figure 5. A poorer correlation coefficient (r^2=0.448) was found between the predicted and measured outflow volumes and this can be attributed largely to the very small outflow volumes measured in the experiments. Similar results have also been found by McClymont *et al.* (1996) for a similar data set collected in the Burdekin Irrigation Area of Australia.

In general, for the three varying irrigation sites the SIRMOD model provided acceptable predictions. The errors in outflow volume were largely due to the very small outflow volumes, hence being a small component of the water balance, which occurred for some of the furrows measured. In most cases, these outflow volumes were only a small amount of the total water applied, hence the errors only represent a small proportion of the total water applied.

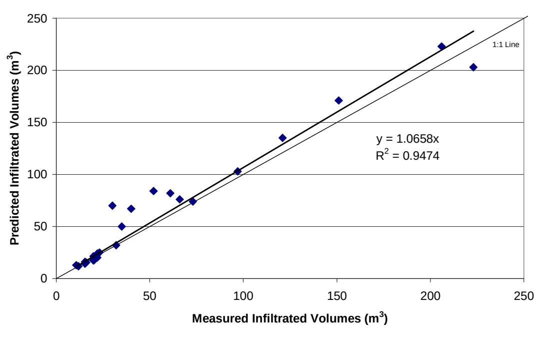

Figure 4. Relationship between predicted and measured infiltrated volumes.

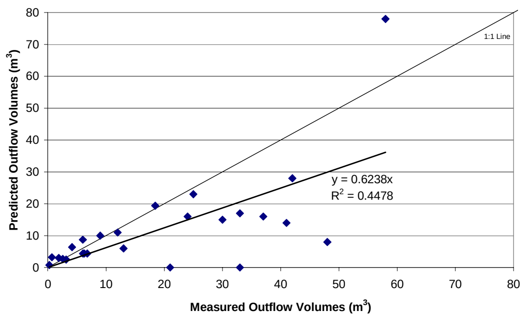

Figure 5. Relationship between predicted and measured outflow volumes.

The good relationship between modeled and measured infiltration volumes indicate that the SIRMOD model is able to simulate the furrow systems measured to an acceptable degree of accuracy for irrigation management decisions to be made. It should also be noted that a number of assumptions made in the SIRMOD model were not always present in the field investigations. These included a step inflow rate to the furrow, which was rarely found in the field data to due variations in the hydraulic head at the outlets over the irrigation periods. Also, the assumption that constant cross sectional furrow profile was not always met, particularly at the MH sites.

6. QUASI REAL TIME MANAGEMENT WITH SIRMOD

Considering the apparent suitability of the SIRMOD model for furrow irrigation in the MIA the model could be used for improving the efficiency and performance of furrow irrigation systems.

Using the equipment and methodology outlined in the materials and methods section of this paper, SIRMOD was investigated for its potential as a quasi real time management tool. This involved using the model to adjust management decisions for the irrigation of subsequent sets of irrigation siphons within a paddock or farm. Generally, irrigation paddocks are irrigated in siphon sets consecutively one after the other. By using the SIRMOD model with inputs from the previous siphon set it can be used as a quasi real time irrigation management tool as soil characteristics are generally uniform across sets for a given paddock.

These methods were used to determine the inflow and advance characteristics for a furrow irrigated vineyard in the 2000/2001 irrigation season to investigate the performance of the system and suggest possible management changes to improve the efficiency and performance. The field investigated used furrow irrigation to water wine grapes on 628m long furrows. Six irrigations were applied throughout the season and the SIRMOD model was used to simulate each of the irrigation events using inputs collected as outlined above.

Applied water for the field down the length of each of the furrows is shown in Figure 6. Solid lines represent SIRMOD model simulations for each of the irrigation events based on the measured inputs for the irrigation event. It can be seen from Figure 6, that there is a considerable difference in water applied down the length of the furrow using these irrigation management practices, which resulted in poor distribution uniformities. In particular, during the first and second irrigations there are considerable differences between the volumes of water applied at the start of the furrow compared to the end. Also, during the first irrigation a considerable amount of over irrigation occurred due to the slow advance times, particularly at the inlet region of the field. In general the irrigator aimed to apply ~50mm per irrigation event to the field, but during the first irrigation event considerably more was applied as can be seen in Figure 6. In order to address these issues, the SIRMOD model was used to develop alternative management methods to improve distribution uniformities. The dashed lines in Figure 6 show the effect of increasing the furrow inflows by a factor of 2 and reducing the irrigation time by a factor of 0.5.

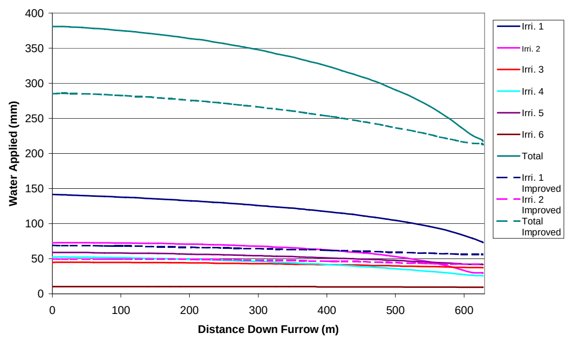

Figure 6. Water applied in relation to distance down furrow for 6 irrigations monitored during the 2000/2001 irrigation season

Figure 7 shows the inflow and outflow volumes using the existing management practices and those predicted by the SIRMOD model through changing the inflow rate and irrigation time as described above. It can be seen that the improved irrigation management resulted in higher volumes of outflows, which at first sight might indicate lower application efficiencies. However, the runoff is only one component of the water balance equation, and the existing management regime resulted in very large quantities of water draining below the root zone, and hence a total loss to the crop. With the use of a recirculation system furrow outflows can be reused, and hence the increased outflow volumes do not present an efficiency loss as the water can be reused.

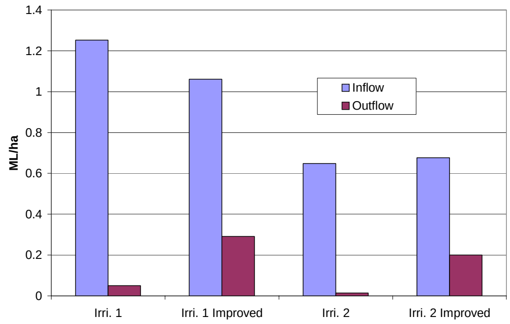

Figure 7. Inflow and outflow volumes to the field with existing management and modeled improved management

The second application involved using the model as a quasi real time management tool for increasing irrigation water use efficiency on a broadacre farming enterprise. This involved measuring inputs required for the model and then running simulations to optimize management practices on the next irrigation set. In these applications a particular paddock may have six to seven siphon sets which are irrigated one after the other. The first set was irrigated and monitored using standard practice. Based on this monitoring, the second set was then optimized using this data and the SIRMOD model to improve water use efficiency. In this situation only two parameters affecting the performance of the system can be easily modified. These are the inflow rate which can be modified by changing the siphon size and/or the number of siphons and the irrigation application time (Cut-off time). These parameters were optimized to achieve the desired target application (1.1 ML/ha) and maximize application efficiency. Results are presented below:

Set 1 (Standard Practice)

Irrigation Time: 39.5 hrs

Irrigation Amount Applied: 1.8 ML/ha

Surface Runoff: 0.4 ML/ha

Water Infiltrated: 1.4 ML/ha

Set 2 (After Management Changes)

Irrigation Time: 28 hrs

Irrigation Amount Applied: 1.2 ML/ha

Surface Runoff: 0.25 ML/ha

Water Infiltrated: 0.95 ML/ha

The results indicated that the management changes resulted in approximately a 0.6 ML/ha reduction in applied water volume. Runoff volumes were also decreased by approximately 0.15 ML/ha.

These examples highlight the potential use of the SIRMOD model to identify management alternatives that can be applied to furrow irrigation systems to improve their efficiency and performance. Simple and easy to implement management changes such as varying irrigation application times and inflow volumes can be seen to have a beneficial effect on the system, and these changes can be investigated with the SIRMOD model in near real time.

7. DISCUSSION

During the course of this research a number of observations have been made by the authors regarding the potential application and use of the SIRMOD model and potential barriers to adoption of the technology. These are discussed below.

7.1. Ease of Gathering Input Data

One of the greatest concerns regarding the use of the model by farmers for improving irrigation efficiency related to the ease of use of collecting input data to run the model. In using a DSS such as SIRMOD, it should be remembered that the model forms one component of the overall toolkit for achieving the desired aim. Just as important as the model itself, is having a series of tools which allow data to be collected with the minimum of effort. While the data collection system presented in this paper using circular flumes and GPS significantly simplified this task, other authors (Raine *et al.* 2005) have developed alternative packages for collecting model inputs that are more streamlined and greatly simplify this task. These efforts should be commended.

7.2. Platform Delivery

Delivery platform of the DSS also plays a key role in the adoption of the system. While the current model SIRMOD has been developed on the PC platform one of the major drawbacks with this approach for real time management is the requirement to have a PC in the field. Alternatives which appear much more attractive are delivery of the application on a mobile phone platform. Farmers already use this technology and it is a readily available tool for paddock management. Delivery of the model on a smartphone platform would overcome many of the problems associated with the delivery of the model on a PC platform.

7.3. Relating Model Outputs to End Use Needs

The ultimate goal in a DSS such as SIRMOD is to either increase economic return (i.e. improve irrigation efficiency) or minimize environmental impacts (i.e. deep drainage). Current outputs from the model are more engineering orientated than irrigator driven. For use by irrigators outputs from the model would be much better linked directly with the economic consequences of the management decision, which is about to be undertaken, based on the results of the DSS. For example, placing an economic value on the decision, based on market prices, provides a much clearer picture to farmers than a runoff or deep drainage volume of water. If this hydrologic data can be linked to the economics of the decision, then the benefit of using the DSS becomes much clearer to the irrigator.

7.4. Importance of Resource and Cost:Benefit Ratio of Use

Use of the DSS will be heavily correlated to the scarcity of the water resource and the cost:benefit ratio gained through using the model. In recent years the low water allocations and increasing cost of water has seen irrigation farmers investigate options for conserving water and making the most of their limited resource. This has driven the interest in models such as SIRMOD, which can be used to maximize the water use productivity of a given enterprise.

7.5. Future Directions

Key to the adoption and future use of the SIRMOD model as a DSS is the development and advancement of a product that allows seamless integration of the DSS into the operating environment of irrigation farmers. While previous efforts in developing DSS have focused on the mathematical linking and understanding of the processes of models linked to the DSS, relatively little effort has focused on developing the required tools that allow users to use such a DSS on a day to day basis. Often the DSS are complex and require understanding not usually available at an irrigation producer level or alternatively require inputs into the DSS which are difficult and/or time consuming to collect.

Future directions should focus on providing solutions to these problems and providing an integrated solution to the problem at hand and present this in a medium the irrigation farmer can readily utilize.

8. CONCLUSIONS

The SIRMOD simulation model was found to adequately predict furrow irrigation on the soil conditions within the MIA. Infiltrated volumes predicted by SIRMOD and measured infiltrated volumes were highly correlated ($r^2 = 0.9474$) providing confidence that the SIRMOD model was able to adequately model furrow irrigation systems commonly used in the MIA. These systems are typical of many furrow irrigation schemes throughout the world.

The SIRMOD model was found to be a valuable aid for managers to improve irrigation efficiencies. Adoption of the model as a DSS has great potential. Future directions in research should focus on providing a streamlined solution which delivers an integrated system. This system should ensure ease of gathering model inputs, have a usable delivery platform, relate model outputs to end use needs and highlight the cost:benefit of using the DSS. This will ensure irrigation producers harness the benefit of the model.

9. ACKNOWLEDGMENTS

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