IMPROVING THE HYDRAULIC PERFORMANCE OF SURFACE IRRIGATION SYSTEMS

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Surface irrigation systems are often described as inherently inefficient.

<table>
<thead>
<tr>
<th>System Type</th>
<th>Application Efficiency Range* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surface Irrigation</strong></td>
<td></td>
</tr>
<tr>
<td>Basin</td>
<td>60 - 95</td>
</tr>
<tr>
<td>Border</td>
<td>60 - 90</td>
</tr>
<tr>
<td>Furrow</td>
<td>50 - 90</td>
</tr>
<tr>
<td>Surge</td>
<td>60 - 90</td>
</tr>
<tr>
<td><strong>Sprinkler Irrigation</strong></td>
<td></td>
</tr>
<tr>
<td>Handmove</td>
<td>65 - 80</td>
</tr>
<tr>
<td>Traveling Gun</td>
<td>60 - 70</td>
</tr>
<tr>
<td>Center Pivot &amp; Linear</td>
<td>70 - 95</td>
</tr>
<tr>
<td>Solid Set</td>
<td>70 - 85</td>
</tr>
<tr>
<td><strong>Microirrigation</strong></td>
<td></td>
</tr>
<tr>
<td>Point source emitters</td>
<td>75 - 95</td>
</tr>
<tr>
<td>Line source emitter</td>
<td>70 - 95</td>
</tr>
</tbody>
</table>

* Efficiencies can be much lower due to poor design or management. These values are intended for general system type comparisons and should not be used for specific systems.
Factors that control the hydraulic performance of irrigation systems

- Hydraulic design
- Operation
- Water management strategy: application amount depends on
  - Crop consumptive use (ET)
  - Yield, productivity of irrigation water, and quality
  - Salinity management
Applied irrigation water and yield for alfalfa

**Applied water**

- WYOMING
- WASHINGTON
- UTAH
- OREGON
- NEW MEXICO
- NEVADA
- MONTANA
- IDAHO
- COLORADO
- CALIFORNIA
- ARIZONA

**Yield**

- WYOMING
- WASHINGTON
- UTAH
- OREGON
- NEW MEXICO
- NEVADA
- MONTANA
- IDAHO
- COLORADO
- CALIFORNIA
- ARIZONA

*Source: FRIS 2013*
Can we improve the performance of existing surface irrigation systems?
The Australian experience

- Challenges
  - Most land is surface irrigated
  - Heavy soils
  - Typically, long runs
  - High energy and labor costs
  - Unpredictable surface water supplies is a disincentive to investing in pressurized irrigation

- Efforts to improve performance of surface irrigation on farm
  - Collaboration between University of Southern Queensland and consultants
  - Field evaluations and modeling work
Improving performance of bay irrigation through higher flow rates

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Evaluating the Performance of Bay Irrigation in the GMID

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ABSTRACT

The CRC for Irrigation Futures recently undertook a project piloting use of the IrriMATE™ performance evaluation process in bay irrigation at a number of sites across the Goulburn Murray Irrigation District (GMID). This evaluation technique, which was developed originally for furrow irrigation, is now well accepted in the cotton industry.

The project successfully demonstrated that evaluation of performance can lead to substantial realisable gains in efficiency for bay irrigation, including the ‘good’ irrigators. For the irrigations evaluated, application efficiencies averaged 72% and realisable gains in efficiency of 19% are possible with changed management. For most farmers this will mean application of higher flow rates and shorter irrigation times. Practically this means on-farm automation.
Irrigation System Evaluation
Volume balance

\[ V_z = V_{in} - V_y - V_{ro} \]

- \( V_{in} \): inflow volume
- \( V_y \): surface volume
- \( V_{ro} \): runoff volume
- \( V_z \): infiltrated volume
Evaluation data

- Field geometry and slope
- Inflow rate
- Runoff rate (free-draining systems)
- Advance times with distance
- Recession times with distance
- Flow depths as a function of time and distance
Volume balance can be calculated at many times during the irrigation event.
Objective is to characterize the infiltration process of the field.
Final infiltration profile, and irrigation performance measures

- Dapp – applied depth
- Dinf – infiltrated depth
- Dreq – required depth
- Dro – runoff depth
- Ddp – deep percolation depth
- Drz – infiltrated depth contributing to the required (Dz in WinSRFR manual)
- Dmin = minimum depth
- Dilq – low-quarter depth
Distribution uniformity of the low quarter (or minimum)

\[ DU_{lq} = \frac{D_{lq}}{D_{inf}} \quad DU_{\text{min}} = \frac{D_{\text{min}}}{D_{inf}} \]
Application efficiency

\[ AE(\%) = \frac{D_{rz}}{D_{app}} \times 100 \]
Adequacy of the low-quarter (or minimum)

\[ AD_{\text{min}} = \frac{D_{\text{min}}}{D_{\text{req}}} \]

\[ AD_{\text{Lq}} = \frac{D_{\text{Lq}}}{D_{\text{req}}} \]
Example 1

- **Field** – 625 ft long × 185 m wide
- **Slope** – 0.001 (blocked)
- **Soil** – very sandy
- **Crop** – Citrus orchard
- **Estimated irrigation requirement** – 2 to 3 in
- **Inflow rate** – 17.6 cfs
Evaluation by post-irrigation volume balance

Inflow rate

Advance and recession

Average applied depth = 3.3 in
Estimated infiltration function and predicted final infiltration profile

Infiltration function

Final infiltration profile
System performance

- \( DU_{Lq} = 0.52 - 0.63 \)
- \( AE = 75 - 78\% \)
- \( AD_{Lq} = 0.58 - 0.7 \)
What can we say about the causes of inadequate performance?

Infiltration profile

Advance-recession times

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Field 1 - Simulation:Folder 1 - NRCS IF=0.9
Field 1 - Simulation:Folder 1 - MKost
Field 1 - Simulation:Folder 1 - GreenAmpt

Field 1 - Event:Folder 1 - Field Data
Effect of reducing inflow rate by half (17.6 vs. 8.8 cfs)

Predicted advance-recession

Predicted final infiltration profile
Effect of inflow rate on flow depths

$Q = 17.6 \text{ cfs}$

$Q = 8.8 \text{ cfs}$
Example 2

- Field dimensions $L = 1052$ ft, $W = 92$ ft
- Slope = 0.003 (free-draining)
- Crop – barley
- Inflow rate 6 cfs
- Soil loamy-sand, sandy loam
- Irrigation requirement – at most 2 in
Evaluation using post-irrigation volume balance

Inflow and runoff

Advance and recession times

Chart Title

Applied depth = 8 in, runoff = 1 in
Potential performance

- DUlq ~ 0.80
- AE ~ 25%
- ADlq ~ 3
Design is very inadequate but operation of the system is very good!
Field example 3

- Near-level furrows (blocked)
- Length - 560 ft, Width - 36 ft (11 furrows per set)
- Slope = 0.0002
- Inflow rate - 0.76 cfs (31 gpm per furrow)
- Soil – sandy-loam to sandy-clay-loam
- Crop – cotton
- Irrigation requirement – 3 to 4 in
Temporal variation of infiltration

Advance and recession

Infiltration function
Spatial variation of infiltration

**Advance and recession**

**Infiltration function**
$\text{DU}_{lq}$ for 16 basins over 7 irrigation events

**Dulq from probe measurements**

**DUlq from evaluation**
Hydraulic performance as a function of geometry, field conditions, and inflow rate

Modern analysis of surface irrigation systems using hydraulic modeling tools
WinSRFR

- Developed for and used by NRCS
- Runs on the Windows OS
- Current version 4.1 (2012); version 5.1 to be released in 2016
- Free of cost
Basic data requirements (simulation)

- Field dimensions (length, width)
  - For furrows, number of furrows and furrow geometry
- Field bottom slope
- Inflow rate
- Description of infiltration and hydraulic resistance
Irrigation models

- … Are tools that allow us to
  - Examine the potential performance of alternative designs or operational scenarios
  - Examining the sensitivity of a recommended design or operational configuration
- Results need to be interpreted judiciously because inputs are uncertain
Potential Application Efficiency (of the minimum or the low quarter)

\[ PAE_{\text{min}} = \frac{D_{rz}}{D_{app} (D_{req} = D_{\text{min}})} \]

\[ PAE_{lq} = \frac{D_{rz}}{D_{app} (D_{req} = D_{lq})} \]
Example: Design of a sloping border irrigation system

- Assume a field 2600 ft long 680 ft wide (≈800 m X 207 m)
- Slope 0.001
- Available inflow rate 10 cfs (1 cfs = 448.8 gpm = 28.32 l/s)
- Soil – loam soil (described by the USDA-NRCS 0.7 infiltration family)
- Crop – alfalfa (hydraulic resistance given by Manning n = 0.15)
- Irrigation requirement - 3.5 in

- OBJECTIVE: recommend a field layout (length and width)
Design contour: Potential Application Efficiency

Potential Application Efficiency (%)
PAElq as a function of border area
Other performance considerations:

Distribution uniformity

Distribution uniformity of the minimum for example

Overlay of PAEmin and DUmin
Relative cutoff ratio

Relative cutoff (R)

Overlay of PAEmin and R
Preliminary design recommendation

- Length 1300 ft, width 226 ft

Performance Indicators:
- Length (L) = 1300 ft
- Runoff (% RO) = 20%
- Precipitation (PAE) = 65%
- Width (W) = 226 ft
- Dry season depth (Dro) = 1.08 in
- Minimum depth (Dmin) = 0.809
- Flow rate (Q) = 10 cfs
- Design depth (DP) = 15%
- Diffusion depth (Dd) = 0.84 in
- Minimum depth (Dmin) = 3.54 in
- Time (Tc) = 3.71 hr
- Apparent depth (Dapp) = 5.46 in
- Diffusion depth (Dlq) = 3.98 in
- Rainfall (R) = 1.0421

Costs = $26.94/acre, Total = $181.73
However, design inputs are uncertain

- The inflow rate is subject to substantial variations, in the range 7 to 12 cfs
- Infiltration exhibits substantial variability during the irrigation season
- How will the proposed system perform under those conditions? (and considering other potential sources of uncertainty in the design)
Robust control methods are designed to deliver adequate performance considering the uncertainty of inputs (and possible unexpected disturbances)
Operation contour: inflow rate vs. cutoff time
Water distribution at three flow rate values

Distribution of applied water

Cutoff and advance time

Water depth (in) vs. Flow rate (cfs)

Cutoff and advance time (hr) vs. Flow rate (cfs)
What is the effect of infiltration variation during the season?

Infiltration function: NRCS IF 0.5-0.9

Distribution of applied water
Automation and surface irrigation

- Control of applied volume
- Control of application flow rate (feedback control)
Controllability of surface irrigation systems

- Surface irrigation systems are
  - inherently stable
  - Have a long time delay
  - Are subject to substantial uncertainty
  - As a result, their controllability is limited

- Adequate performance depends mostly on design
  - Feedback control can enhance operation and performance, but cannot overcome a defective design
Questions?