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A review of Basin (Contour) Irrigation Systems II: Research needs for evaluation and design

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BETTER IRRIGATION

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A review of Basin (Contour) Irrigation Systems II: Research needs for evaluation and design

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Reports in this series

This is a pair of reports aimed at improving the performance of basin (contour) irrigation systems in the Southern Murray-Darling Basin:

1. A review of Basin (Contour) Irrigation Systems I: Current design and management practices in the Southern Murray-Darling Basin, Australia
2. A review of Basin (Contour) Irrigation Systems II: Research needs for evaluation and design

These reports are available from the web at <http://www.irrigationfutures.org.au>

Foreword

There are at least eight different types of basin layout currently in use in the Southern Murray-Darling Basin. These variants have been designed to accommodate different water supplies, crops, soils, machinery and management styles. However, there is little guidance available as to the benefits of any one of these systems over another. Thus farmers have been left to undertake their own experimentation. The aim of this exercise has been to collate our existing understanding of basin (contour) irrigation systems in the Southern Murray-Darling Basin areas and make this available to anyone with an interest, whether farmer, agency staff or academic. This has been undertaken as:

1. Description and analysis of current layouts
2. Collation of existing data
3. Analysis of previous research
4. Determination of research needs

This work has tried to shed some light on our current understanding of these designs and where we need to invest research effort. The first report looks at the current practices. The second report looks at the research needs to evaluate current layouts and provide appropriate designs. We hope that this review material will be useful to anyone seeking to understand this type of irrigation system and promote much needed research into this area.

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Tools for Irrigation Profitability and Longevity project
CRC for Irrigation Futures*

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Executive Summary

There is currently no suitable simulation models available for “off-the-shelf” use with the range of basin systems found in the southern Murray-Darling Basin (MDB). The key issue to be solved is how to account for the volume of surface storage in the current models so that they can be used with field data to determine infiltration parameters from inverse modelling.

CoBaSim has the greatest applicability to the majority of contour basin systems currently installed, but the software is unsupported and unusable. Furthermore, the key input parameters of infiltration and surface roughness can not be obtained from inverse modelling of field data and must be obtained independently.

The SRFR simulation model can cope with a number of field layouts, but it requires validation in typical basin layouts used in the southern MDB.

The in-field evaluation tools used with Irrimate™ in furrow and graded border systems are not suited to basin systems which are characterised by irregular surface storage and two-dimensional flow. Methods are needed for measuring flows which do not influence upstream or downstream conditions and which are not affected by submergence. The following is recommended:

1. that a review be conducted to identify alternatives to flumes for measuring flows e.g. ultrasonic meters or rated head control structures;
2. that techniques for measuring furrow discharges in level furrow systems be investigated
3. measurements of water depth along the length and across the width of the basin be taken to provide information on the uniformity of opportunity times with a view to determining a minimum number of measurements.

1. Introduction

Surface irrigation is the most common form of irrigation in Australia by both water use and cropping area. This broad range of application systems includes furrow, border and basin irrigation where the water is ponded on the soil surface and is distributed by gravity. Generally, surface irrigation offers the potential for high water use efficiency and uniformity, providing it is practiced under suitable soil and crop characteristics. Unfortunately, this level of performance is often compromised through inappropriate field design and irrigation management. The development of measurement tools and techniques, computer models and evaluation procedures has provided great improvements for conventional furrow irrigation systems. The purpose of this article is to discuss the issues involved in adapting these techniques to other forms of surface irrigation.

2. Range of infield application systems

Irrigated basins such as those used by the rice industry traditionally comprise moderately sized, approximately level sections of land bounded by earthen banks. They are constructed following the natural contour of the land, sizes are determined by the land slope and flow capacity of the hydraulic infrastructure. Rice requires even ponding depths for long periods of time. Hence, these systems are developed with zero grades situated on soils with low steady infiltration rates. In recent decades, the adoption of laser levelling and crop rotation has stimulated a push towards larger, rectangular basin systems. These developments have created new issues such as the importance of drainage and the exposure of infertile subsoil layers.

Recently, bankless variants of furrow irrigation have gained interest due to their ability to reduce labour requirements, promote automation and possibly facilitate real-time control. The term “bankless” refers to the field set up where the water flows directly from the head ditch into the furrows or basin where as in traditional furrow irrigation water is applied through siphons or layflat/gated pipe.

In Australia, the most common application system for furrow irrigation is the head-ditch and siphon inflow. Each siphon (typically a polyethylene pipe) must be manually started and later stopped after sufficient infiltration has occurred. The head ditch must be elevated above the field as the flow through the siphon is largely determined by the difference in water level between the two ends of the pipe. Bankless systems behave differently as the flow into each furrow will suffer from far greater sensitivity to the difference in head ditch water depth. More importantly, altering the flow into a single or group of furrows by differing flow rates or furrow geometries has the potential to influence the flow-rate into other furrows. This indicates that the furrows should be modelled as a set rather than as individual furrows.

Conventional furrow systems (flow-through systems) are characterised by small channels running down the predominant slope of the field where water is applied to the highest point and flows to the lower end of the field under gravity. Basin and bankless systems encompass a wide range of field configurations where the water may be applied and or drained from either end of the field, which may be sloping in any

direction. Drainage channels or “toe furrows” are often used to encourage drainage and improve advance/recession rates. Also, the water may be permitted to flow through gates located in the banks between adjacent basins, indicating that a basin cannot be modelled in isolation.

3. Existing simulation models for basin systems

The process of surface irrigation can be described by the continuity and momentum equations. The most accurate and computationally intense methods solve for both equations in their entirety (Saint Venant/Full hydrodynamic). The Zero Inertia model simplifies these equations by ignoring the acceleration terms within the momentum equation, in effect assuming that the difference between the friction slope and the bed slope is equal to the change in water level. The Kinematic Wave approach further simplifies the approach by assuming normal flow (free flowing) conditions and replaces the momentum equation by the Manning equation. Finally the volume balance model ignores the momentum equation completely by assuming the power advance and standard shape for the volume stored on the soil surface. Each simplification reduces the ability of that model to represent field behaviour. However the assumptions of homogeneous infiltration, inflow and surface conditions and low precision of field data often does not justify the use of the more complex approaches.

3.1. Modelling conventional flow-through systems

A number of different simulations have been developed to model the conventional flow through systems, those where water is applied to the highest edge of a rectangular paddock and flows in the direction of predominant slope. Two commonly used models used for furrow irrigation are SIRMOD and SRFR.

3.1.1. SIRMOD

SIRMOD (Surface irrigation simulation, evaluation and design) was developed by Wynn Walker, Utah State University. Two different versions are available, currently Irrimate includes SIRMOD II but SIRMOD III is the most recent release. The two models are essentially identical except for a number of subtle differences, the two most important being that SIRMOD III can:

1. utilise a variable inflow hydrograph, rather than the constant inflow assumption, and
2. adjust the infiltration for differences in wetted perimeter (Walker 2003).

The user can disable either one or both of these enhancements if required.

SIRMOD can be used to simulate both furrow and border/basin irrigation, providing the water is applied to the top end of the field, it cannot cope with situations of reverse slope (where the water is applied to the downstream end of the field). Flow conditions at the downstream end can be either free-flowing, where unobstructed runoff occurs or the blocked end situation where no water exits through the downstream end. It can

model the field hydraulics using the kinematic wave, zero inertia or full-hydrodynamic equations. Infiltration is described using the modified Kostiaikov equation.

3.1.2. SRFR

SRFR (Clemmens & Strelkoff 1999) was developed at the United States Water Conservation Laboratory to simulate one dimensional surface irrigation. Being Dos based, it is slightly less user friendly but can model the water flow in a wider range of field configurations than SIRMOD. It can be operated using either the Kinematic Wave or Zero Inertia hydraulic models, the later being more accurate. SRFR can model both the constant inflow and variable inflow case, with up to 20 changes in application rate during a single event.

In 2007 the same team released WinSRFR (ALARC 2006) to integrate the three separate SRFR, BASIN and BORDER (all 1 dimensional) simulation models for the windows operating environment. The latest version (2.1) includes added design and management optimisation functionality in conjunction with minor improvements to the simulation engine.

SRFR and WinSRFR have the capability to model soil infiltration behaviour based on the Modified Kostiaikov, time related intake curves, branch infiltration, known characteristic infiltration time and SCS intake curves. The user can also specify infiltration rates which can change with distance down the furrow and/or time. They also include furrow geometry and slope characteristics that can vary with distance and time (possibly for erosion modelling). SRFR includes the ability to vary infiltration rates according to the inflow rate by adjusting for upstream or local wetted perimeter.

3.2. Modelling complex water flow systems

Khanna *et al.* (2003a) discuss the various models that have been developed to simulate the 2 dimensional flows in basin irrigation. These models such as the B2D model (Playán *et al.* 1992) generally consider single, regular shaped, level basins with no outflows. Khanna *et al.* (2003a) found that many contour basins in Southeast Australia employ a complex system of toe furrows and gate structures to permit flow from one basin to another. They developed a two-dimensional simulation model based on the zero-inertia approach that can accommodate multiple irregular shaped basins with toe furrows and both line and point inflows. This was developed into the windows based program, CoBaSim. CoBaSim has no provision to calibrate the infiltration or surface roughness from field data; they must be estimated or measured outside the program. The current version of CoBaSim has a number of user interface issues; attempts to use the program were unsuccessful.

For further information, refer to the journal papers of the development of the single basin rectangular system (Khanna *et al.* 2003a) and irregular and/or multiple basin systems (Khanna *et al.* 2003b).

3.3. Opportunities for simple one dimensional modelling

The complex approach explained in the previous section can be simplified by reducing the two dimensional flow equations to a single dimension orientated down the length of

the field. It would be beneficial if the above models could be adapted to accommodate level fields, water inflow to the lower end of the field and outflow at either or both ends of the field. Although SIRMOD appears to handle the advance phase of the reverse slope/level irrigation it does not permit outflow from the supply end of the field.

SRFR is ideally suited to the one dimensional simplification of basin irrigation. In addition to the conventional furrow case it also provides satisfactory representations of level and reverse slope flow when the zero inertia model option is selected. For these situations, SRFR also permits outflow from the supply end at the completion of the inflow time. The estimated outflow and depth at both ends can be found in the output file. By default, the model assumes free flowing conditions at the upstream end; however, the user can slow the recession simply by changing the draw down time (the time taken for the recession to reach the upstream end of the field after inflow stops).

4. Evaluation tools and requirements for basin systems

Evaluation of surface irrigation systems is generally involves two activities. Firstly, the infiltration characteristic for the event is derived from field measurements and then the irrigation event is simulated using a hydraulic model to obtain performance parameters. The models in the previous section can be used to evaluate and optimise irrigation performance. However, these models require suitable estimates of the infiltration characteristic. Point or furrow infiltrometers operate on a relatively small volume of soil and generally do not provide adequate measures of infiltration at the field scale due the large spatial variability in soil properties. The most appropriate technique to estimate the infiltration characteristics at the furrow or field scale involves using an inverse technique and measurements of water advance, recession and runoff. Inverse techniques provide a space averaged value under actual irrigation conditions.

4.1. Conventional flow-through systems

Traditionally models using the volume balance have been used to estimate infiltration characteristics since they provide adequate performance during the advance phase assuming constant inflow discharge and homogeneous field conditions. Calibration of the infiltration function is carried out by fitting the chosen model to the measured advance data. Two examples of this approach are the software package INFILT (McClymont & Smith 1996) and the two Point method (Elliot *et al.* 1983). Recently the volume balance approach has been modified to include runoff measurements, extending the accuracy of the infiltration function to larger irrigation periods. It has also been modified to accommodate temporally variable inflow rates (Gillies *et al* 2006).

The Irrimate surface irrigation evaluation system contains three infield sensors used to take the necessary measurements for performance evaluation of furrow irrigation.

1. **Advance sensors** – record the time taken for the water to reach a specified distance in the field. Each sensor contains eight probes, typically spaced 1 metre apart. Usually 4 to 6 sensors are used positioned along the same furrows, spaced approximately equally down the field length.

2. **Siphon inflow meter** - measure the flow-rate in a siphon and log the discharge (L/s) every 5 minutes during the duration of the event.
3. **Flume flow meter** – measures the flow rate (L/s at 5 minute intervals) at a location in the field (commonly used to measure runoff) by measuring the critical flow depth over a raised section of bed. Flumes can only be used in free-flowing conditions; they cannot be submerged.

Inflow is likely to be the most important measurement required for both infiltration estimation and system evaluation. In traditional furrow irrigation, where water is applied through siphon or gated pipe systems the inflow can be simply estimated using siphon dimensions and head differences or measured using siphon flow-meters. In addition, the inflow should not deviate significantly over time providing correct management and operation of supply channels.

In bankless irrigation systems, furrow inflow is determined by the difference in water level between the head ditch and within the furrow. This is also the case for the siphon application system but there the flow rate is less sensitive to changes in the water level, which should remain relatively static throughout the irrigation. In bankless irrigation, the water depth within the furrow is influenced by the infiltration rate and advance velocity in that furrow. A furrow with greater infiltration or rapid advance rate will cause the water level to drop. This will increase the inflow rate applied to that furrow at the expense of the remaining furrows. In this way, the bankless irrigation system may act to standardise the advance rates, thereby masking variability between furrows but may ultimately increase the variability of cumulative applied depths between furrows in the same field.

In those situations with free flowing conditions, a flume flow meter may be used to measure the flow-rate at the top end of the field. However, the large variability between furrows indicates towards the need to measure inflow rates in a large number of furrows. In addition, the flume may restrict the water flow thereby influencing the flow rate. A different approach is to estimate a representative infiltration function using the total set or basin inflow.

4.2. Complex flow basin and reverse slope systems

The methods used to measure and evaluate traditional furrow irrigation contain a number of simplifications that undermine their use in alternative configurations.

Volume balance models assume that the volume of surface storage is a constant function of the up-stream flow area (commonly $V=0.77 \cdot A_0 L$). The assumption is only valid for steady inflow rates where water is applied to the top end of the field with a constant downstream slope. For the alternative configurations found in basin irrigation, it is anticipated that this relationship will become time-dependent. Field trials recording water depths will be necessary to determine the nature of this relationship.

The temporally variable inflow and recession could prove difficult for the current measurement techniques. In multiple basin systems, the flow from one furrow to another will change with time, posing a problem for the volume balance approach. The

outflow from each furrow will be restricted by the water level at the bottom end of the field, therefore flume flow meters cannot be used to measure the runoff.

Alternatively a new inverse solution for infiltration using the zero inertia or full hydrodynamic models could be developed, as currently there are no models available to perform this task.

5. Recommendations for further research

5.1. Field Trials/Experimentation

The techniques to measure, model and evaluate conventional furrow systems have been devised and verified through a series of comprehensive irrigation trials. Continuing development of these practices is suggested by problems and opportunities identified through everyday application of these techniques. The same approach should be taken for basin and alternative surface irrigation systems. At this point, there is limited field data available on the behaviour and performance of these systems. The first stage of field trials should aim to maximise the number and types of measurements. It is likely that the knowledge gained from these initial trials will uncover opportunities to reduce and simplify data requirements.

Inflow is possibly the most important piece of information required to understand surface irrigation systems. Firstly, as the field application is more sensitive to changes in the head ditch measurements should be taken of the supply channel that are not commonly considered in the evaluation of conventional furrow irrigation. These measurements include:

1. flow depths in the supply channel
2. discharge in the supply channel
3. supply channel geometry – to quantify the relationship between flow depth and discharge rates

As previously discussed the existing flume flow meters can only be operated in free-flowing conditions. A review is required to identify applications for alternative flow measurement apparatus such as ultrasonic meters or rated head control structures.

Measures of advance rate within the alternative furrow or basin systems can be measured using normal electronic sensors such as the Irrimate advance sensors. In the reverse slope systems, it is possible that the surface storage will make up a significant proportion of the volume balance. Therefore, field trials should not only measure the water front advance but also the ponding depth at locations within the field throughout the irrigation duration. In the reverse slope layouts, it is anticipated that the inflow into individual furrows will self-adjust to standardise advance rates. Hence, to obtain information at the furrow scale it will be necessary to measure the inflow into individual furrows. An investigation will be required to identify techniques to measure these discharges with minimal flow restriction. The alternative is to use advance measurements to estimate the average field infiltration and use estimated soil variances to model the field performance.

In many systems, water recession may take up a significant proportion of total irrigation time and in multiple basin configurations will dictate the inflow into successive basins. Measurements should be taken of both the recession along the field length and across the basin to provide information on the uniformity of opportunity times.

5.2. Model Development

The major issue regarding the inverse volume balance solution for infiltration is the volume of surface storage. Initial field trials should indicate whether those techniques developed for conventional furrow can be adapted to alternative surface irrigation systems. The alternative is to develop an iterative procedure to estimate soil intake rates using the zero-inertia or hydrodynamic models.

Although the SRF simulation model can cope with a number of field layouts, it still requires validation under Australian soil conditions. The validation will identify those situations where this model can be and others where it should not be used.

The interrelated behaviour of furrows within the bankless systems suggests the value of a simulation that combines furrow hydraulics with a simple head channel model. It may be difficult to collect the measurements required to validate such a simulation but it would be valuable in the design and optimisation processes. At the present time all available models are completely reliant on a known inflow discharge at the furrow/basin inlet. As the furrow inflow is dictated by the flow depth it would be more appropriate to simulate based on a known depth rather than flow rate. With sufficient field slope in the downstream direction, the flow rate can be expressed explicitly from a measured flow depth and vice versa using the Manning equation. However, for near-zero or increasing grades the flow rate is dictated not only by the depth of flow at that point but the behaviour of the entire furrow (including water velocity, infiltration and depth) downstream of that point. For this reason it may be necessary to develop a new simulation model drawing on existing approaches which can characterise inflow rates from known or measured flow depths.

Another alternative is to re-visit the CoBaSim simulation model. Since the literature describes a working version of this software, it is most likely that the actual hydraulic model is working and the issues found by the authors are caused by problems in the user interface.

Once models have been selected or developed, the next stage is to verify the predicted infiltrated depths and discharges against field measurements. Only then can these models be used with confidence.

6. Conclusion

This article identifies the main issues involved with the field measurement and simulation of basin and bankless irrigation systems. It is clear that the current tools and techniques cannot be readily applied to these systems. Further research should include a number of comprehensive field trials, adaptation of existing and/or development of new simulation models and validation under the range of irrigation systems found in Australia.

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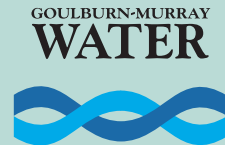
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- NOTES -



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