TOWARD REAL-TIME CONTROL OF SURFACE IRRIGATION

A Dissertation Submitted by

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To my wife and our daughters with Love

Thank you very much.

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ABSTRACT

The performance 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. The infiltration characteristic of the soil is the most crucial of all the factors affecting the performance of surface irrigation and both spatial and temporal variations in the infiltration characteristic are a major physical constraint to achieving higher irrigation application efficiencies. Real-time optimisation and control has the potential to overcome these spatial and temporal variations and return highly significant improvements in performance. Calculation of the infiltration parameters from irrigation advance data is now the preferred method. If the process is to be included in a real time control system it must be done accurately, reliably and rapidly, and with a minimum of field data. Substantial work has been directed towards developing methods to estimate the infiltration characteristics of soil from irrigation advance data. However, none of the existing methods are entirely suitable for use in real time control. The greatest limitation is that they are data intensive and or unreliable and provide soil infiltration properties after an irrigation event.

A simple real-time control system for furrow irrigation is proposed that: predicts the infiltration characteristics of the soil in real-time using data measured during an irrigation event, simulates the irrigation, and determines the optimum time to cut-off for that irrigation. The basis of the system is a new method for the Real-time Estimation of the Infiltration Parameters (REIP) under furrow irrigation, developed during this research study, and that uses a model infiltration curve, and a scaling process to predict the infiltration characteristics for each furrow and each irrigation event. The underlying hypothesis for the method is that the shape of the infiltration characteristic for a particular field or soil is relatively constant (across the field and with time), despite variations in the magnitude of the infiltration rate or amount. A typical furrow in the field is selected for evaluation (known as the model furrow) and its infiltration parameters \((a, k, f_o)\) in the Kostiakov–Lewis equation are determined by a model such as INFILT or IPARM using inflow, advance and runoff.
data. Subsequently the infiltration parameters for this model furrow can be scaled to give the cumulative infiltration curves for the whole field. In this process a scaling factor \( F \) is formulated from rearrangement of the volume balance equation and is calculated for each furrow/event using the model infiltration parameters and the single advance point. The performance of each furrow can then be simulated and optimised using an appropriate simulation model to determine the preferred time to cut-off.

Using this new method, infiltration parameters were calculated for two different fields T & C. The SIRMOD simulation model was then used to simulate irrigation performance (application efficiency, requirement efficiency and uniformity) under different model strategies. These strategies were framed to assess the feasibility of and demonstrate the gains from the real-time control strategy. The infiltration evaluation results revealed that the infiltration curves produced by the proposed method were of similar shape and hence gave a distribution of cumulative depths of infiltration for the whole field that was statistically equivalent to that given using the complete set of advance data for each furrow. The advance trajectories produced by the proposed method also matched favourably to the measured advances.

The simulation results showed firstly that the scaled infiltration gave predictions of the irrigation performance similar to the actual performance. They also indicated that by adopting the simple real time control system, irrigation application efficiencies for the two fields could be improved from 76% for field T and 39% for field C (under usual farm management) to 83% and 70% for the fields T & C, respectively. Savings of 1239 m\(^3\) in the total volume of water applied per irrigation over the area of 7.1 ha of both fields were indicated, which can be used beneficially to grow more crop. The proposed real-time control system is shown to be feasible. It requires few data for its operation and provides the infiltration characteristics for each furrow without significant loss of accuracy. The irrigation performance is improved greatly from that achieved under current farmer management and a substantial reduction in the volume of water applied per irrigation is achievable.
CERTIFICATION OF DISSERTATION

I certify that the ideas, experimental work, results, analyses and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

20/12/2007

__________________________                   ___________________
Signature of Candidate    Date
(Engineer Kanya Lal)

ENDORSEMENT

____________________________                  ___________________
Signature of Principal Supervisor   Date
(Professor Rod Smith)

____________________________                   ___________________
Signature of Associate Supervisor   Date
(Professor Steven Raine)
PREFACE

All of work reported herein is the original work of the author, contributing toward development of a practical real-time control system for furrow irrigation. Data on furrow irrigation advance for different soils analysed under this study were provided by the National Centre for Engineering in Agriculture (NCEA), USQ, Toowoomba.

Evaluation of methods for determining infiltration characteristics under different furrow characteristics and a range of flow rates and soil types is original and has been published as Khatri & Smith (2005). The new method developed for determining the soil infiltration characteristics from a single advance point in real-time, in conjunction with the new idea of model infiltration curve is novel. This has been published as Khatri & Smith (2006). Evaluation of the method, evaluation of different management strategies to assess the benefits from a simple real-time control and the conclusions reached are all original. This evaluation is being published as Khatri & Smith (2007).

Publications and national or international conference presentations arising from the work reported in the dissertation are listed below.


Khatri, K.L. and Smith, R.J., 2007. Toward a simple real-time control system for efficient management of furrow irrigation. Irrigation and Drainage (In press)


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Gratitude to my wife and our children, parents, sisters and brothers for their love, support and patience throughout this long endeavour. Lastly I would like to thank my friends including Tek Nrayan, Kumaran, Jyotiprakash, Amjad, Elizabeth McCarthy and Malcolm Gillies who offered the wonderful encouragement.

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NOTATION

\( A_o \)  Cross sectional area of flow at the upstream end of the field (m\(^2\))

\( E_a \)  Application efficiency (percent)

\( W_s \)  Volume of water stored in the root-zone (m\(^3\))

\( W_f \)  Volume of water delivered to the field (m\(^3\))

\( R_f \)  Volume of water lost as run-off (m\(^3\))

\( D_f \)  Volume of water lost as deep percolation below the root-zone (m\(^3\))

\( E_r, E_s \)  Requirement or storage efficiency (percent)

\( W_r \)  Volume of water stored in the root-zone (m\(^3\))

\( W_d \)  Volume of water required in the root-zone

\( DU, E_d \)  Distribution uniformity (percent)

\( W_l \)  An average infiltrated depth of water in the lowest one quarter of the field (m)

\( W_a \)  Average infiltrated depth of water over the whole field (m)

\( Q, Q_o \)  Inflow to furrow or bay (m\(^3\)/min)

\( t \)  Time of the advance phase of the irrigation (minute)

\( A_x \)  Volume stored on the surface of the furrow or bay (m\(^3\))

\( Z_{req} \)  Desired depth of application prior to irrigation (mm)

\( Z \)  Infiltrated depth (mm)

\( a, k, and f_o \)  Modified Kostiakov infiltration parameters (constants)

\( V_l \)  Volume infiltrated (m\(^3\))

\( V_S \)  Volume temporarily stored on the soil surface (m\(^3\))

\( V_R \)  Volume of run-off (m\(^3\))

\( x \)  Advance distance (m)

\( \bar{A} \)  Average cross sectional area of the surface flow

\( \sigma_y \)  Surface storage shape factor (Constant)

\( \sigma_z \)  Sub-surface shape factor for the model infiltration function

\( p \)  and \( r \)  Advance power function fitted parameters (constants)

\( I \)  Cumulative infiltration (m\(^3\)/m)

\( \tau \)  Infiltration opportunity time (min)

\( Q_{out} \)  Irrigation runoff from end of field (m\(^3\)/minute)
\(c\) Constant of USDA infiltration model (0.007)

\(F, \theta\) Upadhyaya and Raghuwanshi fitted parameters

\(x_{max}\) Maximum possible advance distance (m)

\(Z_{CR}\) Depth of water infiltrated into soil cracks

\(S, A\) Philip and Farrell modified empirical parameters

\(I_s\) Scaled infiltration (\(m^3/m\))

\(t_{co}\) cut-off time (min)

\(t_{measured}\) Measured advance time (minute)

\(t_{simulated}\) Simulated advance time (minute)
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