Performance Evaluation and Improvement of Bankless Channel Surface Irrigation Systems

A dissertation submitted by
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ABSTRACT

Bankless Channel Irrigation Systems (BCISs) are a surface irrigation system composed of adjacent, terraced bays with an interconnecting channel constructed such that the rim of the channel is level with the floor of each adjoining bay. The mode of irrigation is similar to Drain Back Level Basins (DBLBs) where the accumulated surface storage of each upstream bay is used to augment flow to a downstream bay. The systems of this study have been adapted from rice-based layouts to incorporate furrows for row-cropping. It is this style of BCIS that has generated considerable interest in Australia, particularly in the south east, where the system is used to grow a variety of crops and offers considerable labour and machine efficiency savings. Two defining features of BCISs are a positive field slope which rises from the bankless channel, and the hydraulic interaction between adjoining bays during the recession phase of the upstream bay and the advance phase in the downstream bay. These two features make evaluation challenging and mean no available hydraulic simulation model can simulate irrigation in these systems across an entire field.

To improve the irrigation performance of BCISs a method of evaluating current performance was required. Consequently, the objectives of this research were to firstly identify appropriate evaluation methods for evaluating BCISs, then use these methods to evaluate the performance of current systems. This understanding could then be used to identify appropriate hydraulic models for the purpose of identifying parameters which influence irrigation performance in BCISs.

In developing appropriate irrigation evaluation techniques for BCISs, a variety of evaluation methods were employed on a commercially operated BCIS in the Murrumbidgee Irrigation Area (MIA) of south eastern Australia. Field measurements were taken during a number of irrigations in the 2007/08 irrigation season from a central furrow in each bay of the three bay system. It was assumed that advance across the bay would
be uniform given the positive slope of each bay. Observed variation in the advance front between furrows within individual bays suggested advance was not uniform. Consequently, several furrows were instrumented in the subsequent irrigation season of 2008/2009. Evaluation results showed a significant difference ($p<0.05$) between trafficked (wheel) and non-trafficked (non-wheel) furrows for factors of furrow inflow rate, advance and furrow base elevation. On average, inflow rate into wheel furrows was 37% higher than into non-wheel furrows and wheel furrow base elevation averaged 17mm lower than non-wheel furrows, or 38% of the design furrow elevation. As a result of this variation between furrows, a considerable negative crop response was anticipated. However, while insufficient crop samples were collected to provide a statistically reliable analysis of within bay yield variation, field scale production yields were above the national production average suggesting any impact to be less than anticipated. It is assumed that post-irrigation lateral redistribution of profile moisture may mitigate variability, especially in the fields of this study where an equal ratio of wheel and non-wheel furrows existed.

In contrast to the measured variation within individual bays, application depths varied considerably between bays during each irrigation event. In one measured irrigation the highest application depth was 255% of the lowest applied depth. It was concluded, as a result of this substantial variation, that the greatest potential for improving irrigation performance in BCISs was in reducing the variability in applied depths between individual bays. To reduce variability, an understanding of the design and management features that affect application depth in BCISs was required. Consequently, the potential of various hydraulic simulation models was examined.

Despite a number of hydraulic models with capacity to simulate various aspects of BCISs none had capacity to describe irrigation at both the bay and field scales. Consequently, a simulation model was developed to describe both within-bay irrigation and the hydraulic interaction between bays; viz the B2B model. To achieve this, a surface irrigation hydraulic design model (Clemmens 2007a,b) was adapted to accommodate the
elements associated with a positive field slope. Parallel routines of this model where then coupled using a routine based adaptation of the Darcy-Weisbach equation to describe bay-to-bay hydraulics, thus enabling hydraulic simulation of an entire BCIS field.

B2B simulations were then used to demonstrate the capacity of the model and to test the sensitivity of BCISs to various design and management variables. Current assumptions within the B2B model limit the model to describing general trends in Distribution Uniformity (DU). This capacity provides an important tool to examine the effect design and management variables have on the performance of the system. Variables examined within this dissertation include bay dimensions, the vertical separation between bays, slope, field supply rate, delivery pipe capacity, irrigation deficits and duration.

The results showed DU down the furrow to be more sensitive to adjustments in bay length than width, with performance declining as completion of advance became reliant on field supply ‘base’ flow. As the vertical step between bays was increased, an increase in furrow inflow was apparent, commensurate with the increasing hydraulic head between the bays. However, despite the higher inflow, the impact on overall irrigation performance was relatively minor. The higher inflows generated a faster advance. However, the benefits of the higher discharge lasted for a shorter duration. This resulted in a reliance on the ‘base’ flow, similar to the above, for completion of advance which ultimately undermined the performance gains generated by the higher, but short duration inflows. Similar results were achieved for scenarios where pipe diameter, and thus capacity were increased.

B2B simulations of slope indicated that any increase in slope reduces DU in the field. Furthermore, as slope increases, the depth of flow at the furrow inlet increases to a point where waterlogging at the inlet end of the bay is apparent. However, the presence of some slope within the bay reduced the risk of internal drainage and also assisted in the management of irrigation water where topographical constraints limit the ‘step’ between bays. Where water ‘backs up’ into the upstream bay, the presence of a positive field slope assists in constraining water to the bankless channel.
Increasing the field deficit improved the simulated $[DU]$ for each bay. However, to satisfy the higher deficits irrigation duration was increased. For the infiltration characteristic used in these simulations, a prolonger irrigation interval was required resulting in the accumulation of a considerable surface storage volume, and thus depth, in each bay. While simulations were theoretical, it was concluded that consideration must be given to water depth when increasing irrigation deficits.

The B2B model provides a design simulation capacity providing a useful resource for describing trends in irrigation performance across a BCIS field. However, the model relies on reliable estimates of the infiltration characteristic of a field and does not simulate variation within individual bays. Consequently, evaluation of irrigation performance is required using field measurement. To effectively evaluate and determine suitable infiltration parameters for a field, this research identified several necessary field measurements as necessary: relative furrow elevation, furrow and bay inlet/outlet discharge, furrow advance and water depth at the furrow inlet. These measurements enable the infiltration characteristic for a field to be estimated and provide an insight into the uniformity of application between the bays of a field.
CERTIFICATE OF DISSERTATION

I certify that the ideas, designs, experimental work, software code, results, analyses and conclusions presented in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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A PhD taught me many things, including a precious lesson,
That love and support of those around, is really what I depend on.
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Each time the tunnel’s sun lit end, was a freight train: when progress ceases.
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MG.
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8.1 Range of application depths across several fields.
### Nomenclature

- $\alpha_1$: Unit conversion coefficient
- $a$: Empirical Kostiakov infiltration parameter
- $\alpha_2$: Labour use fraction
- $A$: Cross-sectional area of flow, m$^2$
- $\alpha_3$: Unit conversion coefficient
- $A_f$: Furrow water-surface area, m$^2$
- $A_p$: Pipe cross-sectional area of flow, m$^2$
- $\alpha_5$: Unit conversion coefficient
- $\bar{A}$: Average cross-sectional area, m$^2$
- $C$: Crack fill volume term, m$^3$/m
- $C_1$: Cost of water
- $C_2$: Cost of labour
- $C_3$: Cost of construction
- $C_4$: Cost of runoff
- $C_5$: Cost of deep drainage
- $C_p$: Cost of production
- $\Delta H$: Head difference, m
- $\Delta H_b$: Base flow head difference, m
- $D$: Pipe Diameter, m
$D_c$ Conveyance depth

$D_i$ Irrigating depth

$d$ Day

$\epsilon$ Error value OR Absolute pipe roughness, mm

$f$ Darcy friction factor, dimensionless

$f_0$ Semi-empirical steady state infiltration parameter, m$^3$/m/min

$f_b$ Free board

$Fr$ Froude number

$g$ Acceleration due to gravity, m/s/s

$g$ Grams

$h$ Advance exponent

$h_e$ Pipe entrance friction loss, m

$H_f$ Pipe friction loss, m

$h_o$ Pipe outlet friction loss, m

$h$ Hours

$i$ Infiltration rate

$k$ Empirical Kostiakov infiltration parameter, m$^3$/m/min$^i$

$K_c$ Crop Coefficient

$k_e$ Pipe inlet friction coefficient

$k_o$ Pipe outlet friction coefficient

$L$ Field length, m

$l$ Pipe length, m

$\mu$ Viscosity, Nsm$^{-2}$ or kg(ms)$^{-1}$

$m$ Metres

$\text{min}$ Minutes
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ML</td>
<td>Mega litres</td>
</tr>
<tr>
<td>$n$</td>
<td>Manning resistance coefficient</td>
</tr>
<tr>
<td>$N_f$</td>
<td>Number of furrows</td>
</tr>
<tr>
<td>$N_i$</td>
<td>Number of irrigations per season</td>
</tr>
<tr>
<td>$N_l$</td>
<td>Number of run lengths</td>
</tr>
<tr>
<td>$N_w$</td>
<td>Number of sets in width direction</td>
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<tr>
<td>$P_c$</td>
<td>Profit coefficient</td>
</tr>
<tr>
<td>$P_n$</td>
<td>Net return on investment</td>
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<tr>
<td>$Q$</td>
<td>Furrow discharge, l/s</td>
</tr>
<tr>
<td>$q_0$</td>
<td>Inflow rate per unit width, m$^3$/s</td>
</tr>
<tr>
<td>$Q_b$</td>
<td>Field base supply rate, ML/d</td>
</tr>
<tr>
<td>$Q_r$</td>
<td>Recession or runoff discharge, ML/d</td>
</tr>
<tr>
<td>$Re$</td>
<td>Reynolds number, dimensionless</td>
</tr>
<tr>
<td>$\rho_1$</td>
<td>Empirical data fitting parameter</td>
</tr>
<tr>
<td>$\rho_2$</td>
<td>Empirical data fitting parameter</td>
</tr>
<tr>
<td>$R$</td>
<td>Hydraulic Radius, m</td>
</tr>
<tr>
<td>$r^2$</td>
<td>Coefficient of determination</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>$\sigma_1$</td>
<td>Empirical data fitting parameter</td>
</tr>
<tr>
<td>$\sigma_2$</td>
<td>Empirical data fitting parameter</td>
</tr>
<tr>
<td>$\sigma_y$</td>
<td>Surface water profile shape factor</td>
</tr>
<tr>
<td>$S_0$</td>
<td>Field slope</td>
</tr>
<tr>
<td>$S_f$</td>
<td>Friction slope</td>
</tr>
<tr>
<td>$s$</td>
<td>Seconds</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Infiltration opportunity time, min</td>
</tr>
</tbody>
</table>
$\tau_B$ Kostiakov branch function time of branch, $\text{min}$

t Elapsed time from start of irrigation, min or sec

t$_{co}$ Time to cut-off, min or sec

$V$ Total volume applied = $Q_0t$, $\text{m}^3$

$v$ Flow velocity, m/s

$V_r$ Runoff volume, $\text{m}^3$

$V_y$ Surface storage volume, $\text{m}^3$

$V_z$ Infiltrated volume, $\text{m}^3$

$V_{dp}$ Deep drainage volume

$W$ Furrow spacing, m

$W_b$ Furrow base width, m

$W_f$ Field width, m

$W_s$ Furrow side slope, m/m

$W_t$ Furrow surface water width, m

$WP$ Wetted perimeter, m

$\bar{x}$ Half field wetted length, m

$x$ Distance from furrow inlet, m

$x_r$ Distance from furrow inlet during recession, m

$y$ Flow depth, m

$Y_R$ Relative crop yield

$z$ Infiltrated volume

$Z_b$ Furrow side slope, m/m

$z_d$ Required depth of infiltration or soil moisture deficit, m

$z_g$ Average depth of infiltration or soil moisture deficit, m

$z_n$ Minimum infiltrated depth, m

$Z_s$ Vertical step between bays, m
Glossary

Bioturbation  Mixing of soils by living organisms. pg: 92

Broadacre  Land suitable for large-scale cropping operations. pg: 3, 4

Distribution Uniformity  The ratio of the average of the lowest quarter of measurements of infiltrated depth to the average depth of irrigation water infiltrated, expressed as a percentage (USDA NRCS, 1997). pg: 119

Guess row  The intervening row, hill or bed formed by the outside edge of a bed forming implement on two separate passes. pg: 81, 84

Land forming  Laser controlled grading of the land to a uniform plane. pg: 24, 68, 69, 75

Microtopography  Topographical patterns embedded into the general zero-slope levelling of a field, (Playán et al., 1996b, p. 339). pg: 46, 64

Rotobucks  The area between the supply channel and furrows when pulled up into hills for the purpose of delivering water from a siphon to one or more furrows. This area must be levelled to enable machinery to turn at the head of the field and re-constructed before an irrigation event. pg: 4, 13

Tailwater  Flow of surface water from a given area resulting from the effects of applied irrigation water in excess of crop water requirement. pg: 76

Top soiling  The application of top soil to a soil profile. Top soil may have been removed for adjustment to field slope before being re-applied or may be sourced from another area. pg: 69

Wheel row  A furrow trafficked by a wheel during field operations. pg: 84
Acronyms

**AE** Application Efficiency. pg: xxi, 10, 15, 24, 28, 36, 38, 39, 51, 54, 55, 76, 118, 172, 180, 229


**EC_a** Apparent Electrical Conductivity. pg: 69, 70

**ET_c** Crop Evapotranspiration. pg: 85

**ET_o** Reference Evapotranspiration. pg: 85

**E_i** Irrigation Efficiency. pg: 224

**IOT** Infiltration Opportunity Time. pg: 15, 19, 25, 32, 120, 121, 136, 137, 184, 185, 230

**PAE** Potential Application Efficiency. pg: 40, 121

**ADV** Acoustic Doppler Velocimeter. pg: 226

**AHD** Australian Height Datum. pg: 75


**DBLB** Drain Back Level Basin. pg: i, xx, xxviii, 5, 13, 15, 17, 19, 24, 25, 50, 51, 53, 61, 62, 64, 218–220, 224

**dGPS** Differential Global Positioning System. pg: 69, 83