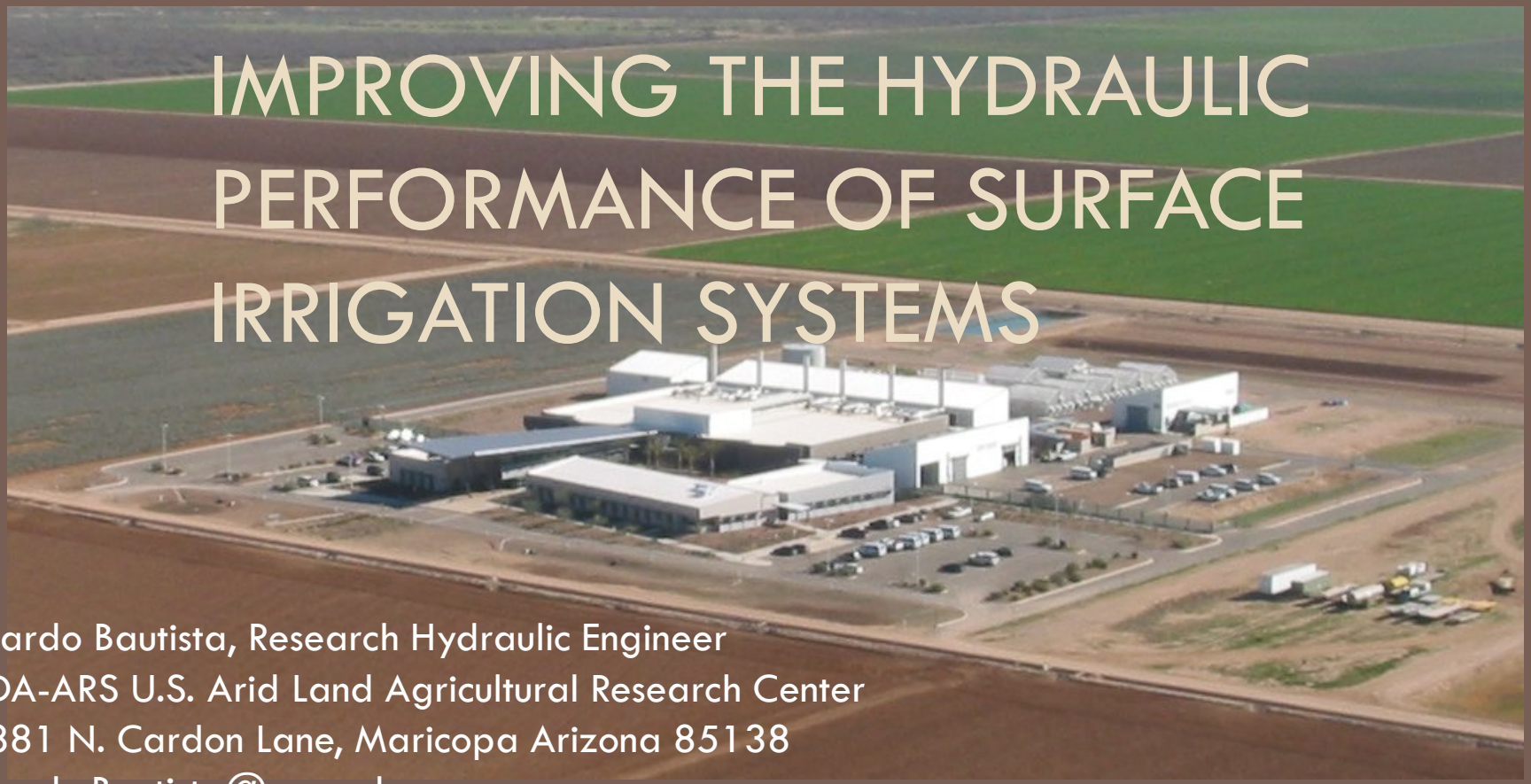
IMPROVING THE HYDRAULIC PERFORMANCE OF SURFACE IRRIGATION SYSTEMS



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Surface irrigation Workshop, Univ. of California Kearney Agricultural Center, June 3, 2016

ARID-LAND AGRICULTURAL RESEARCH CENTER

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Surface irrigation systems are often described as inherently inefficient

IRRIGATION MANAGEMENT SERIES

EFFICIENCIES AND WATER LOSSES OF IRRIGATION SYSTEMS

Danny H. Rogers, Freddie R. Lamm, Mahbub Alam, Todd P. Trooien, Gary A. Clark, Philip L. Barnes and Kyle Mankin, Kansas State University, Research and Extension Engineers

Table 1. Range of Application Efficiencies for Various Irrigation Systems

System Type	Application Efficiency Range* (%)
Surface Irrigation	
Basin	60 - 95
Border	60 - 90
Furrow	50 - 90
Surge	60 - 90
Sprinkler Irrigation	
Handmove	65 - 80
Traveling Gun	60 - 70
Center Pivot & Linear	70 - 95
Solid Set	70 - 85
Microirrigation	
Point source emitters	75 - 95
Line source emitter	70 - 95

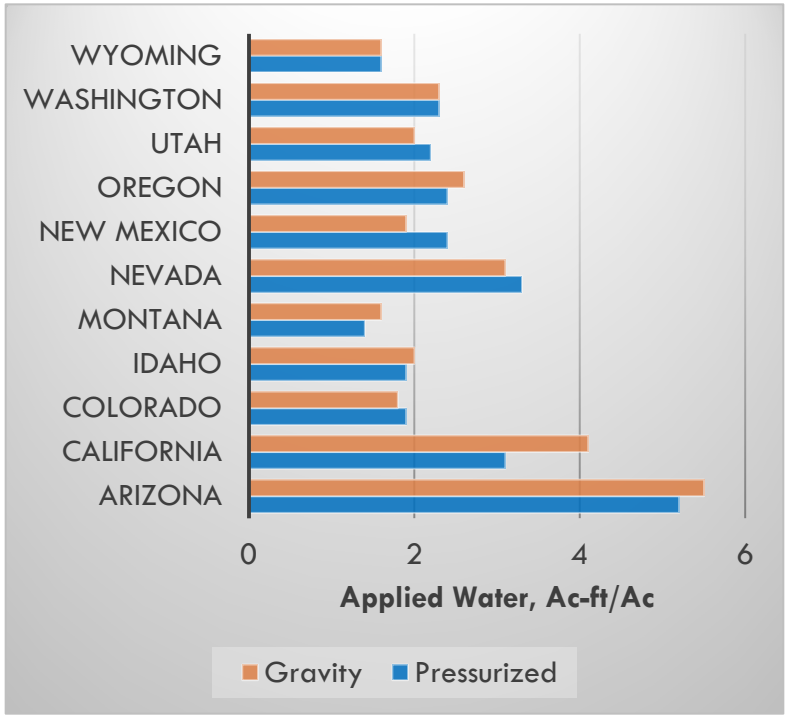
** Efficiencies can be much lower due to poor design or management. These values are intended for general system type comparisons and should not be used for specific systems.*

Factors that control the hydraulic performance of irrigation systems

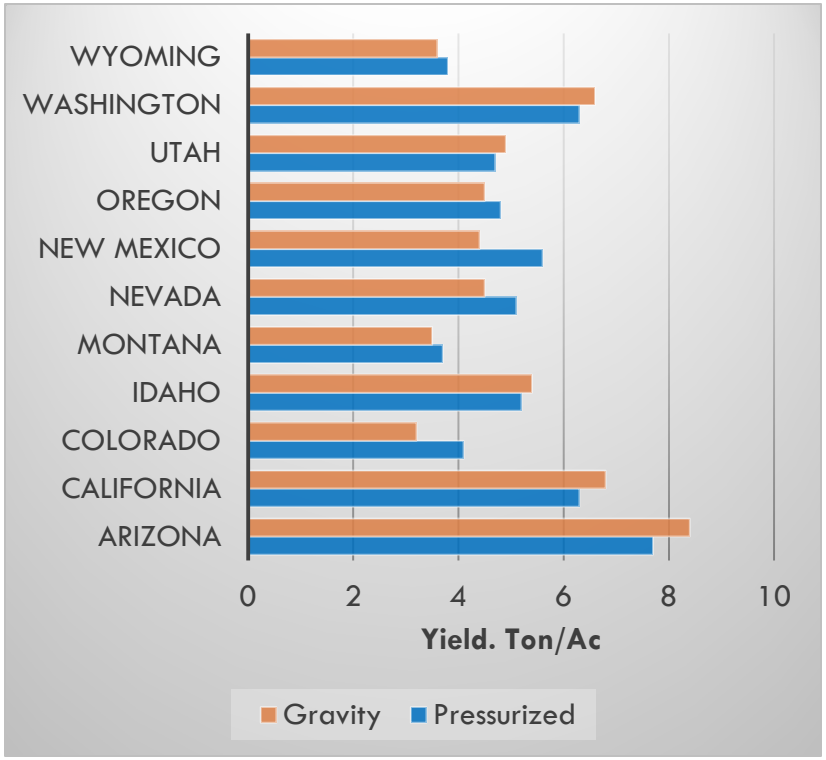
- Hydraulic design
- Operation
- Water management strategy: application amount depends on
  - Crop consumptive use (ET)
  - Yield, productivity of irrigation water, and quality
  - Salinity management

Applied irrigation water and yield for alfalfa

Applied water



Yield



Source: FRIS 2013

Can we improve the performance of exisiting 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

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Irrigation application efficiency and deep drainage potential under surface irrigated cotton

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Contents lists available at ScienceDirect
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A comparative analysis of water application and energy consumption at the irrigated field level

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Improving performance of bay irrigation through higher flow rates

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INCREASED FURROW IRRIGATION EFFICIENCY THROUGH BETTER DESIGN AND MANAGEMENT OF CANE FIELDS

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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

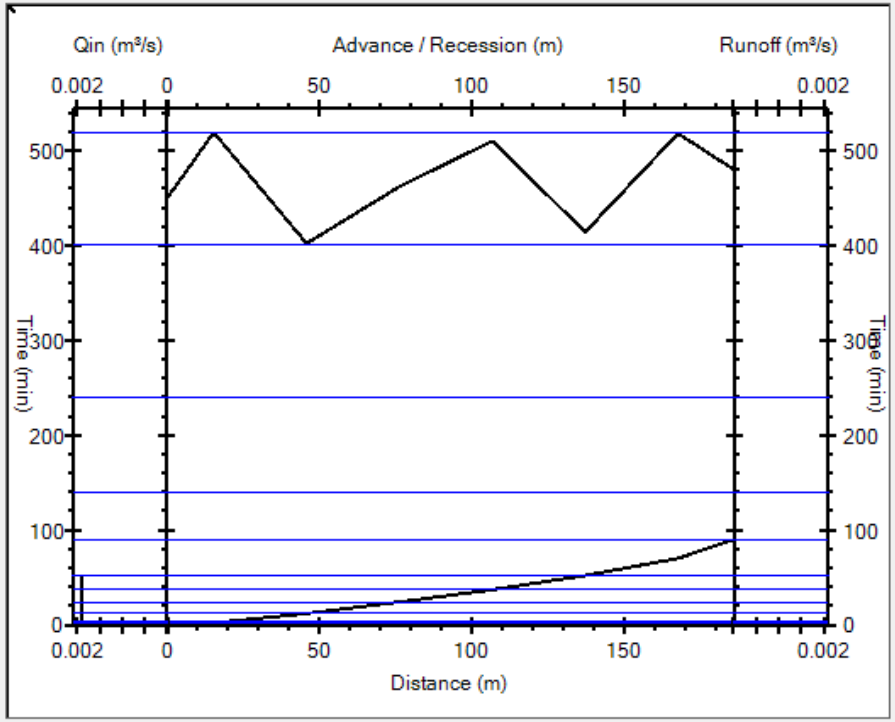
Farm: Project 1, **Field:** Case 1
Folder: Level basin-CRC1, **Analysis:** Evalue: advance, flow depths,and recession

EVALUE Analysis

Suggest Times for Volume Balance Calculations

Volume Balance

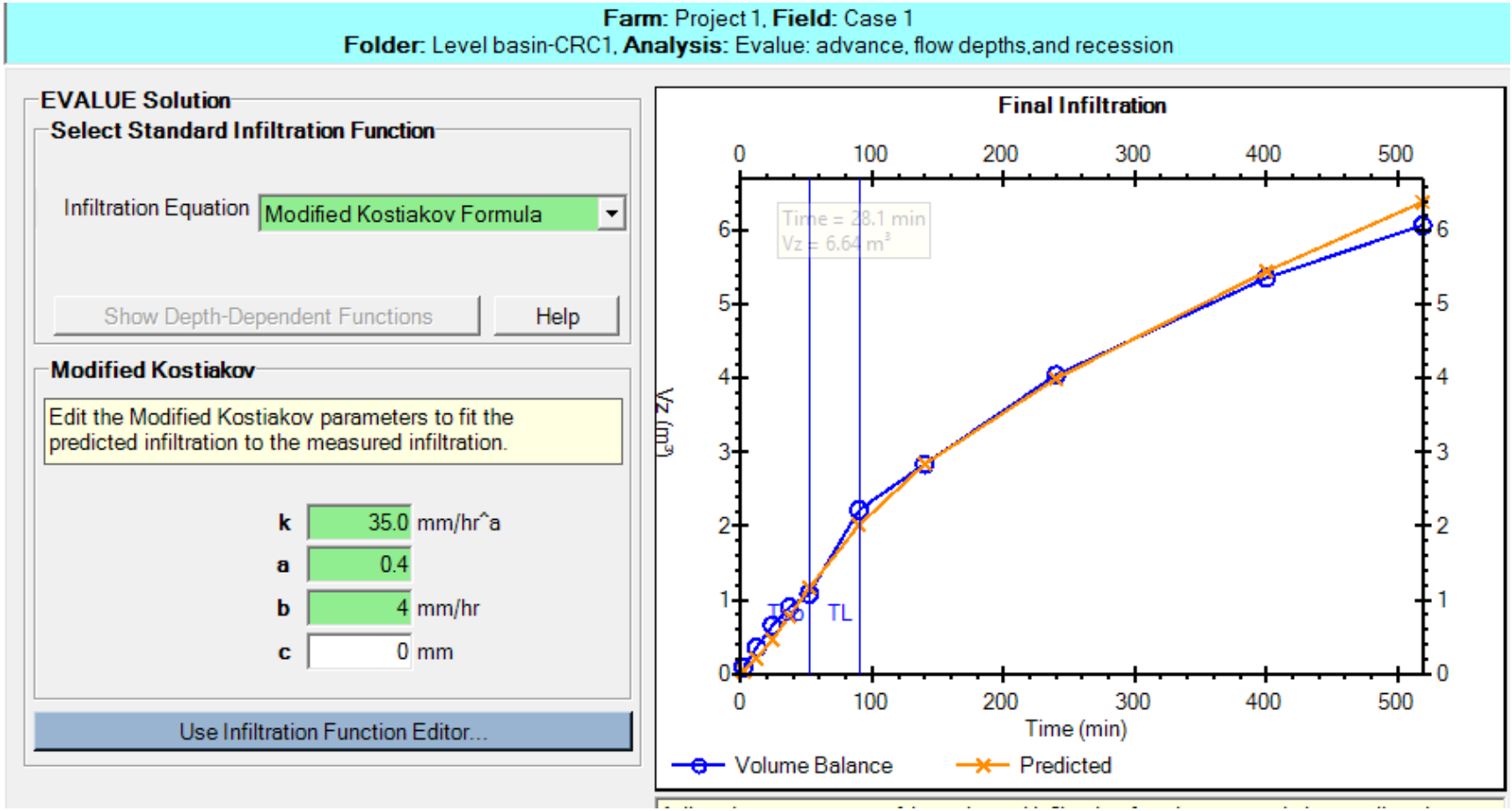
Time (min)	Vin (m^3) *	Vy (m^3) *	Vro (m^3) *	Vz (m^3) *
2	0.23	0.14	0.00	0.09
12	1.38	1.02	0.00	0.36
24	2.75	2.10	0.00	0.65
37	4.24	3.34	0.00	0.90
52	5.96	4.88	0.00	1.08
90	6.07	3.86	0.00	2.22
140	6.07	3.23	0.00	2.84
240	6.07	2.03	0.00	4.05
400	6.07	0.71	0.00	5.36
519	6.07	0.00	0.00	6.07



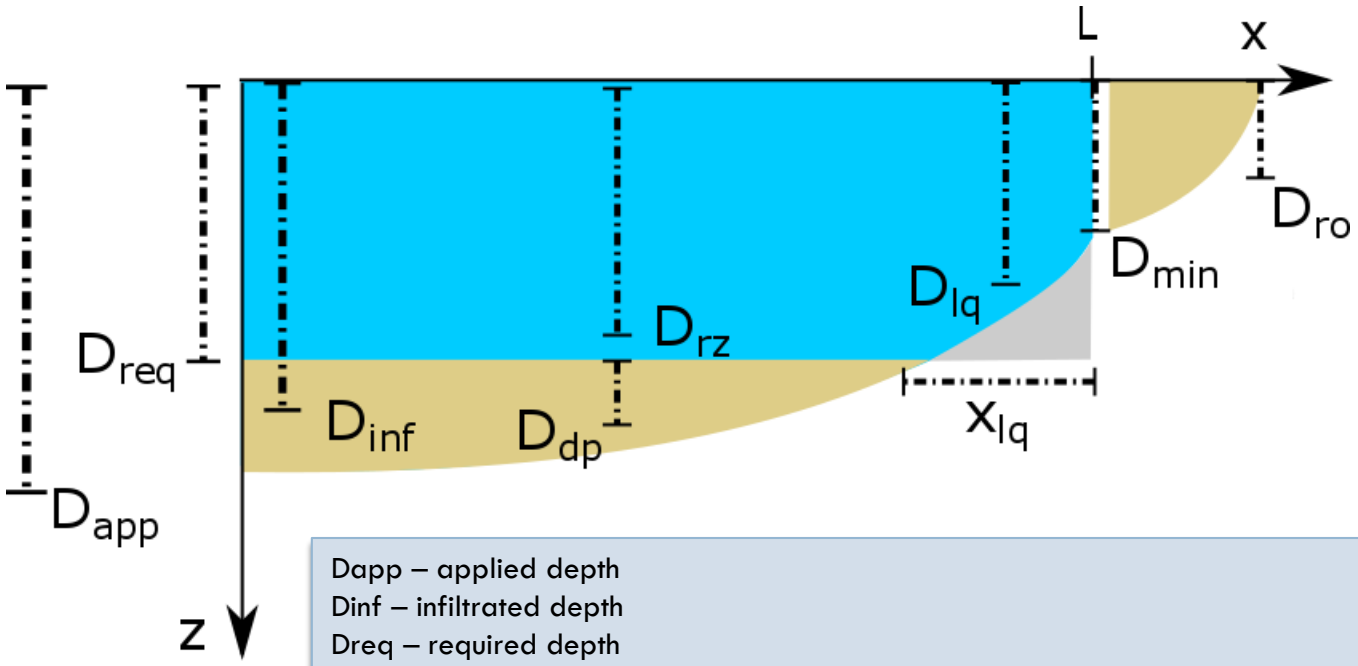
Volume balance calculation times are shown with blue lines.

These irrigation measurements will be used for calculating volume balances:
Inflow, Advance, Recession, Flow Depths

Objective is to characterize the infiltration process of the field

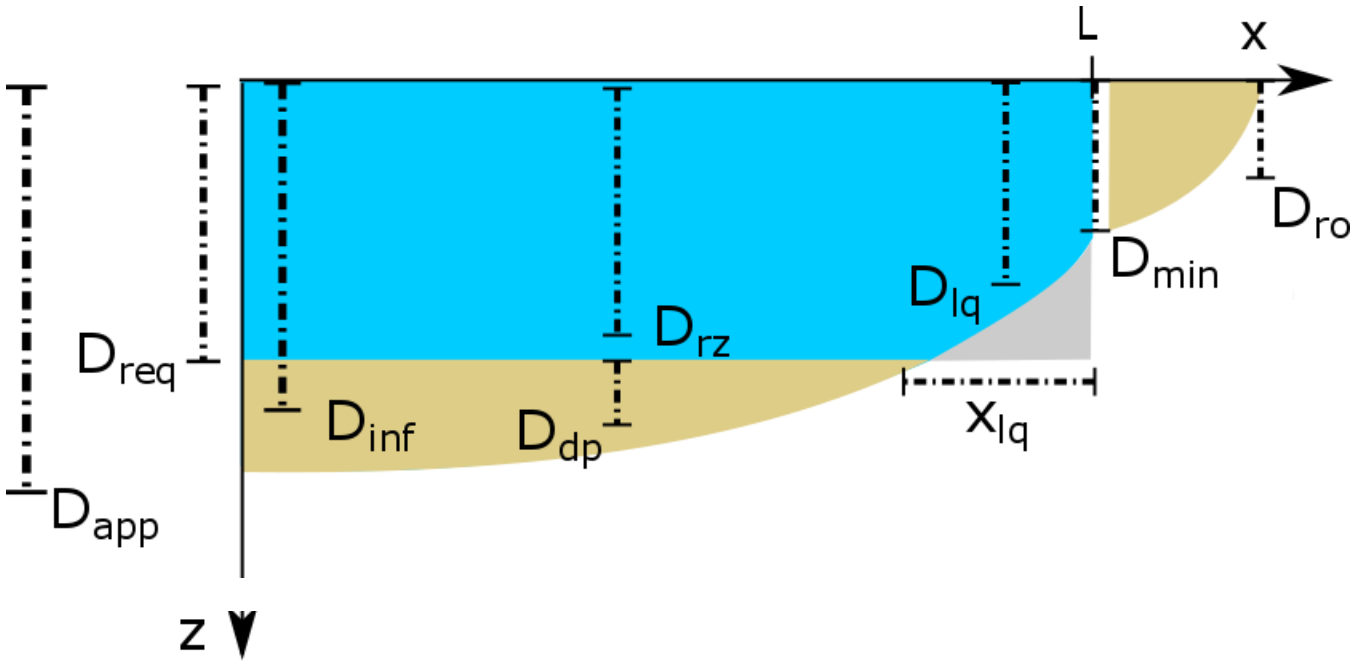


Final infiltration profile, and irrigation performance measures



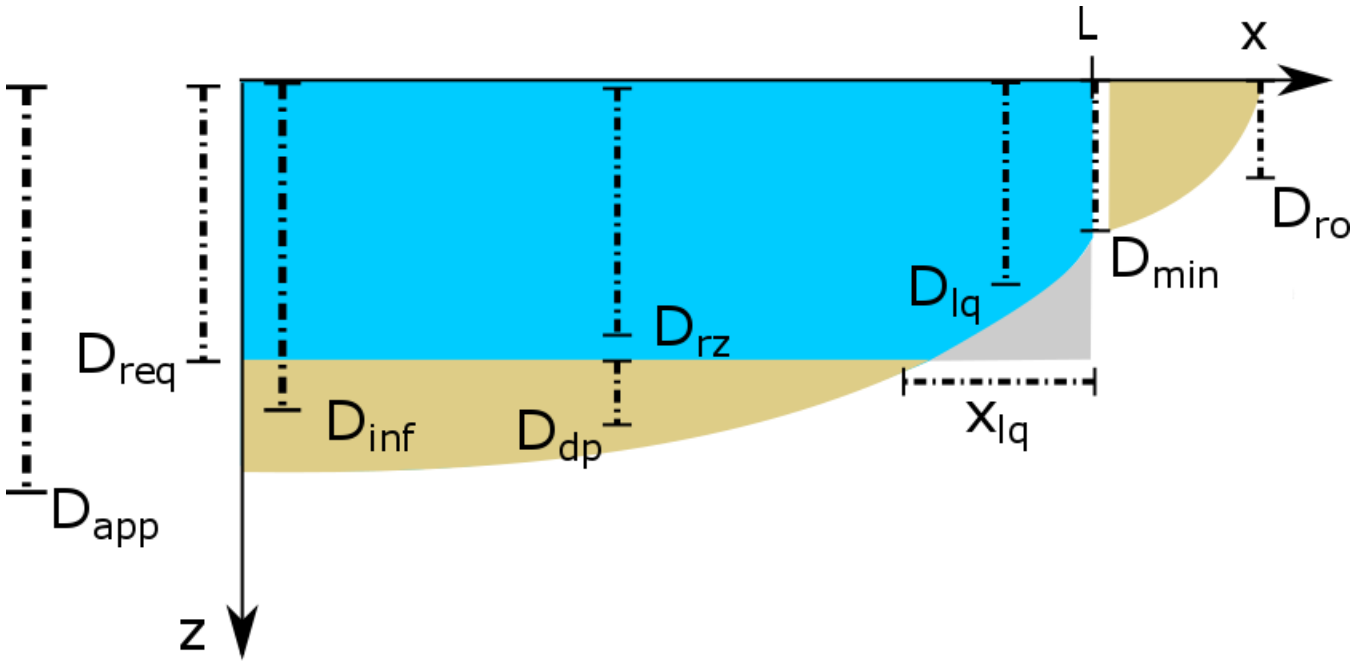
Dapp – applied depth
Dinf – infiltrated depth
Dreq – required depth
Dro – runoff depth
Ddp – deep percolation depth
Drz – infiltrated depth contributing to the required (Dz in WinSRFR manual)
Dmin = minimum depth
Dlq – low-quarter depth

Distribution uniformity of the low quarter (or minimum)



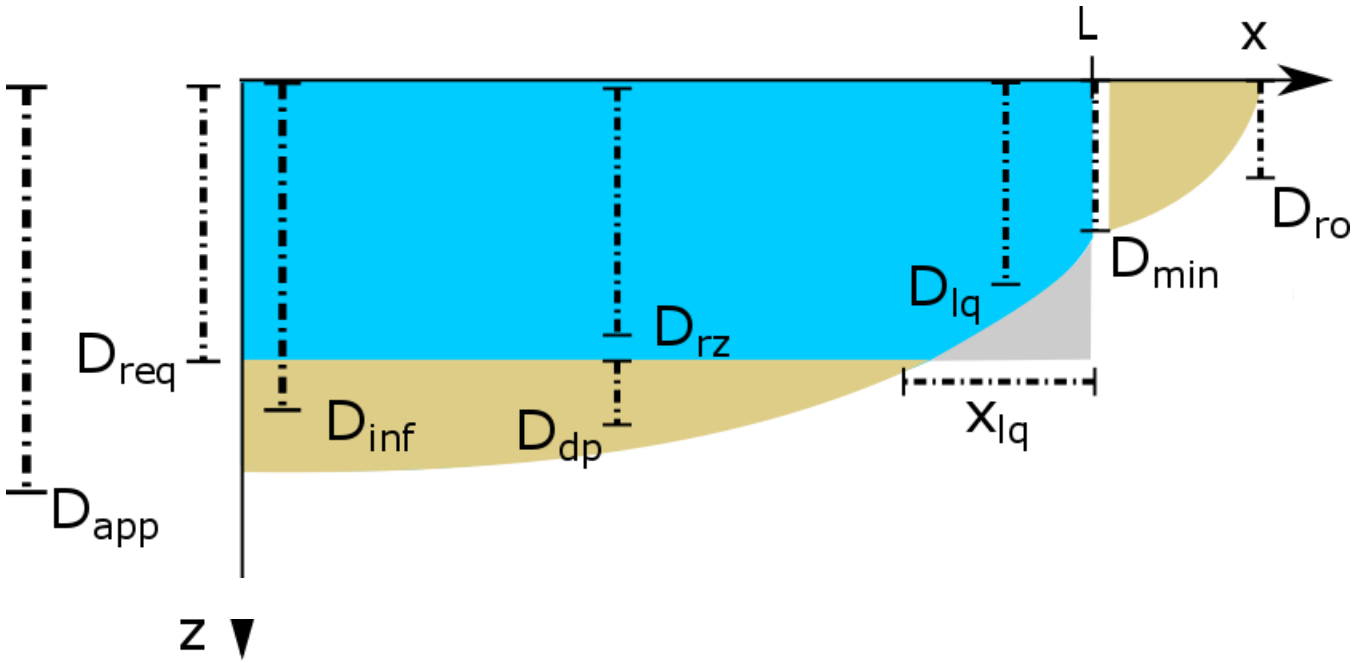
$$DU_{lq} = \frac{D_{lq}}{D_{\inf}} \qquad DU_{\min} = \frac{D_{\min}}{D_{\inf}}$$

Application efficiency



$$AE(\%) = \frac{D_{rz}}{D_{app}} \times 100$$

Adequacy of the low-quarter (or minimum)



$$AD_{\min} = \frac{D_{\min}}{D_{req}}$$

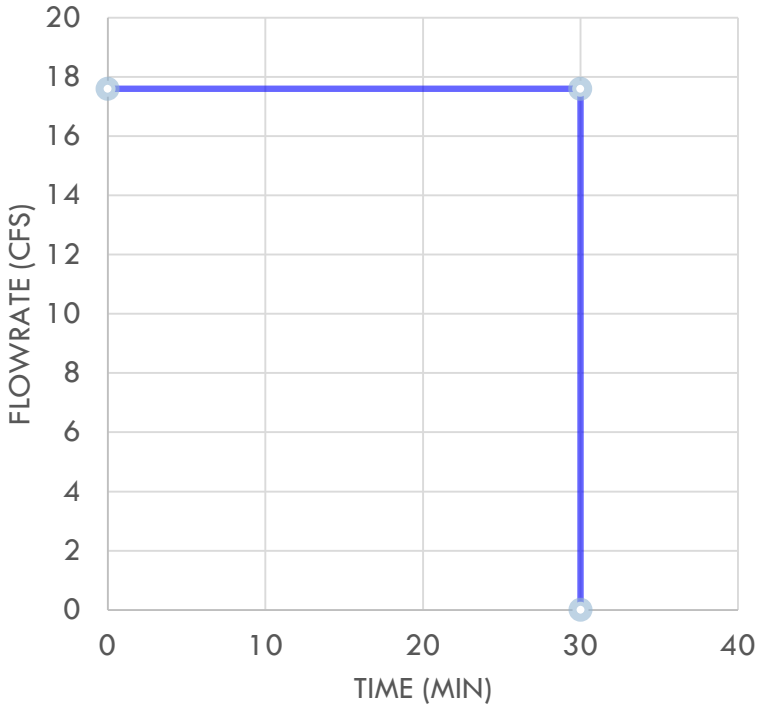
$$AD_{lq} = \frac{D_{lq}}{D_{req}}$$

Example 1

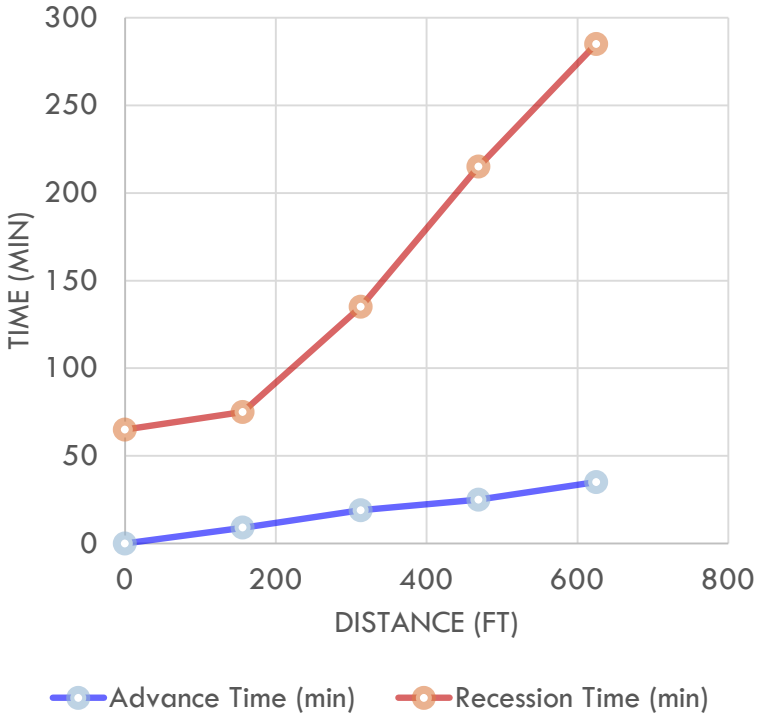
- Field – 625 ft long X 185 m wide
- Slope – 0.001 (blocked)
- Soil – very sandy
- Crop – Citrus orchard
- Estimated irrigation requirement – 2 to 3 in
- Inflow rate -17.6 cfs

Evaluation by post-irrigation volume balance

Inflow rate



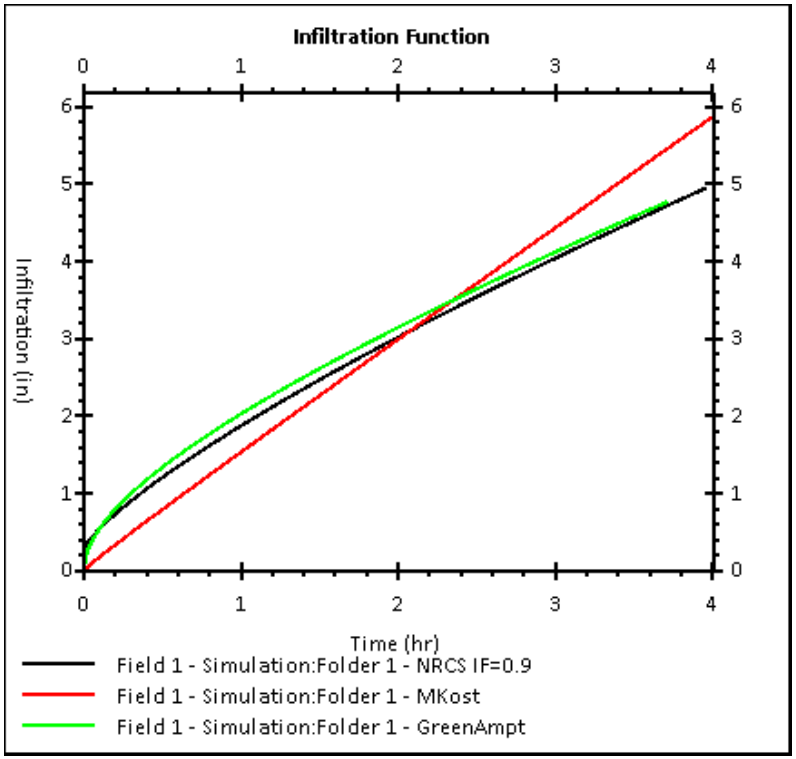
Advance and recession



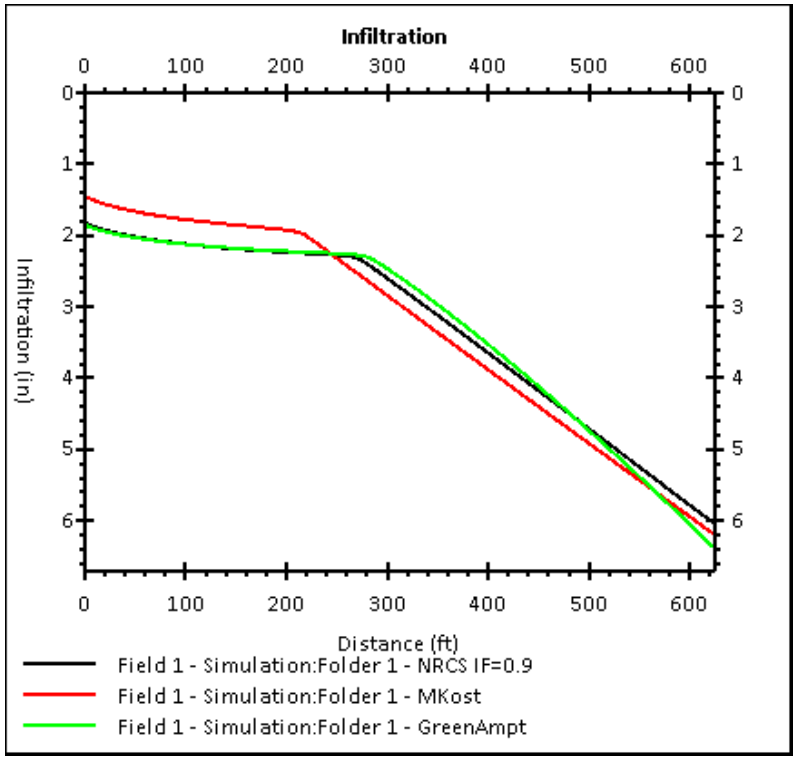
Average applied depth = 3.3 in

Estimated infiltration function and predicted final infiltration profile

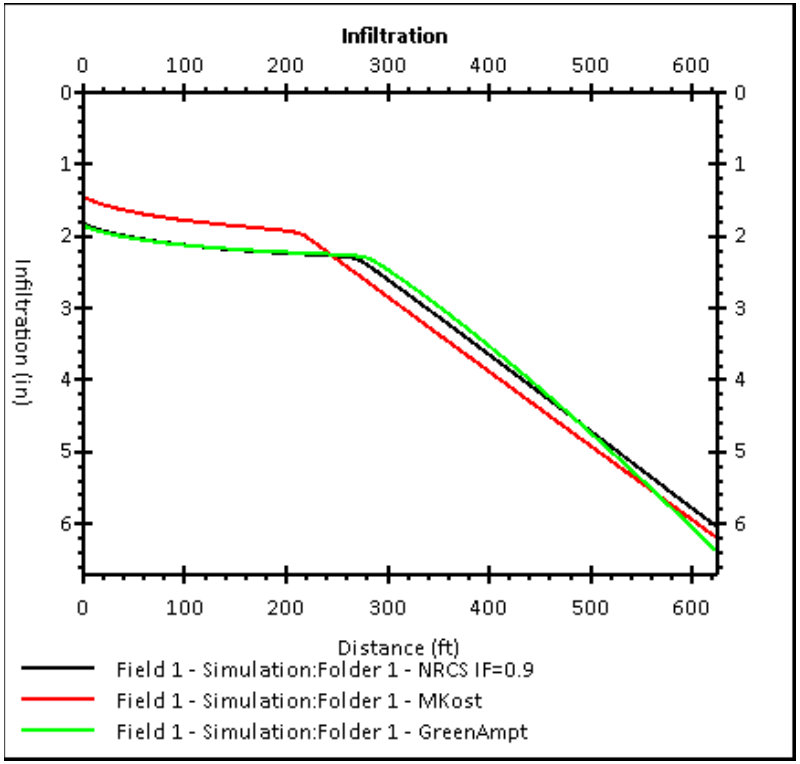
Infiltration function



Final infiltration profile



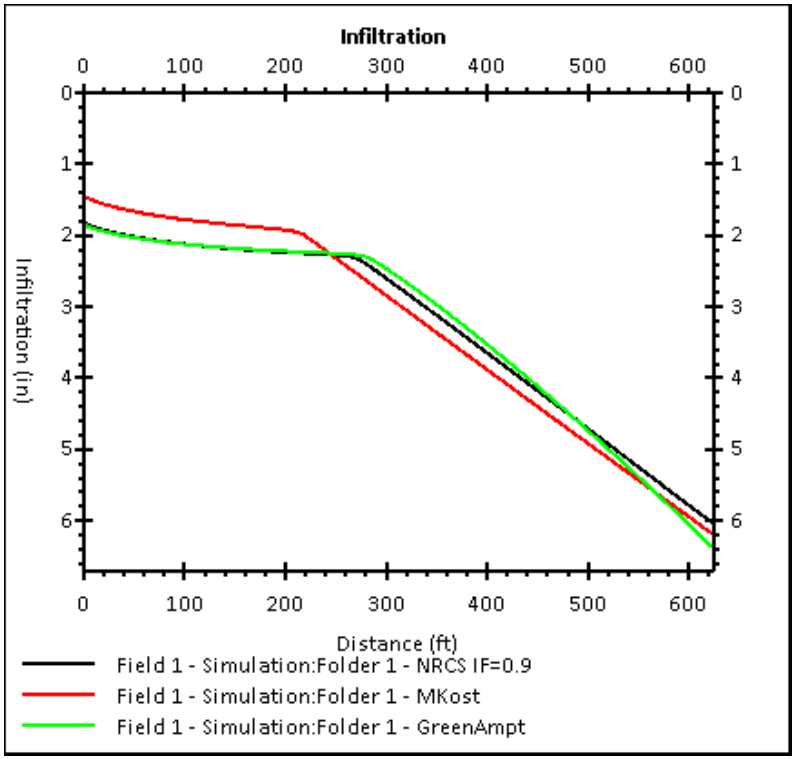
System performance



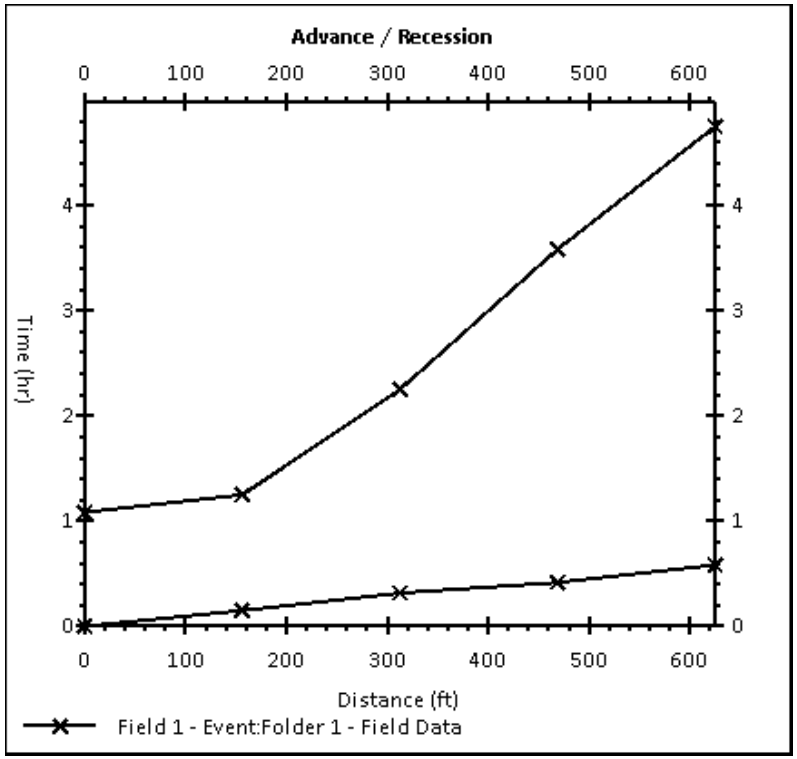
- DUlq = 0.52-.63
- AE = 75-78 %
- ADlq = 0.58-0.7

What can we say about the causes of inadequate performance?

Infiltration profile

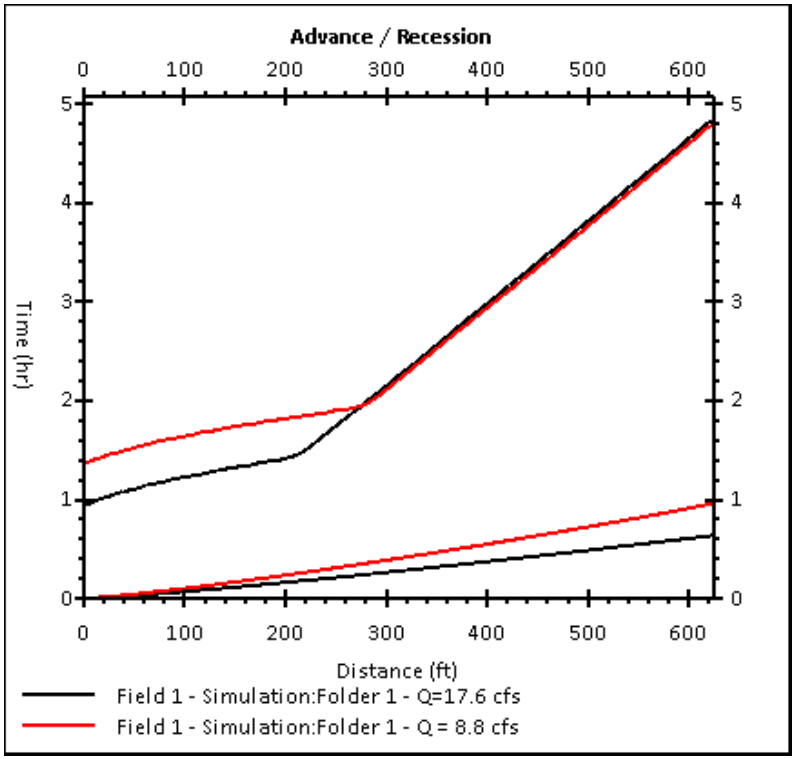


Advance-recession times

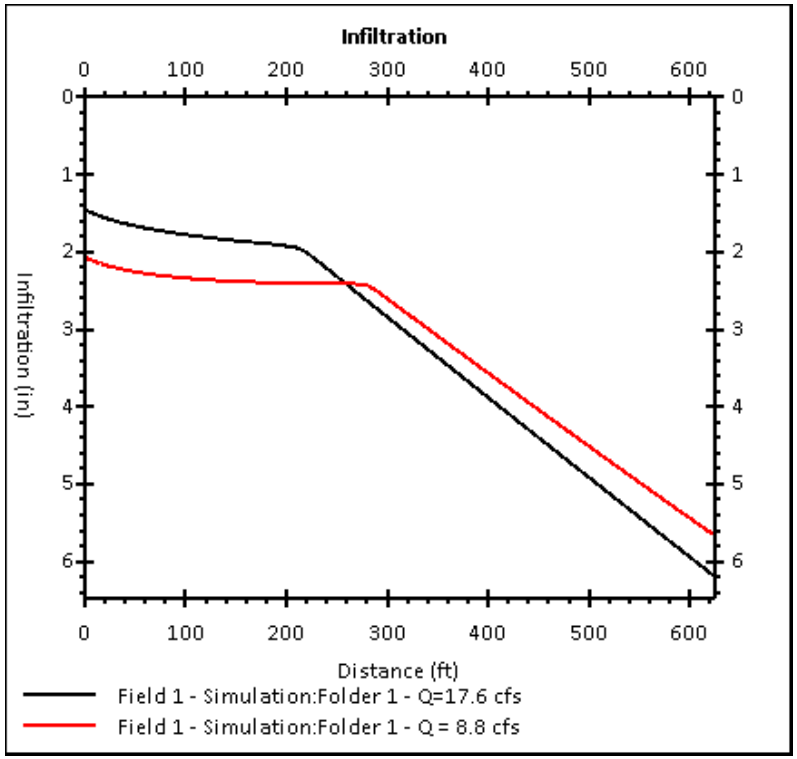


Effect of reducing inflow rate by half (17.6 vs. 8.8 cfs)

Predicted advance-recession

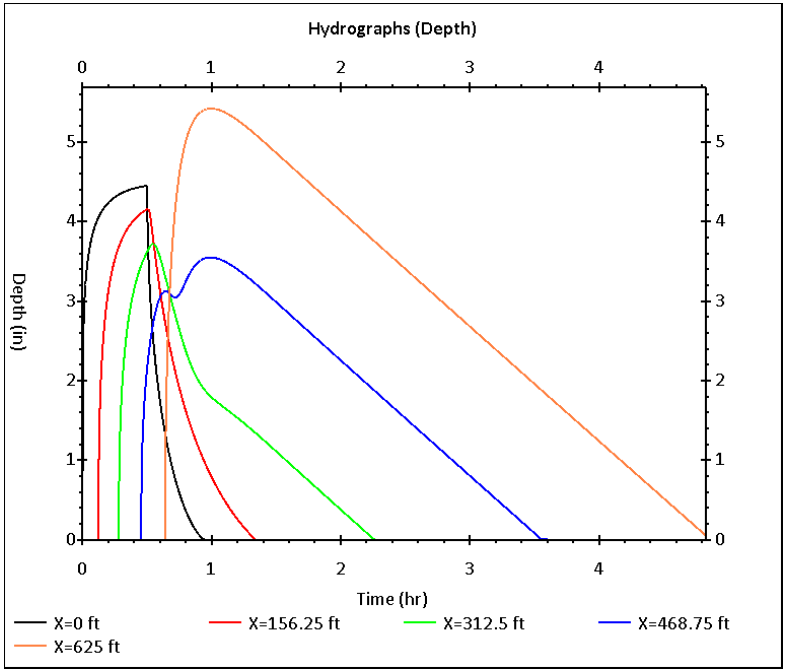


Predicted final infiltration profile

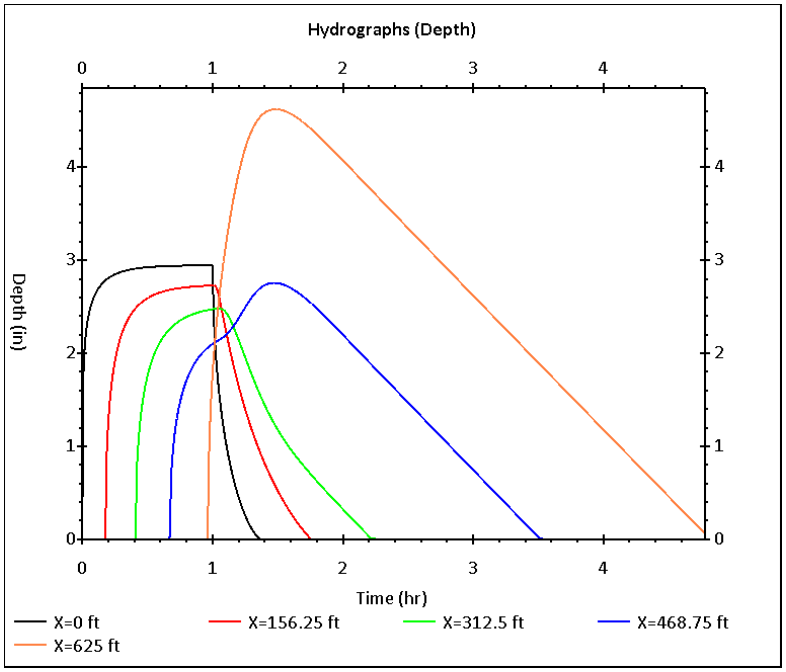


Effect of inflow rate on flow depths

Q = 17.6 cfs



Q = 8.8 cfs

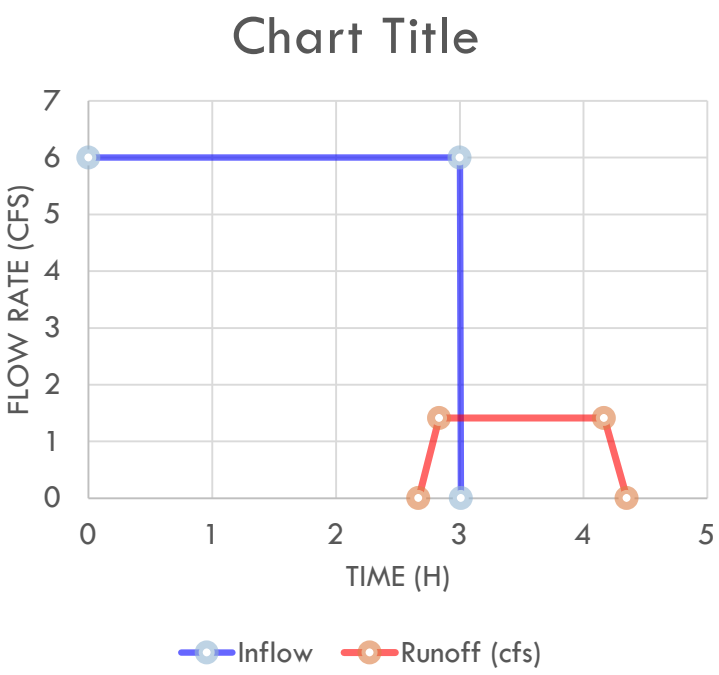


Example 2

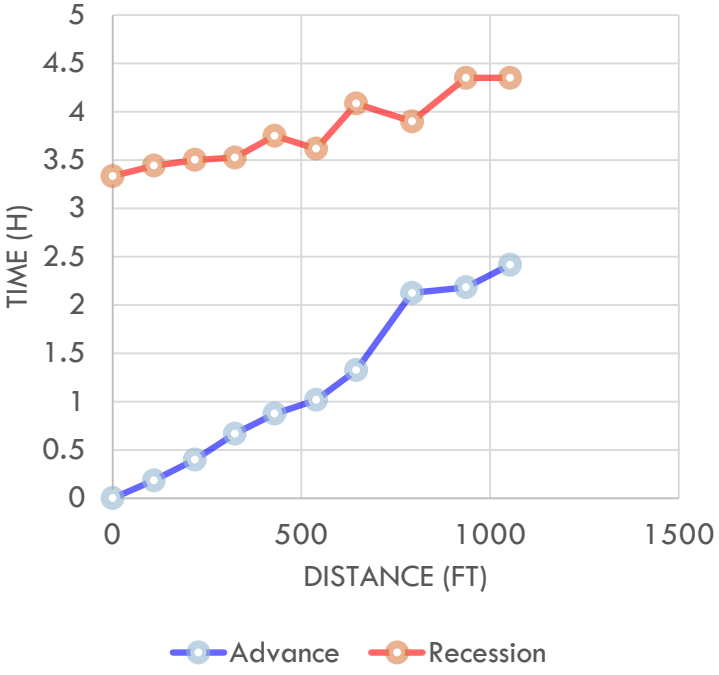
- Field dimensions L = 1052 ft, W = 92 ft
- Slope = 0.003 (free-draining)
- Crop – barley
- Inflow rate 6 cfs
- Soil loamy-sand, sandy loam
- Irrigation requirement – at most 2 in

Evaluation using post-irrigation volume balance

Inflow and runoff



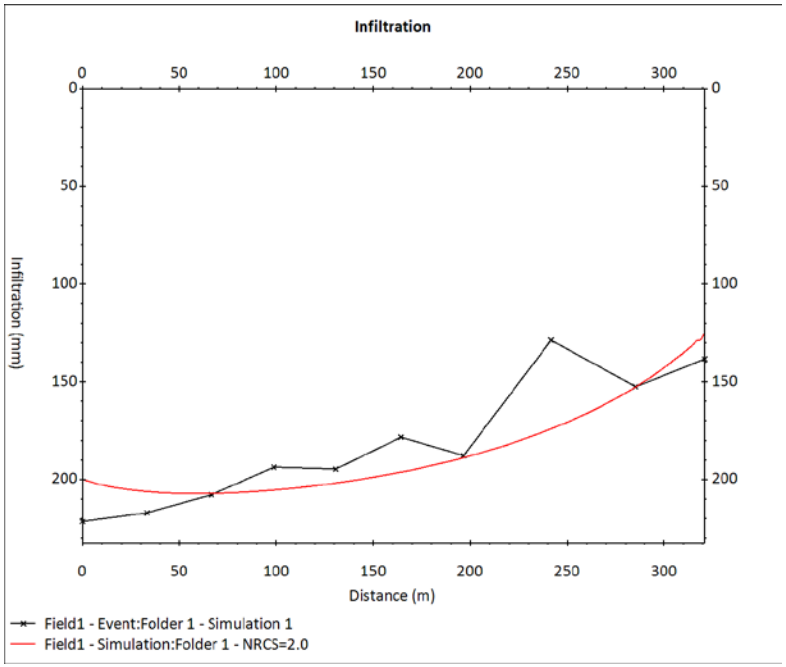
Advance and recession times



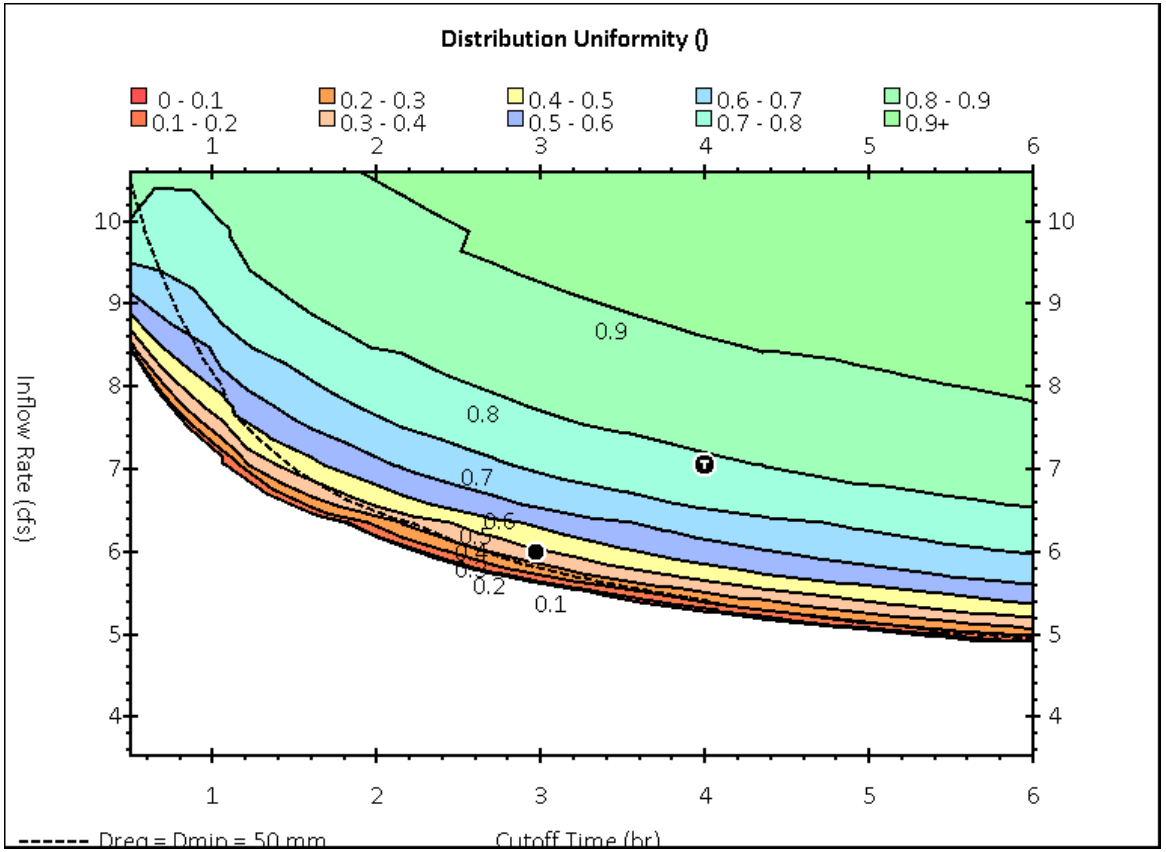
Applied depth – 8 in, runoff = 1 in

Potential performance

- DUlq ~ 0.80
- AE ~ 25%
- ADlq ~ 3



Distribution uniformity as a function of flow rate and cutoff time



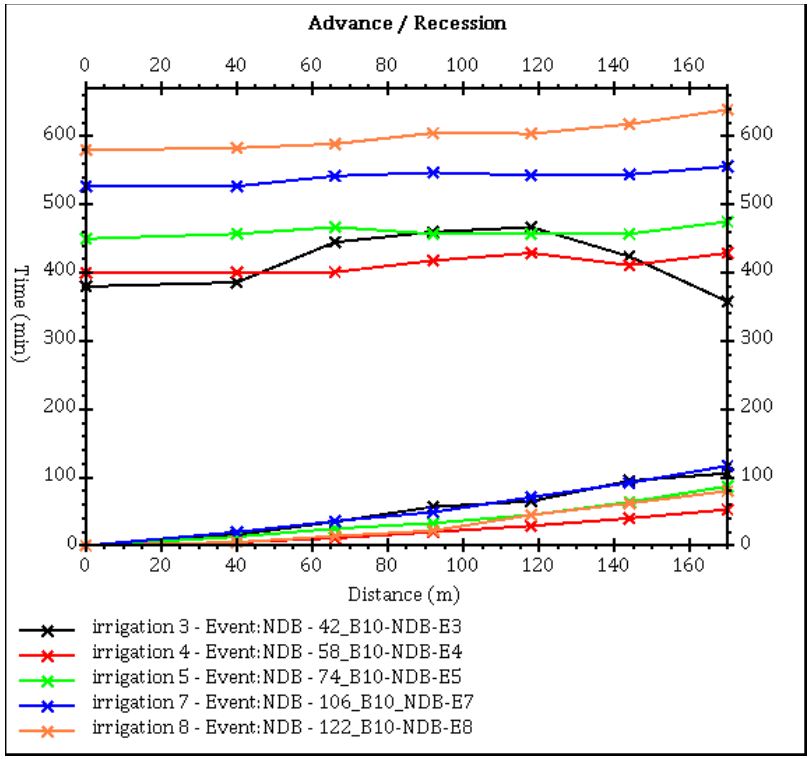
Design is very inadequate but operation of the system is very good!

Field example 3

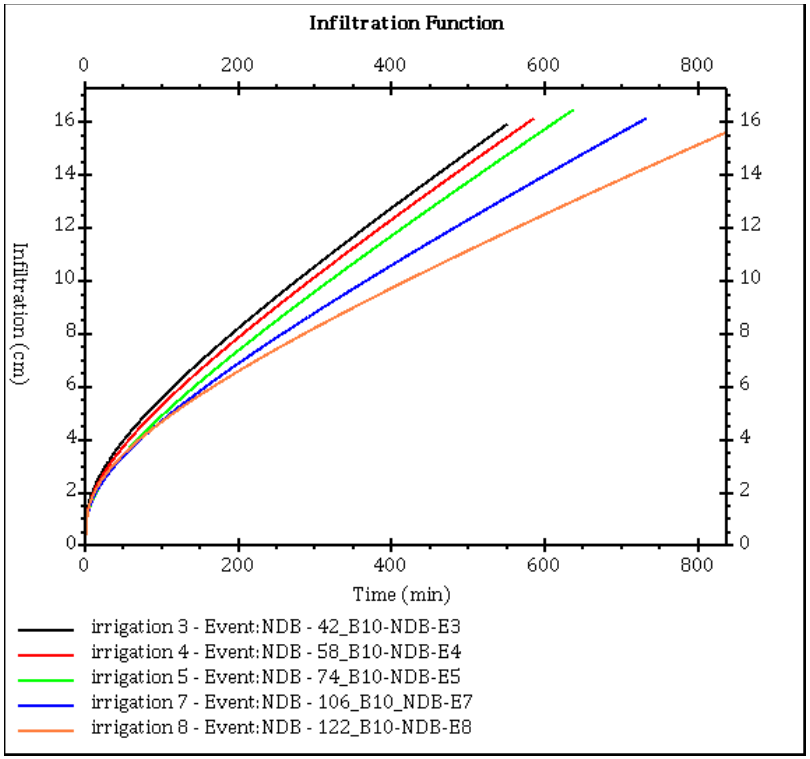
- Near-level furrows (blocked)
- Length - 560 ft, Width - 36 ft (11 furrows per set)
- Slope = 0.0002
- Inflow rate - 0.76 cfs (31 gpm per furrow)
- Soil – sandy-loam to sandy-clay-loam
- Crop – cotton
- Irrigation requirement – 3 to 4 in

Temporal variation of infiltration

Advance and recession

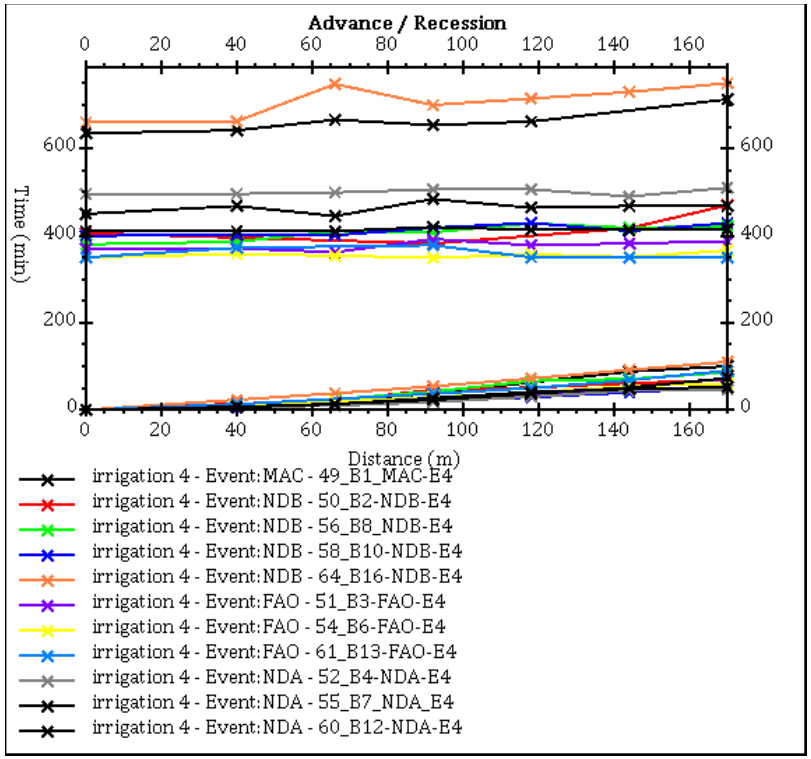


Infiltration function

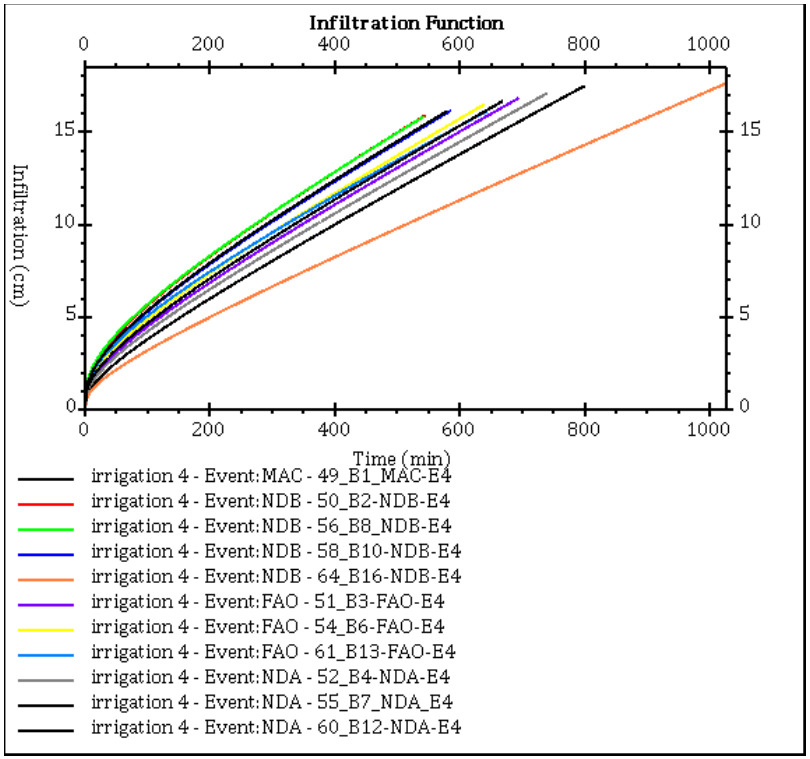


Spatial variation of infiltration

Advance and recession

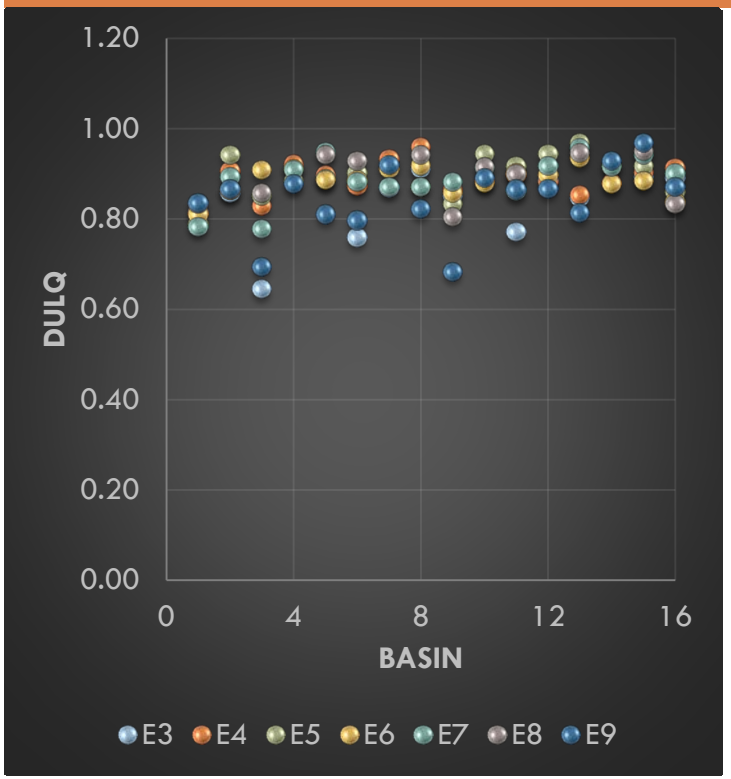


Infiltration function

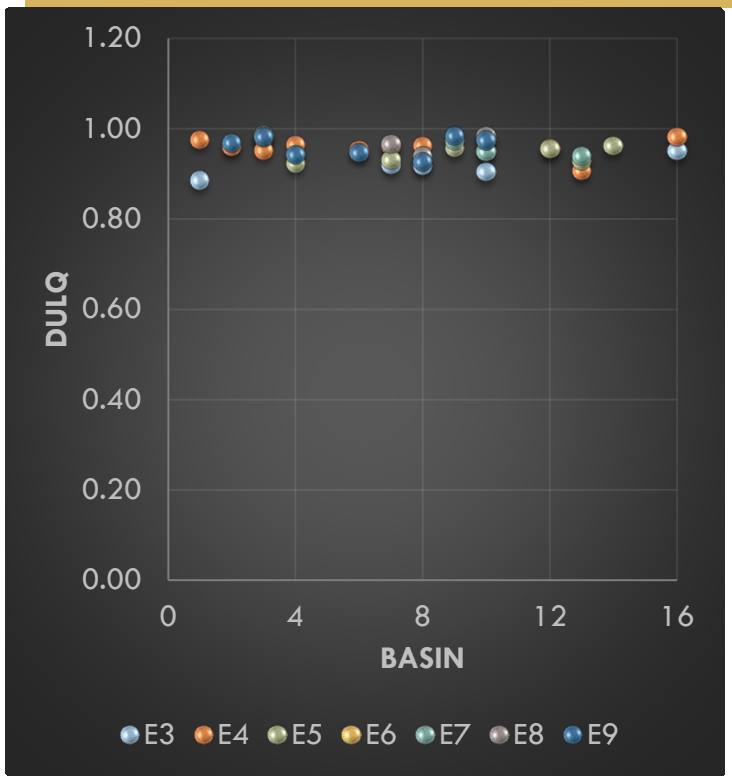


DU_{lq} for 16 basins over 7 irrigation events

Dulq from probe measurements



DUlq from evaluation

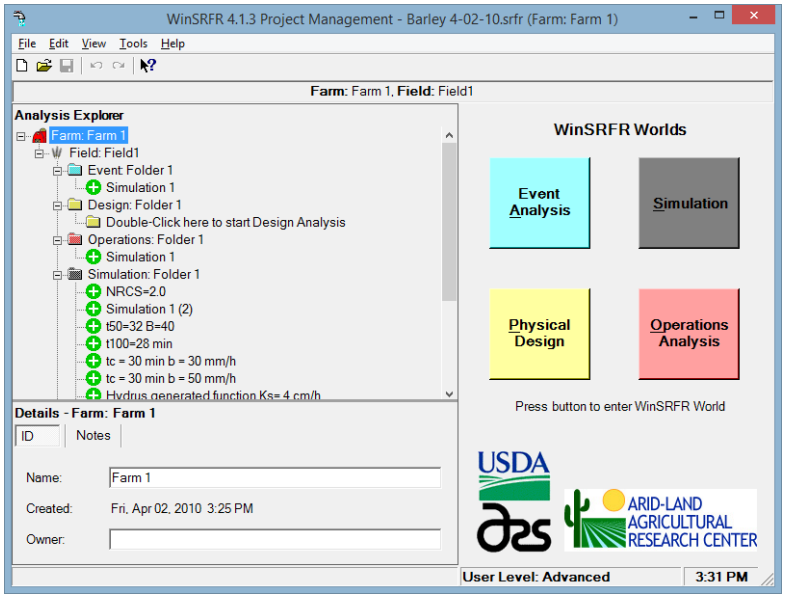


Hydraulic performance as a function of geometry, field conditions, and inflow rate

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
- http://www.ars.usda.gov/services/software/download.htm?softwareid=438



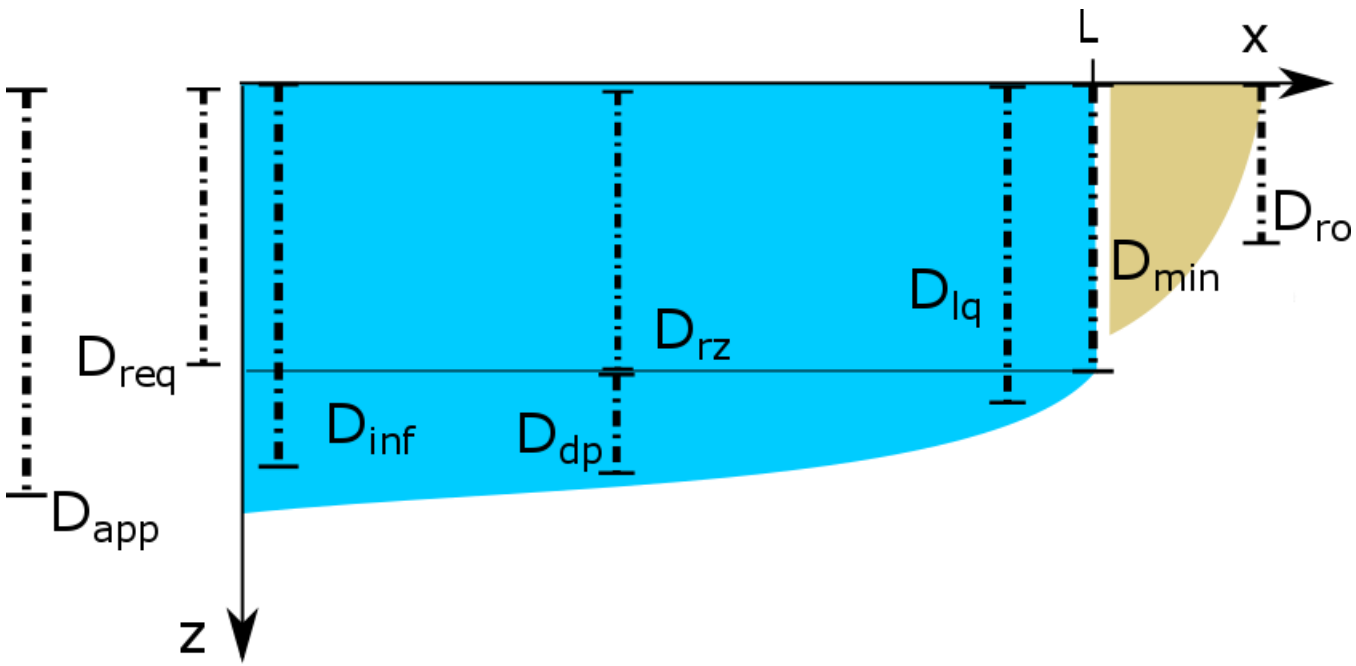
Basic data requirements (simulation)

- 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)



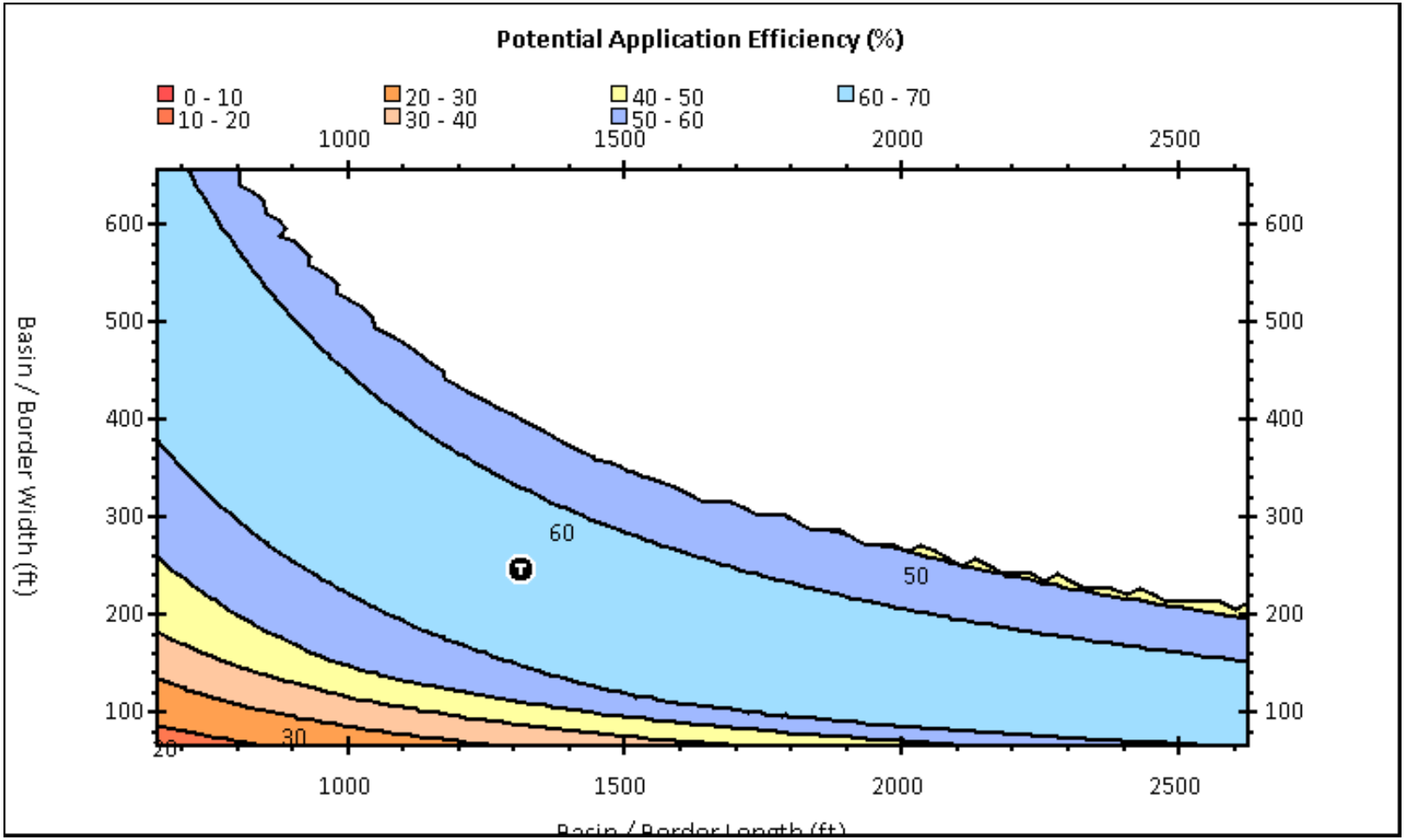
$$PAE_{\min} = \frac{D_{rz}}{D_{app}(D_{req} = D_{\min})} \qquad PAE_{lq} = \frac{D_{rz}}{D_{app}(D_{req} = D_{lq})}$$

Example: Design of a sloping border irrigation system

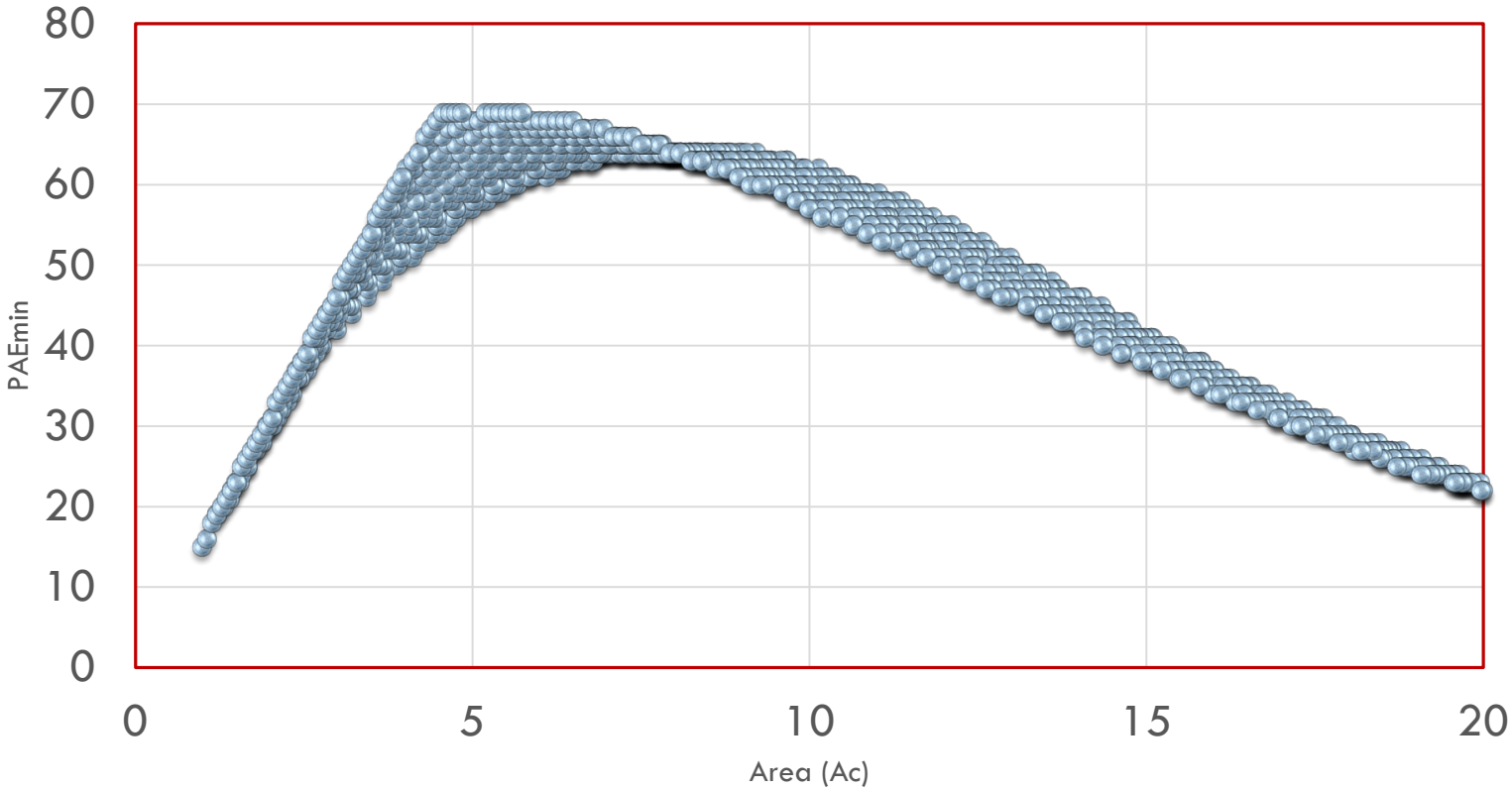
- Assume a field 2600 ft long 680 ft wide (~800 m X 207 m)
- Slope 0.001
- Available inflow rate 10 cfs (1 cfs = 448.8 gpm = 28.32 l/s)
- Soil – loam soil (described by the USDA-NRCS 0.7 infiltration family)
- Crop – alfalfa (hydraulic resistance given by Manning n – 0.15)
- Irrigation requirement -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

- OBJECTIVE: recommend a field layout (length and width)

Design contour: Potential Application Efficiency

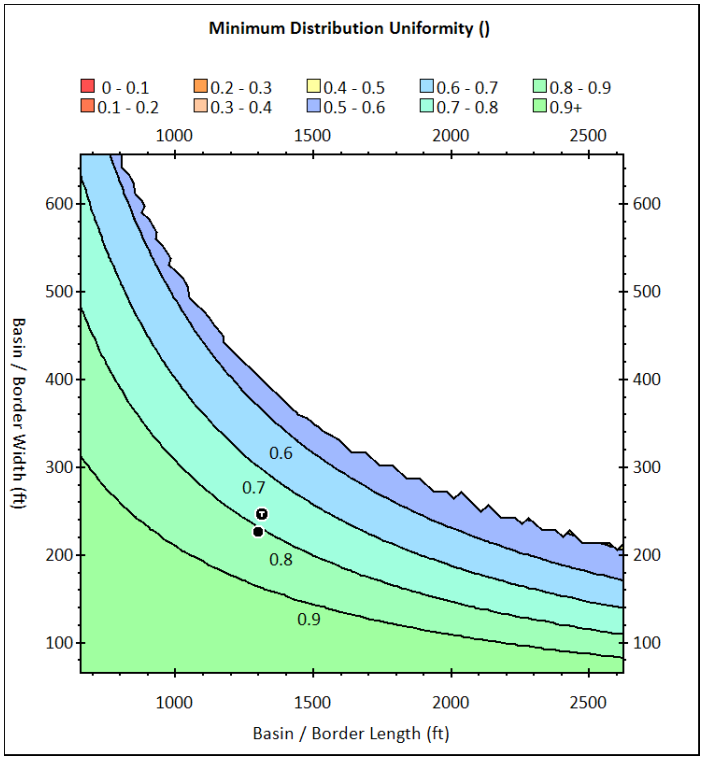


PAEIq as a function of border area

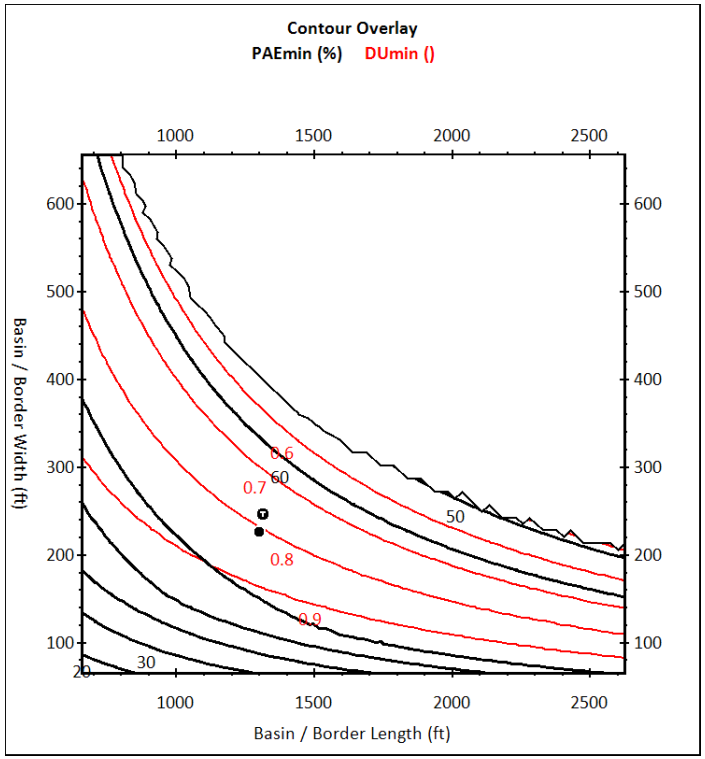


Other performance considerations: Distribution uniformity

Distribution uniformity of the mininimum for example

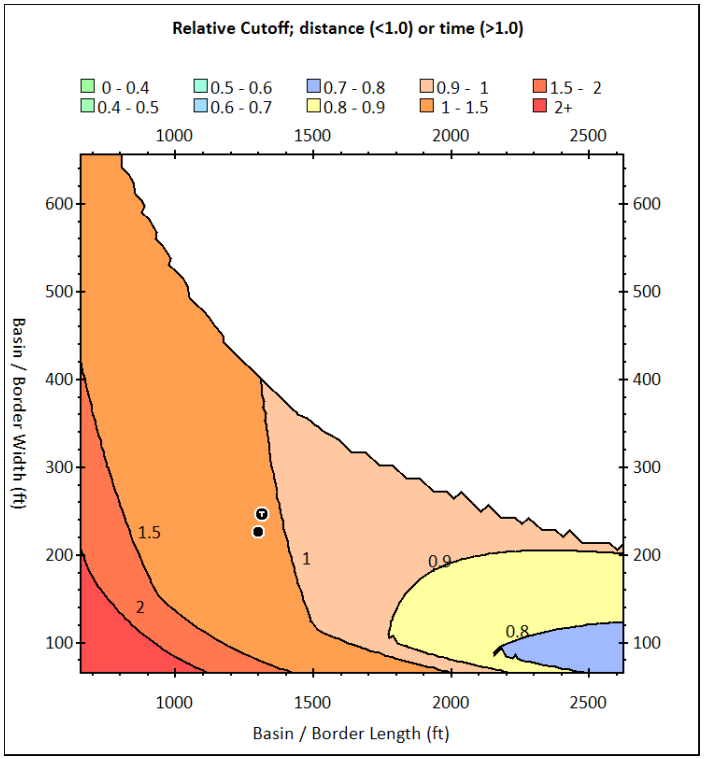


Overlay of PAEmin and DUmin

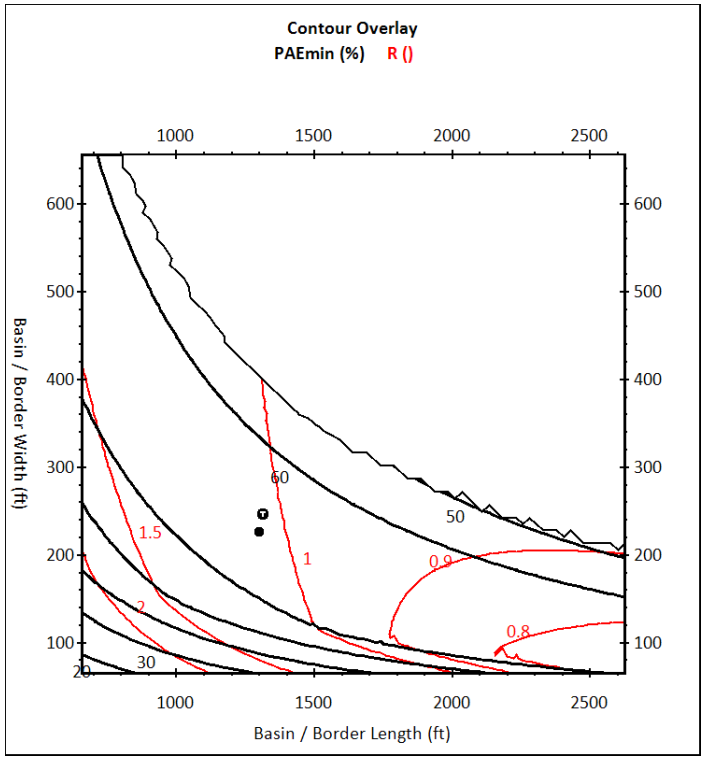


Relative cutoff ratio

Relative cutoff (R)

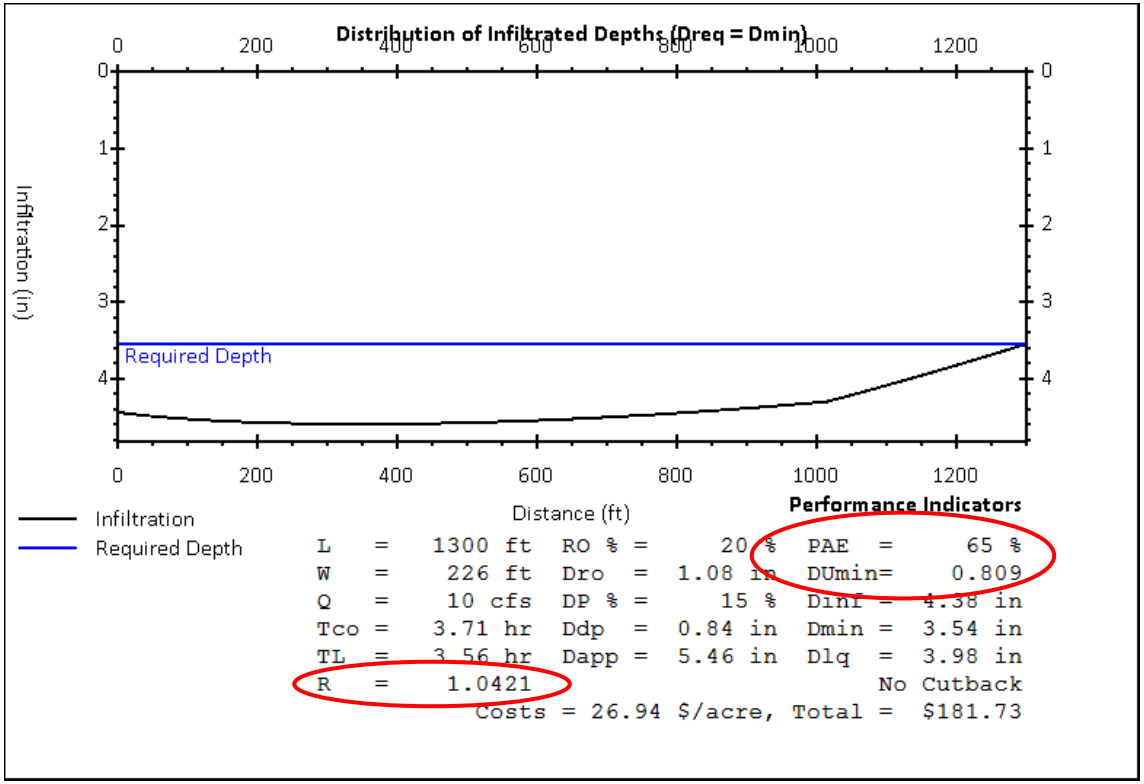


Overlay of PAEmin and R



Preliminary design recommendation

- Length 1300 ft, width 226 ft



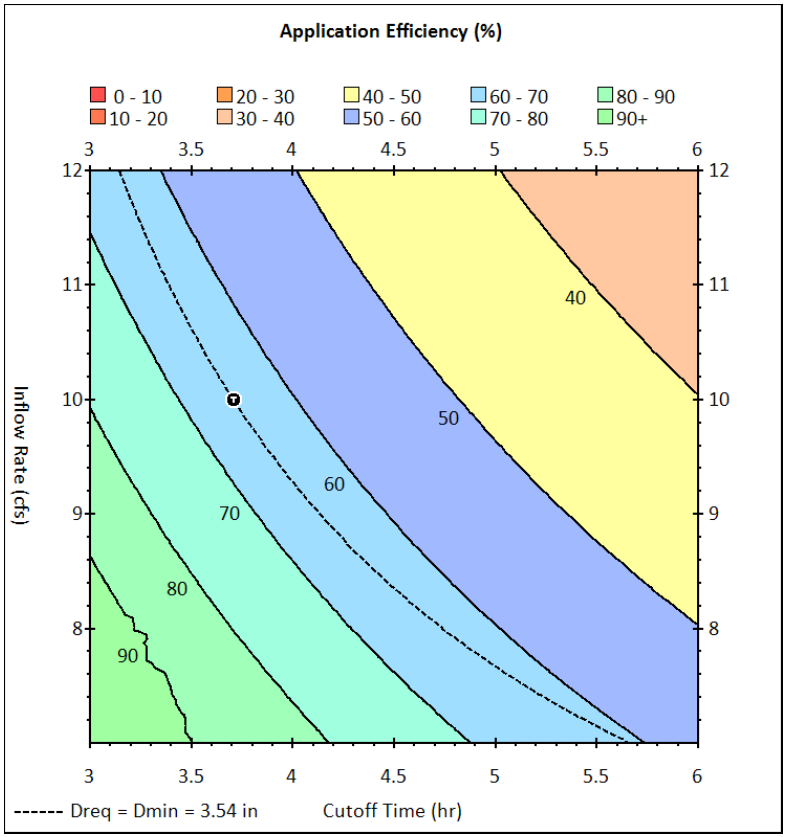
However, design inputs are uncertain

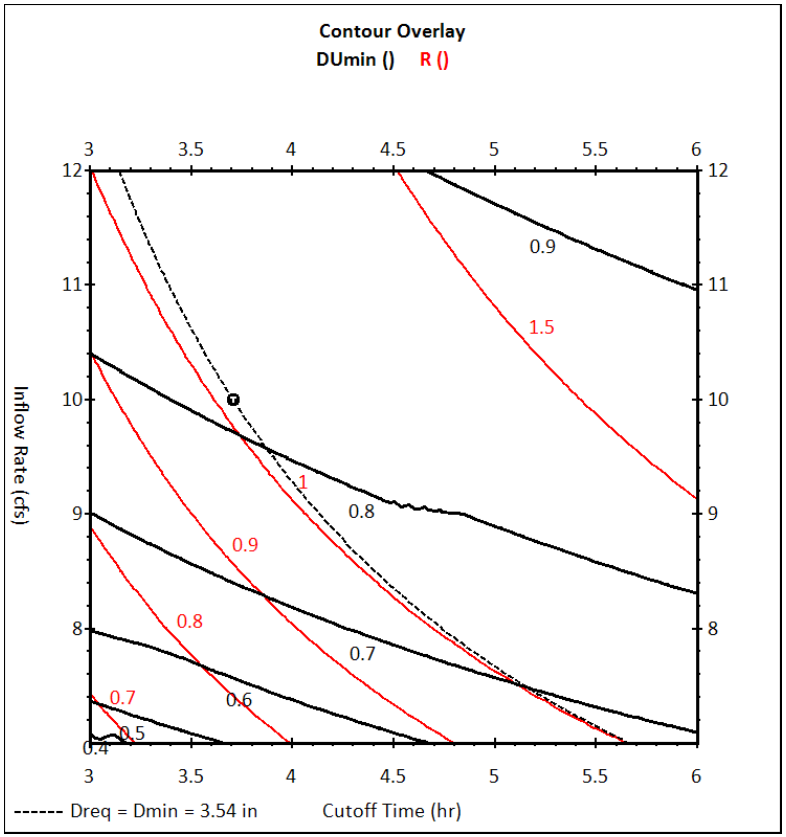
- The inflow rate is subject to substantial variations, in the range 7 to 12 cfs
- Infiltration exhibits substantial variability during the irrigation season
- How will the proposed system perform under those conditions? (and considering other potential sources of uncertainty in the design)

Robust control

- Robust control methods are designed to deliver adequate performance considering the uncertainty of inputs (and possible unexpected disturbances)

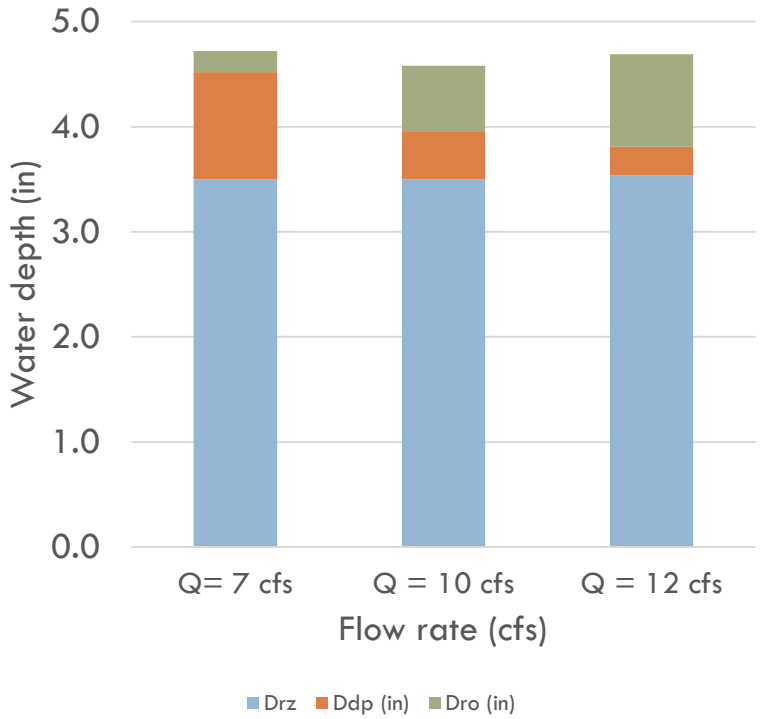
Operation contour: inflow rate vs. cutoff time



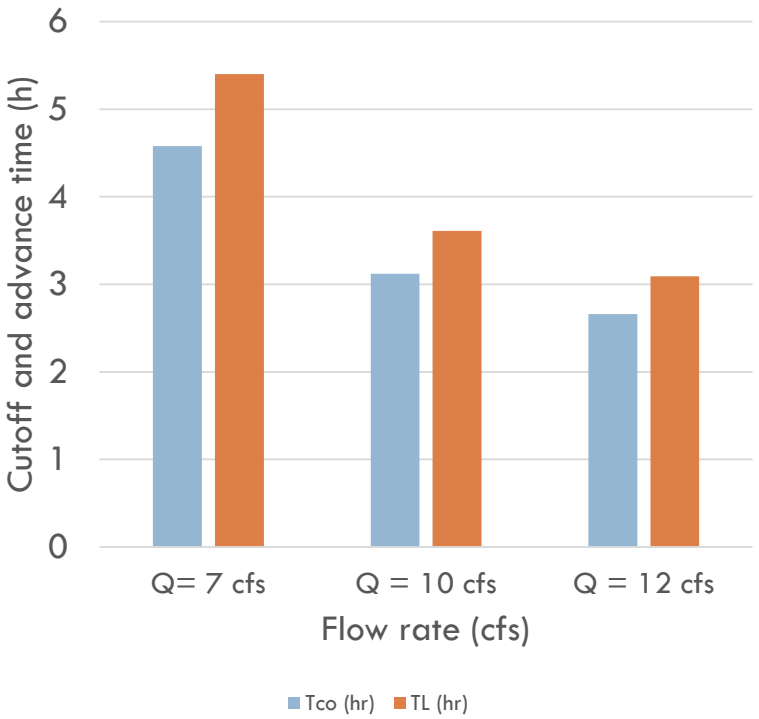


Water distribution at three flow rate values

Distribution of applied water

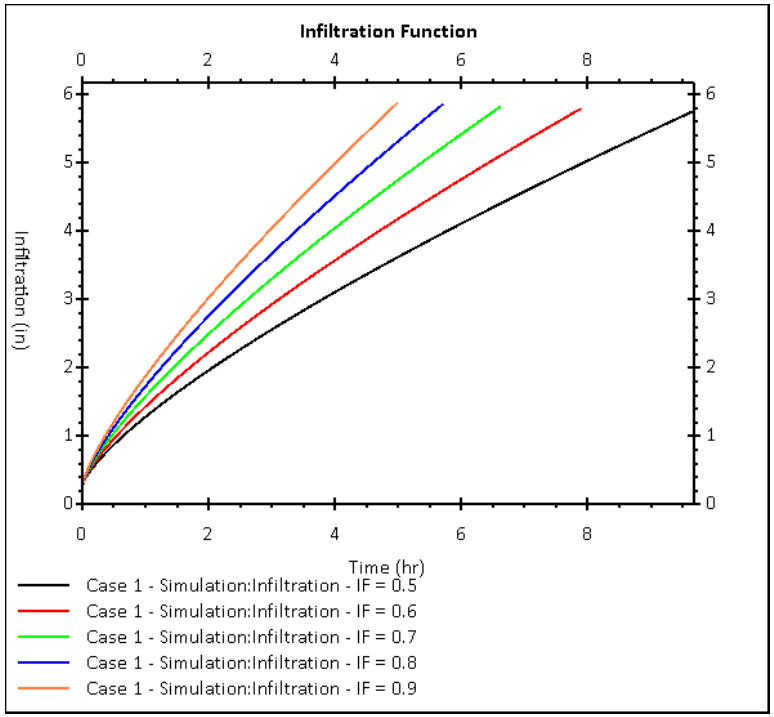


Cutoff and advance time

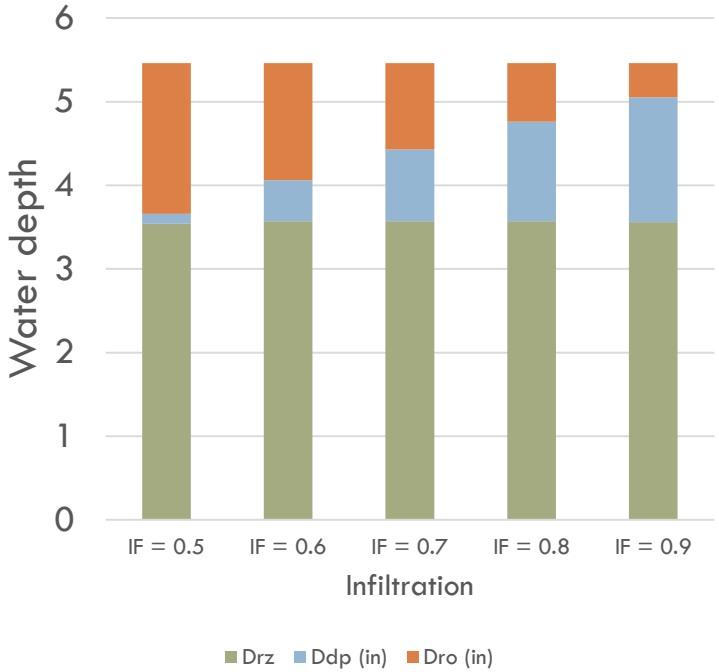


What is the effect of infiltration variation during the season?

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?