Irrigation Engineering

technological innovations for sustainable agricultural systems

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Sustainable Irrigated Agriculture in Arid Environments

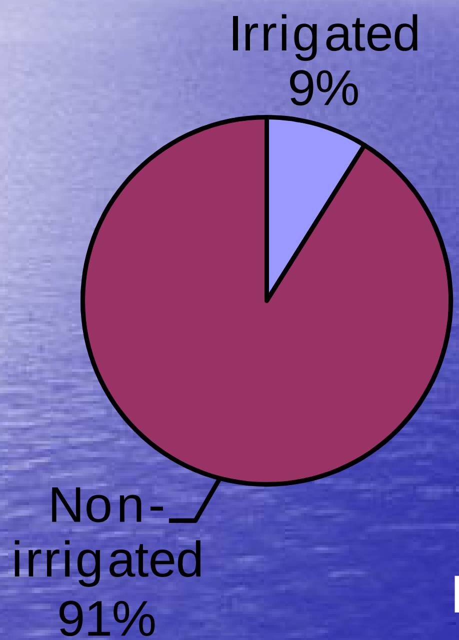
- Limited by
  - Water availability
  - Economics of crop production
  - And thus water productivity
- This talk focuses on the engineering aspects of water productivity

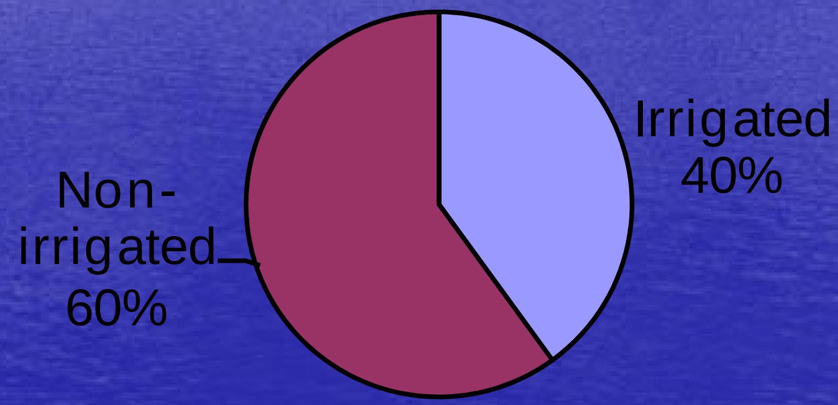
Outline

- Background
  - water productivity
  - water balance
- Flow Measurement
  - WinFlume Software
- Irrigation Uniformity and Efficiency
- Canal Automation
  - SacMan Software
- Surface Irrigation Improvement
  - WinSRFR Software

Irrigated agriculture is a significant contributor to world food supplies

2002 Census of Agriculture

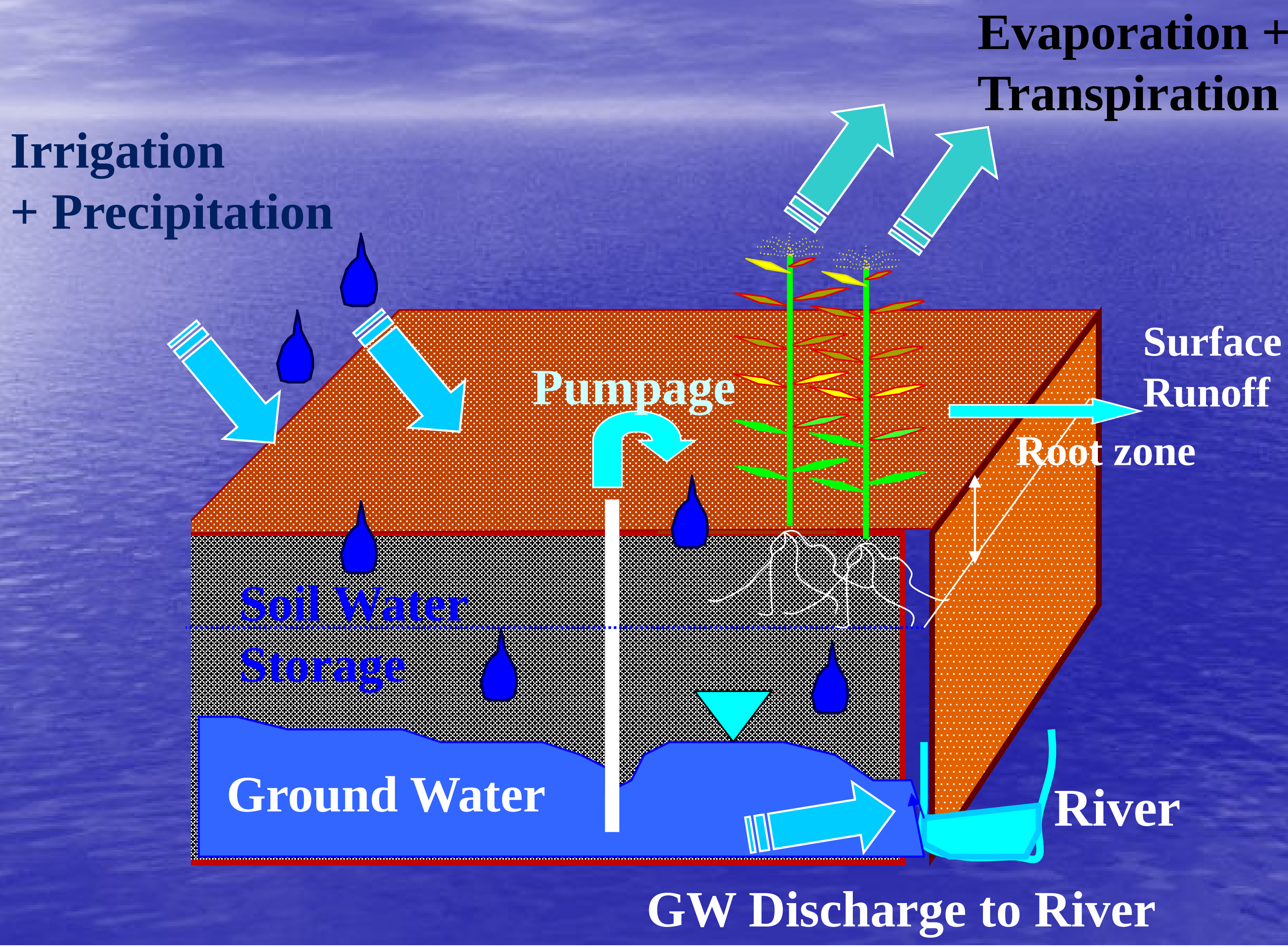




	Harvested Crop ha (millions)
Irrigated	11
Non-irrigated	110

	Harvested Crop Value (billions)
Irrigated	$38
Non-irrigated	$57

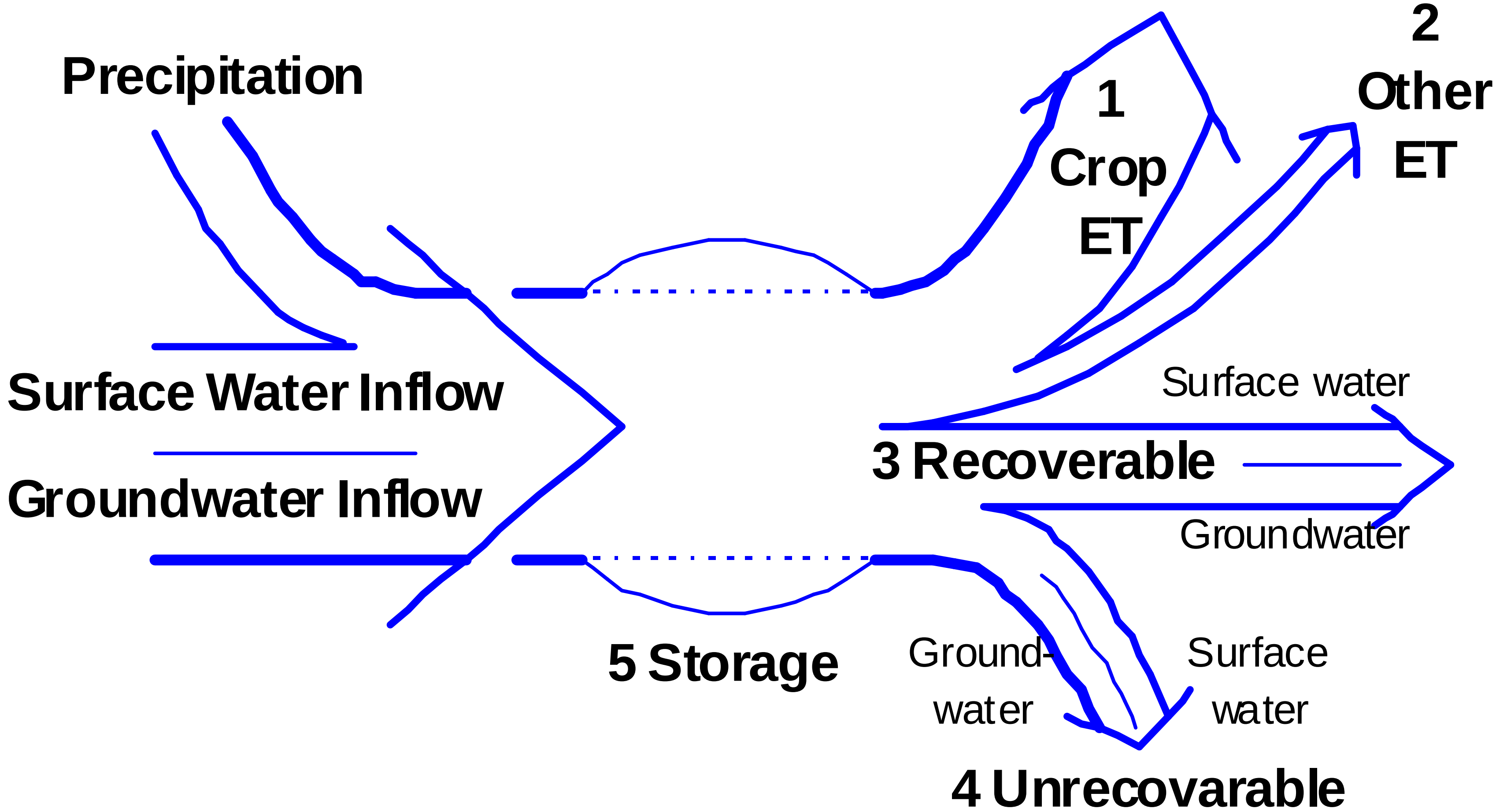
WATER BALANCE needed to evaluate water productivity for large-scale systems



Destinations of Applied Water

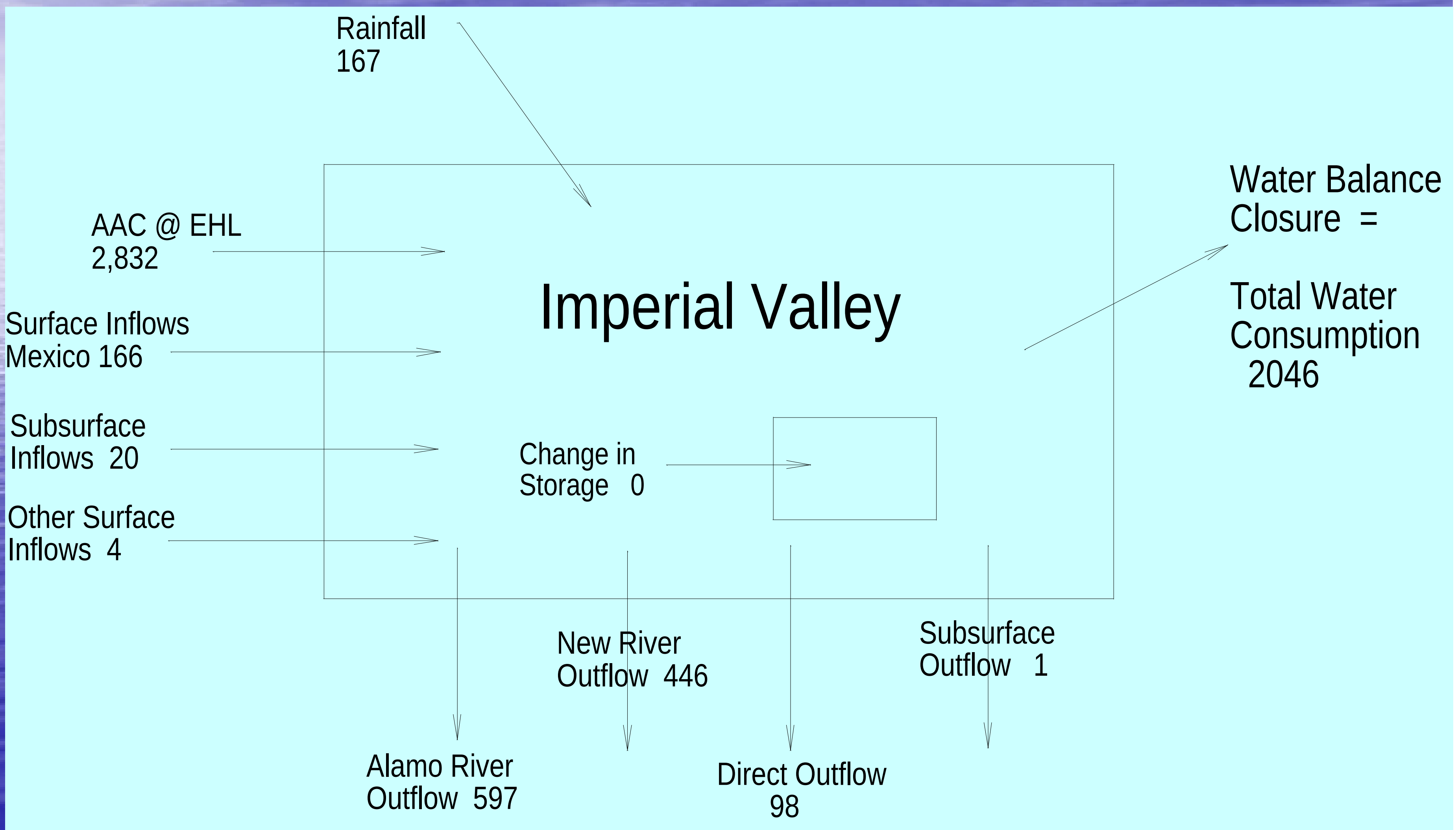
- Water consumed - beneficial
- Water consumed - not beneficial
- Water flows out - recovered and reused.
- Water flows out - not recoverable or not reusable.
- Water in storage

Water Inflows and Outflows



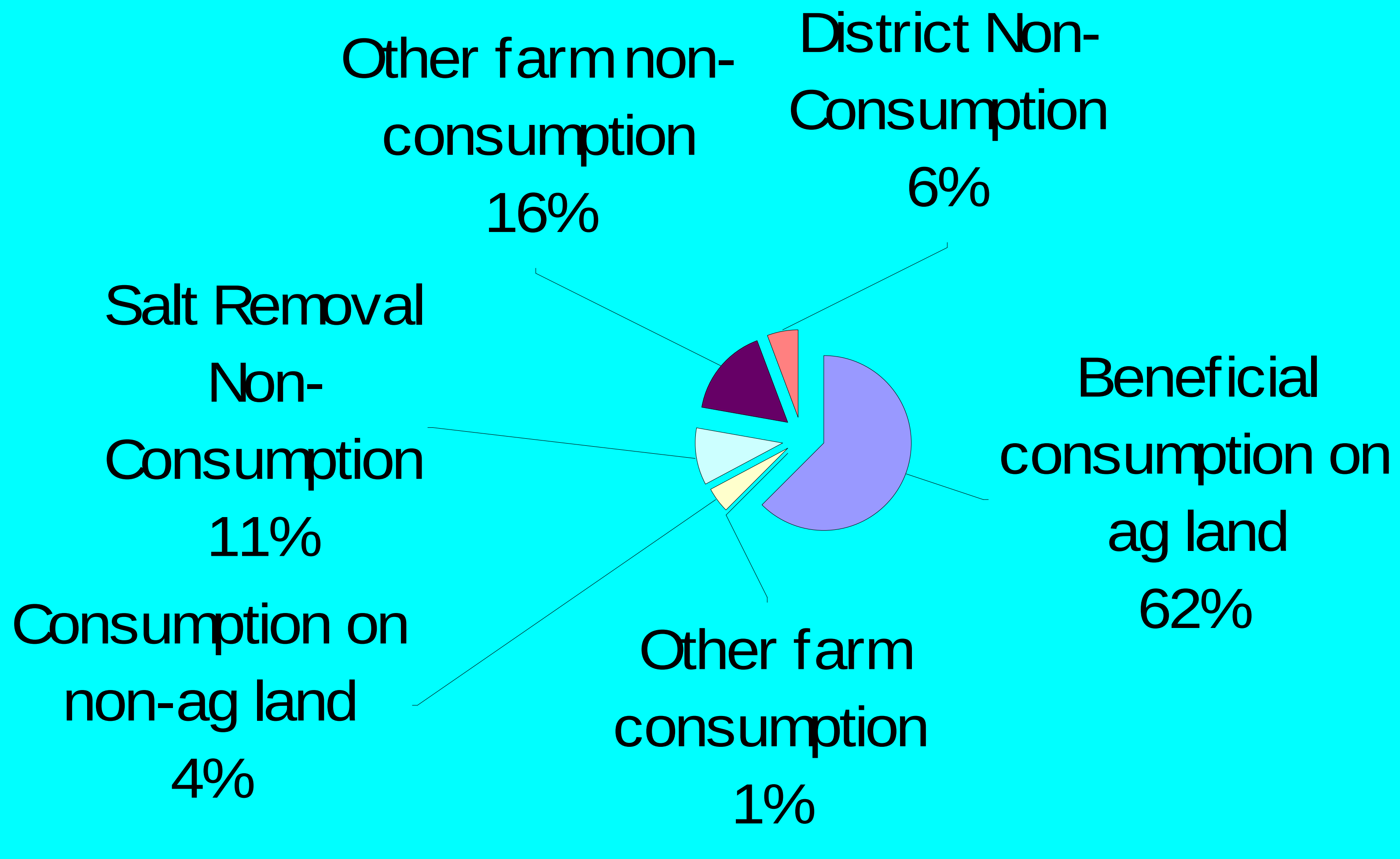
IID Water Balance

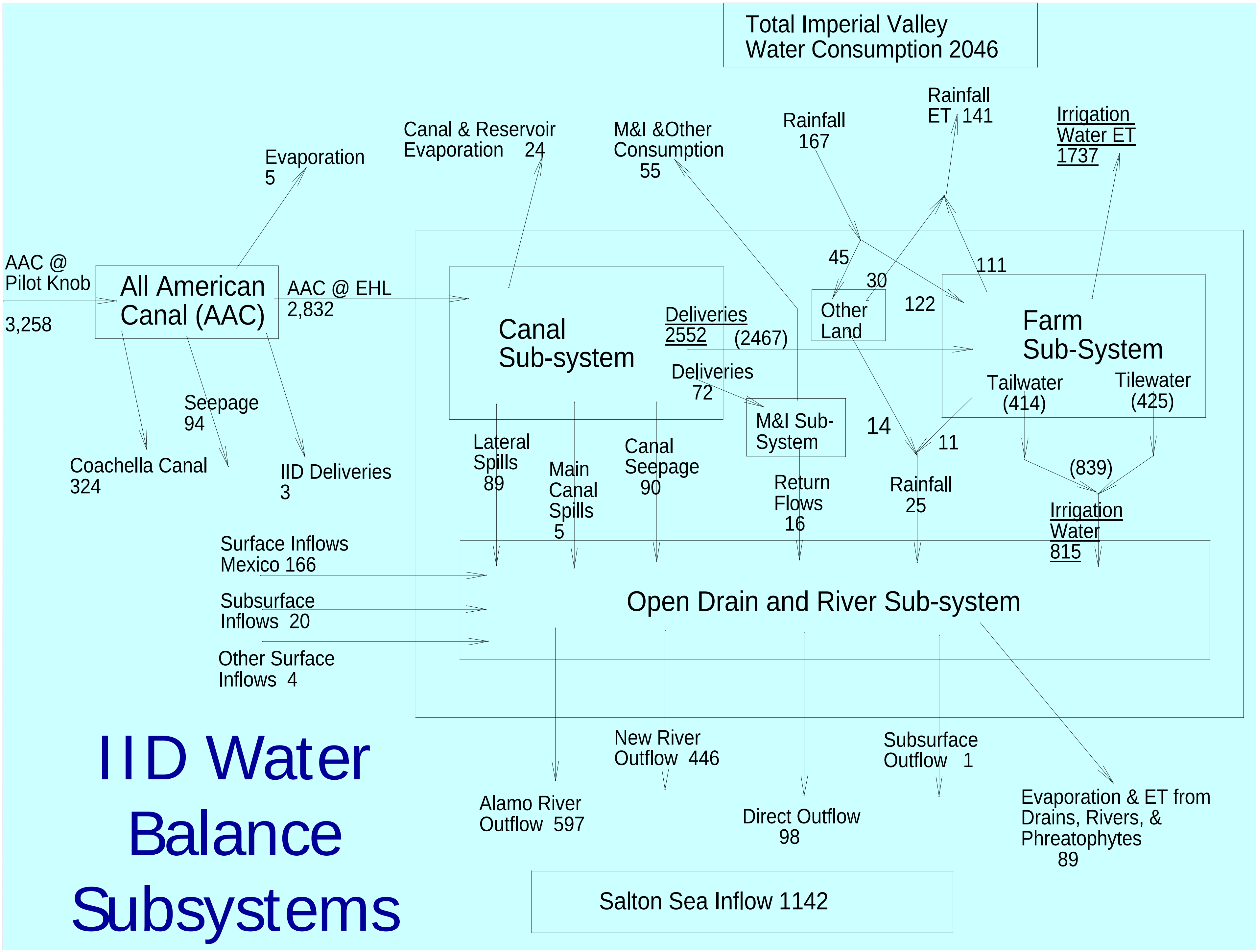
(1987-1996 average, 1,000 ac-ft = 1,234 ML)



Disposition of Irrigation Water in IID

(1987-1996)

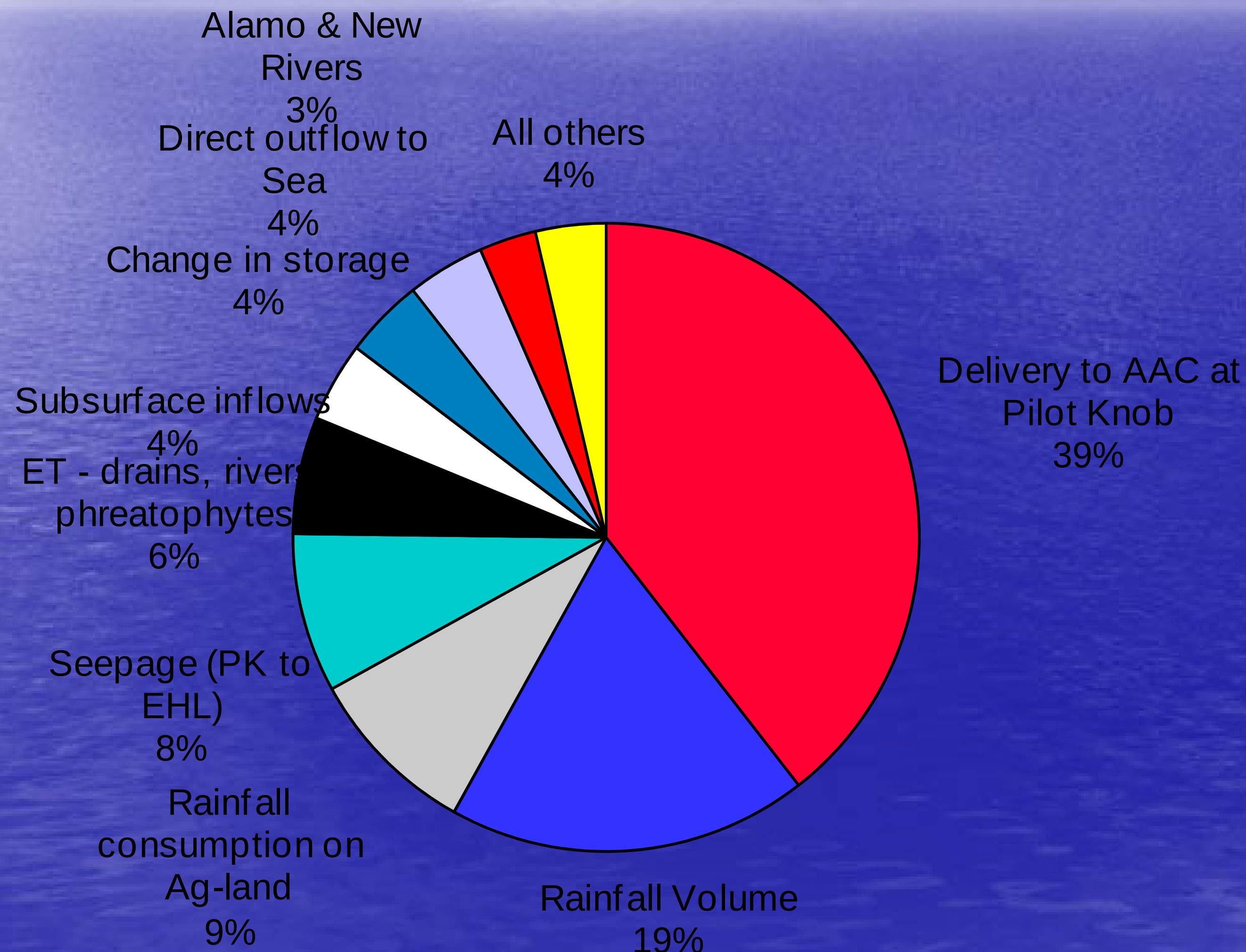



Total Imperial Valley
Water Consumption 2046
AAC @
Pilot Knob
3,258
All American
Canal (AAC)
Evaporation
5
AAC @ EHL
2,832
Canal & Reservoir
Evaporation 24
M&I &Other
Consumption
55
Rainfall
167
Rainfall
ET 141
Irrigation
Water ET
1737
45
30
111
122
Canal
Sub-system
Deliveries
2552
(2467)
Other
Land
Farm
Sub-System
Deliveries
72
M&I Sub-
System
Tailwater
(414)
Tilewater
(425)
14
11
(839)
Seepage
94
Coachella Canal
324
IID Deliveries
3
Lateral
Spills
89
Main
Canal
Spills
5
Canal
Seepage
90
Return
Flows
16
Rainfall
25
Irrigation
Water
815
Surface Inflows
Mexico 166
Subsurface
Inflows 20
Other Surface
Inflows 4
Open Drain and River Sub-system
New River
Outflow 446
Subsurface
Outflow 1
Alamo River
Outflow 597
Direct Outflow
98
Evaporation & ET from
Drains, Rivers, &
Phreatophytes
89
IID Water
Balance
Subsystems
Salton Sea Inflow 1142

Opportunities for conservation

- Reduce consumption of water outside the cropped area (e.g., phreatophytes)
- Reduce non-productive consumption within the cropped area (e.g., weed ET)
- Reduce outflow of water that cannot be recovered (with reasonable quality)
- Reduce degradation in quality of water that leaves the watershed (more water is required when salinity is higher)

Water Balance Accuracy Confidence Interval ±5%



Accuracy of Water Measurement is Key to Good Water Balance!

- Even with 2% accuracy of main supply, accuracy of consumption as remainder only 5%
- Flumes and weirs can have 2 to 5% accuracy
- Current metering stations 2 to 5% accuracy
- Sluice and radial gates –
  - 2 to 10% accuracy, free flow
  - 5 to 50% accuracy, submerged flow

Key Water Measurement Locations

- Where water is extracted from water supply (i.e., reservoir or groundwater)
- Where water passes from one administrative unit to another (e.g., water district to farmer)
- Within administrative unit
  - to aid in overall management


Broad-crested weir measures
Water diverted from river


Zero-setting of
Long-throated Flume for farm delivery

WinFlume

SOFTWARE FOR THE DESIGN AND CALIBRATION OF LONG-THROATED FLUMES AND BROAD-CRESTED WEIRS

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Water Resources Research Laboratory
Denver, Colorado

http://www.usbr.gov/pmts/hydraulics_lab/winflume/

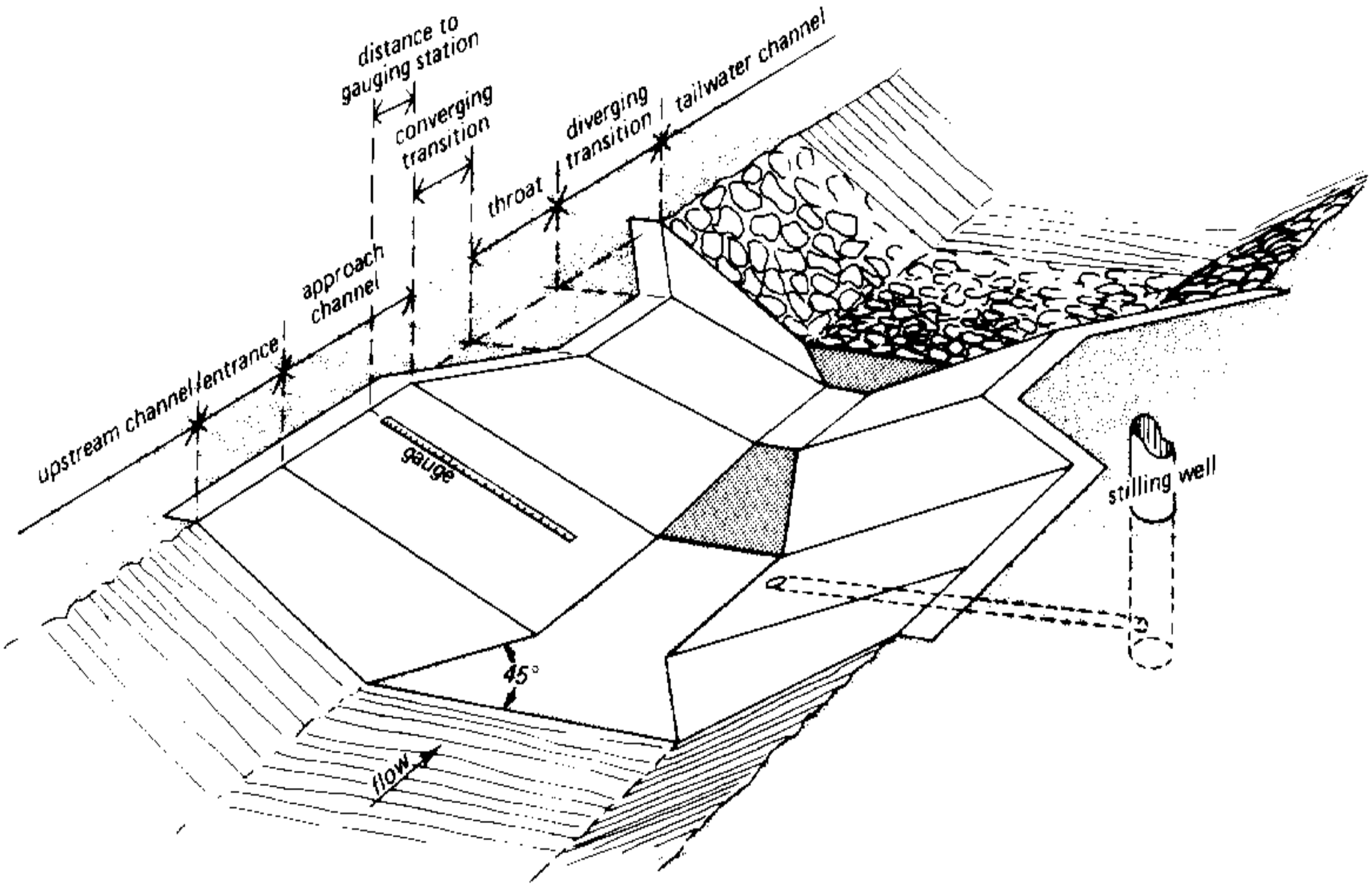
ARID-LAND AGRICULTURAL RESEARCH CENTER

U.S. Arid Land Agricultural Research Center

ALTERRA
WAGENINGEN UR

International Institute for Land Reclamation & Improvement

Components of Long-Throated Flumes
Approach Channel



Advantages:

- Accurate
  - Provided that critical flow occurs in the throat, a rating table can be calculated with an error of less than 2% in the listed discharge. The calculation can be made for any combination of a prismatic throat and an arbitrarily shaped approach channel.
- Wide range of flows
  - The throat, perpendicular to the direction of flow, can be shaped in such a way that the complete range of discharges can be measured accurately.
- Low head loss
  - The required head loss over the weir or flume is minimal to ensure a unique relationship between the upstream sill-referenced head, h_1, and the discharge, Q.
- As-built calibrations are possible

Design Criteria, Methods, Objectives

- Primary Design Criteria (4)
  - Maintain necessary **freeboard at maximum flow**
  - Maintain **modular (critical) flow** at **minimum** and **maximum** flow (ensure free flow)
  - **Froude number** at maximum flow must be **less than 0.5**
- Secondary Design Criteria (2)
  - Control section must produce sufficient head to provide a user-specified level of **discharge-measurement precision** at both **minimum** and **maximum** flow, based on the precision of the device used to measure upstream water level.

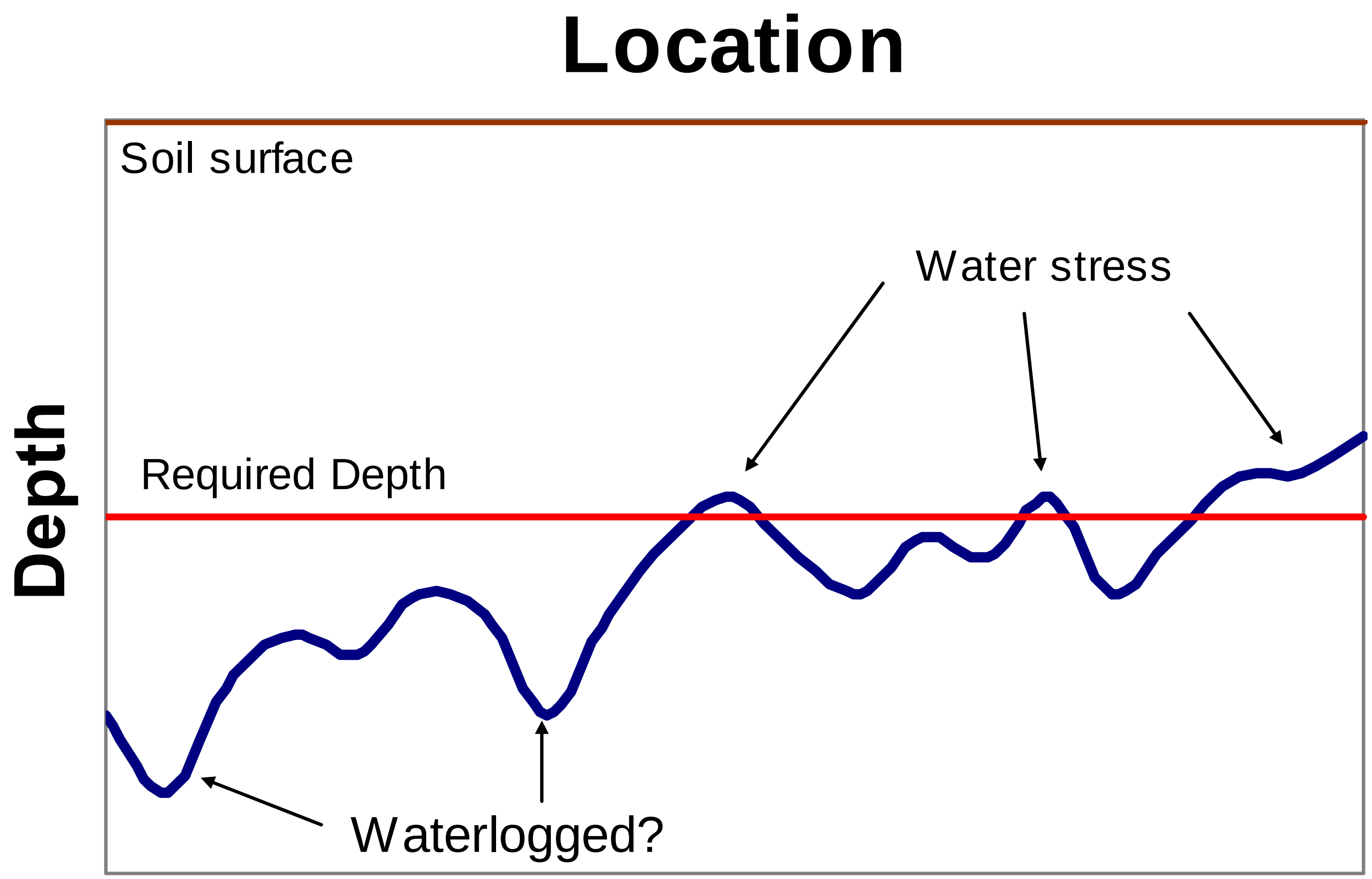
- Control Section Adjustment Methods
  - Raise sill height
  - Raise entire throat section
  - Raise inner section of throat (used with complex cross-sections)
  - Adjust lateral contraction by changing bottom width of throat section or changing diameter or focal distance of circular or parabolic sections (only option for movable-crest flumes)
- Head Loss Objectives
  - Minimum head loss
  - Maximum head loss
  - Intermediate head loss
  - Match head loss to drop in canal invert at site

Other advances in flow measurement

- Ultrasonic
  - Transit time
  - Doppler – multipath/profiling
- Magnetic (pipe flows, smaller pipes)

Irrigation Productivity is limited by Uniformity

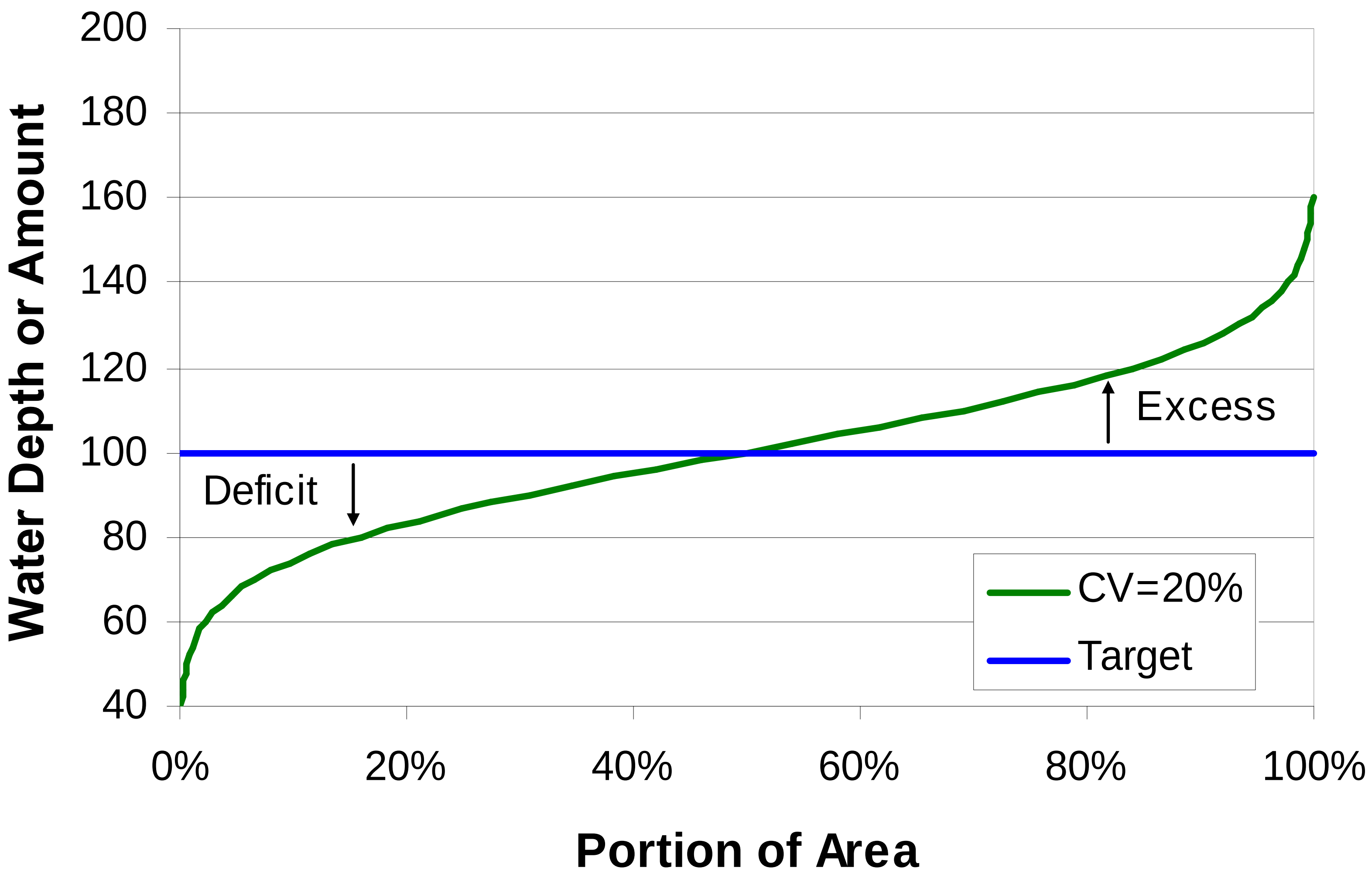
All irrigation systems have some non-uniformity, which influences yield and irrigation efficiency



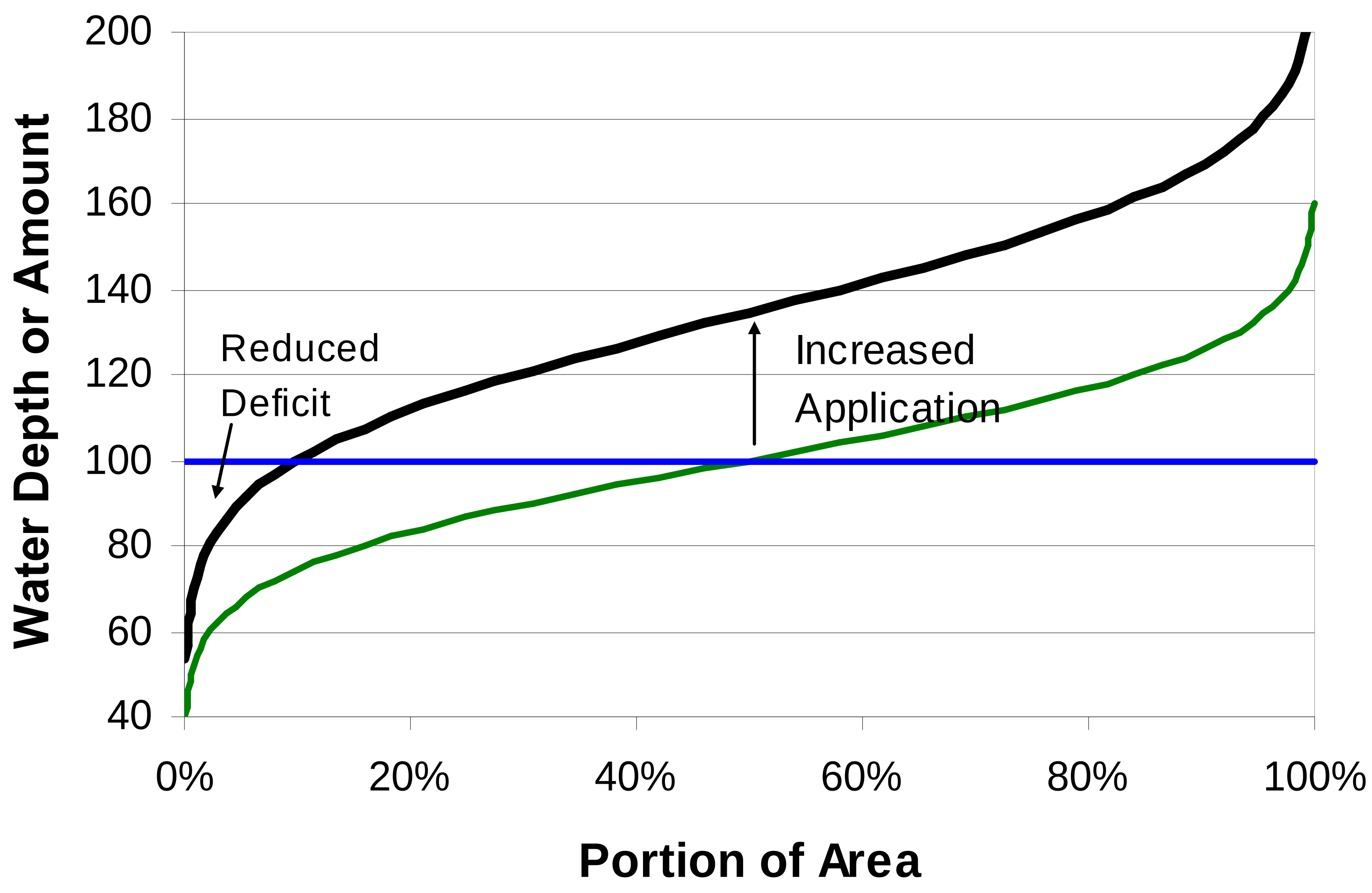
Some nonuniformity is self created.

- Most non-uniformity tends to be systematic!

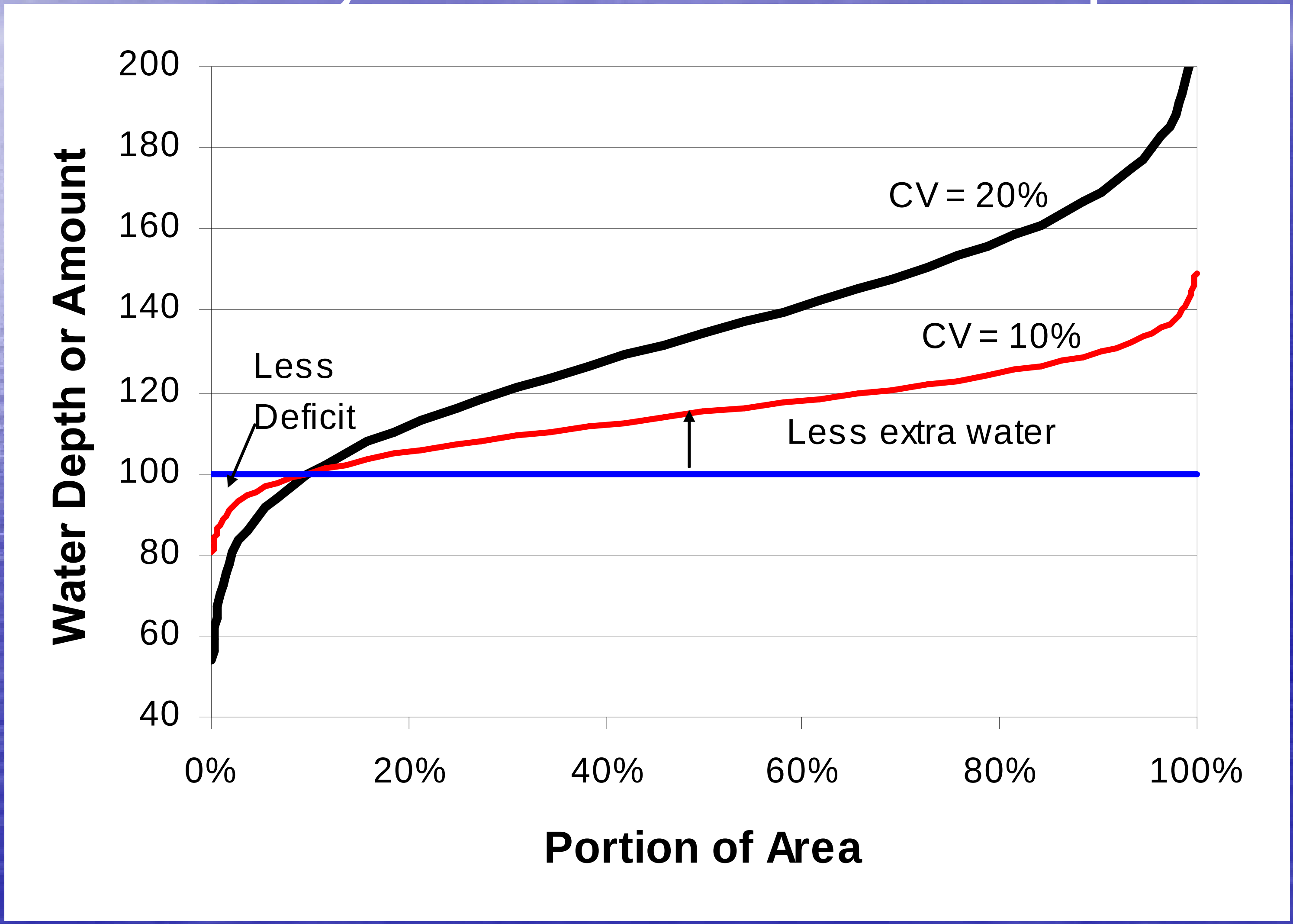
Irrigation Uniformity influences water consumption and "losses"



Irrigators apply extra water to avoid deficits caused by non-uniformity, but there is diminishing return. Most non-uniformity tends to be systematic.



Improving uniformity reduces water applied and reduces the deficit, and may also increase consumption



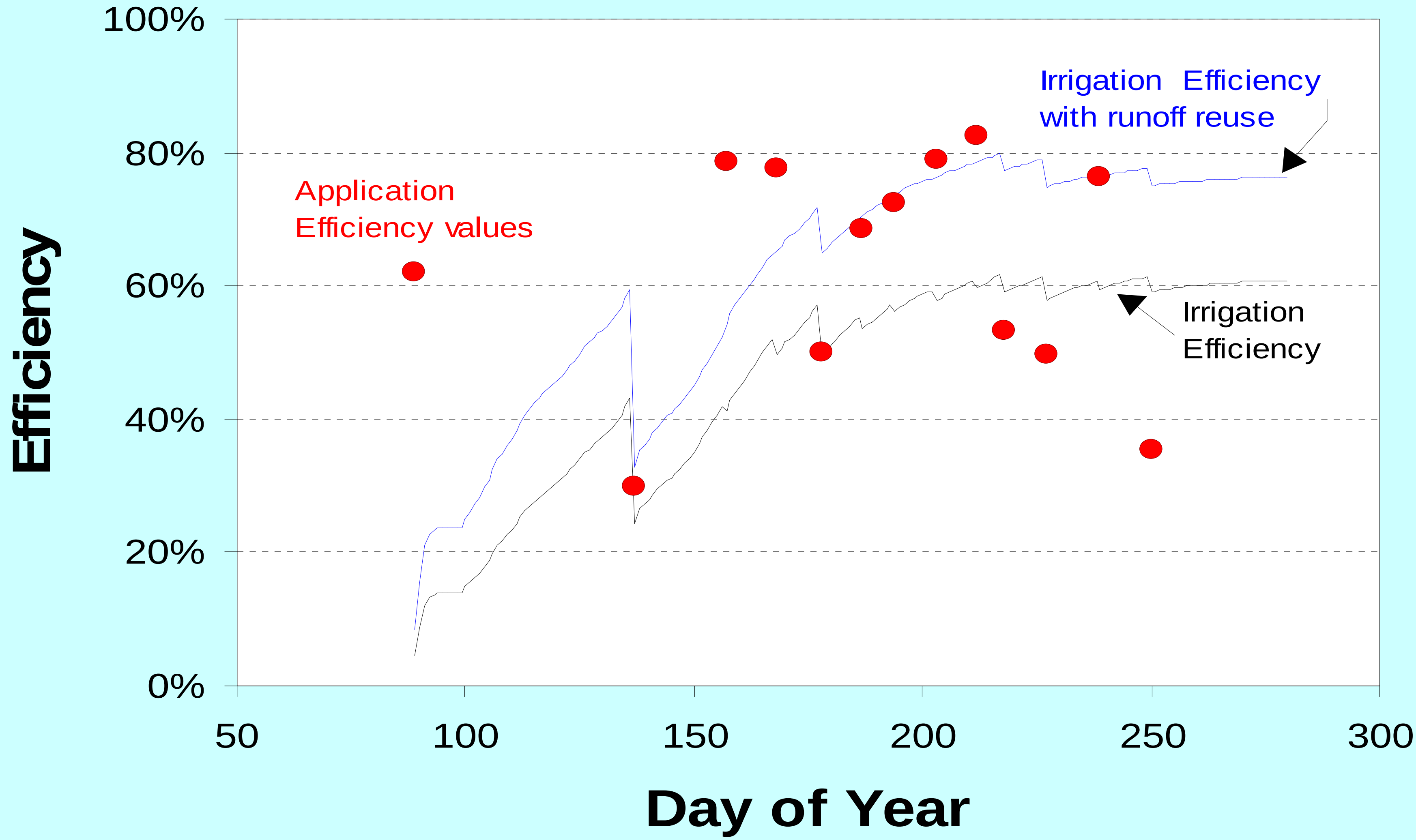
- Irrigation Efficiency (Burt et al. 1997)
  - water is only considered beneficial or not when it leaves the boundaries
  - IE is defined in terms of a time interval

$$IE = \frac{Volume\ of\ \ H_2O_{iw}\ Beneficially\ Used}{Volume\ of\ \ H_2O_{iw}\ Applied - \Delta Storage_{iw}} \times 100\%$$

- Application Efficiency (Burt et al. 1997)
  - Event based
  - Primarily to add water to soil storage
  - A target application amount is implied

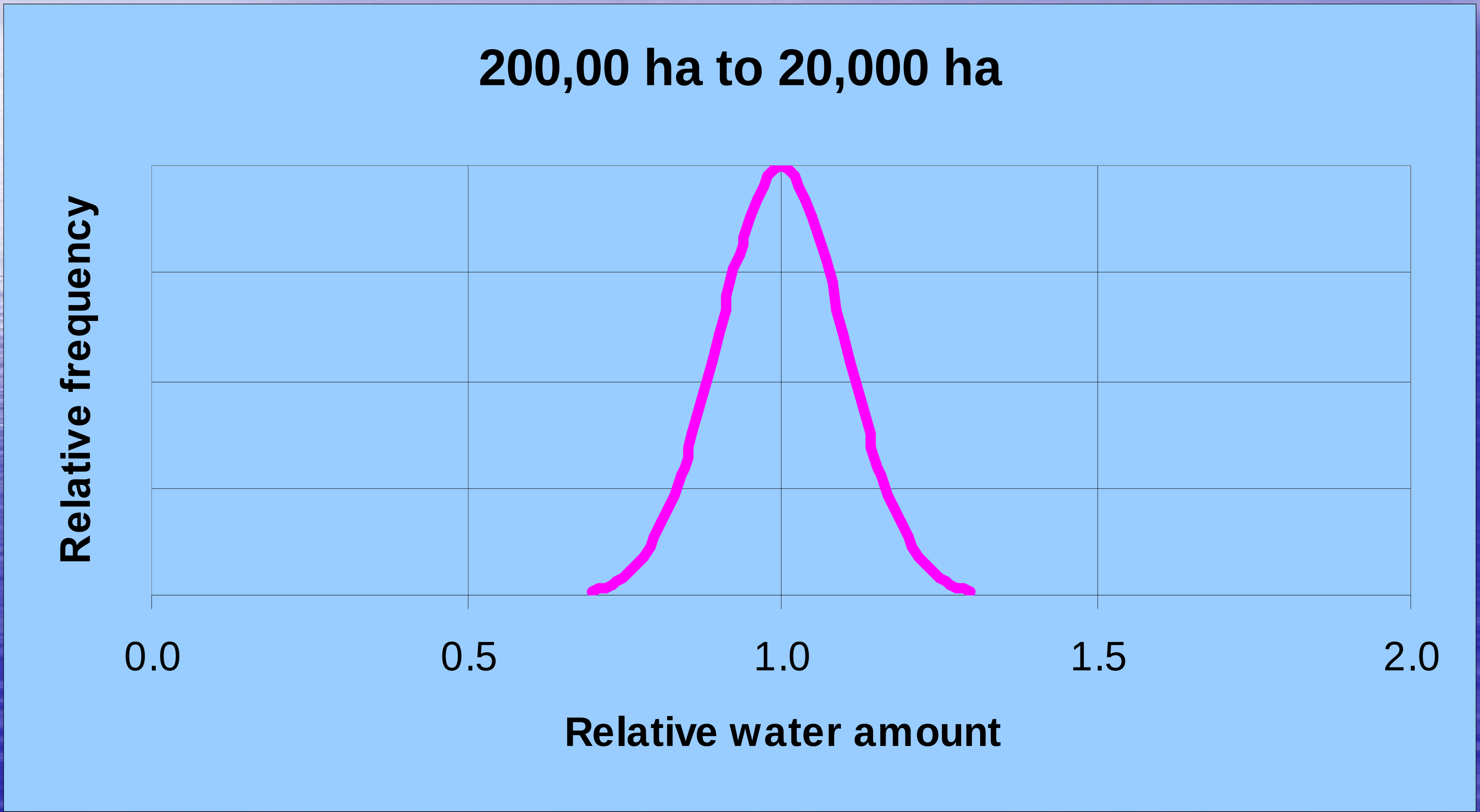
$$AE = \frac{\text{Ave. Depth of } H_2O_{iw} \text{ Contributing to Target}}{\text{Ave. Depth of } H_2O_{iw} \text{ Applied}} \times 100\%$$

Field example contrasts AE & IE

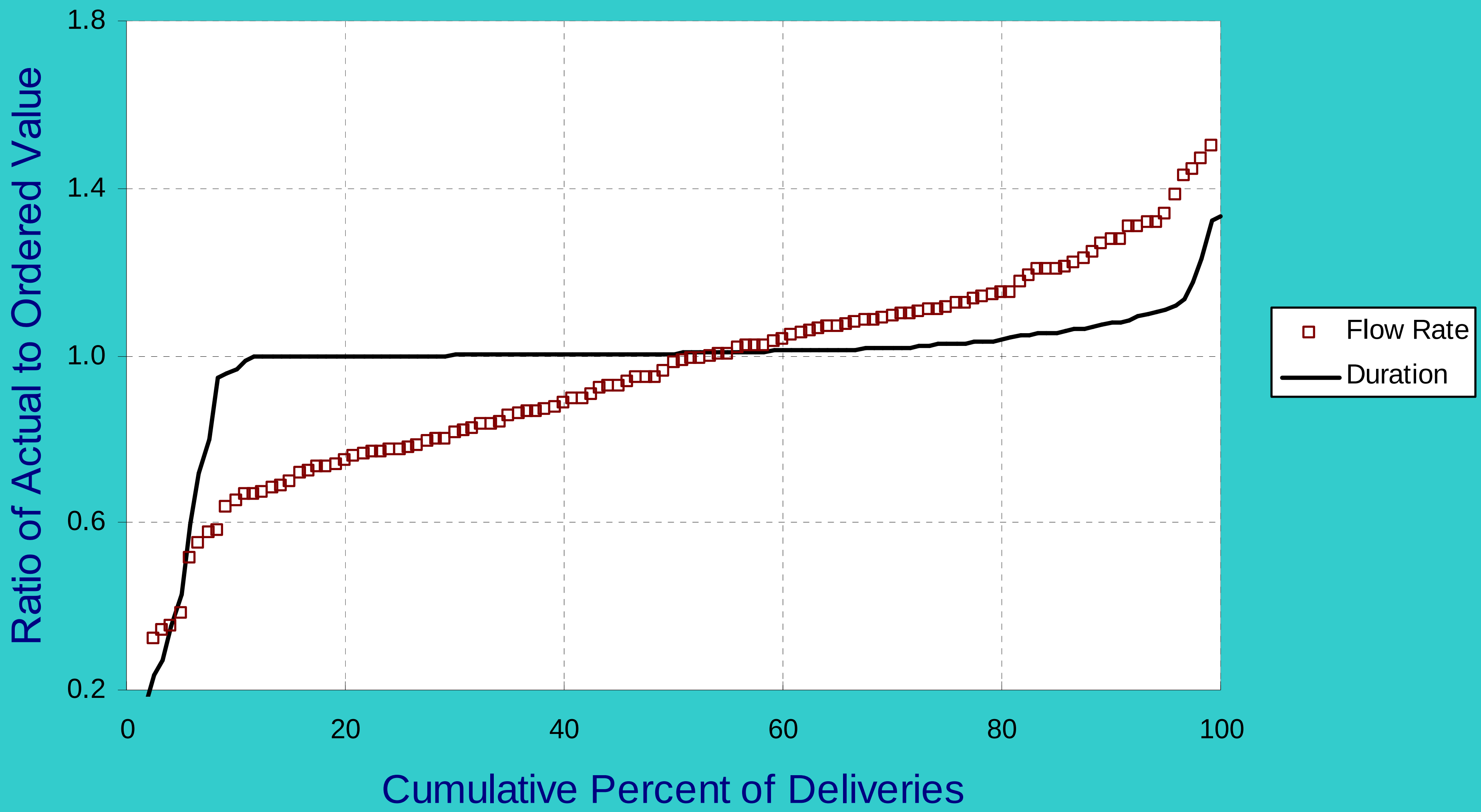


Uniformity of Irrigation Project

Distribution from Main Canal to Primary Canals

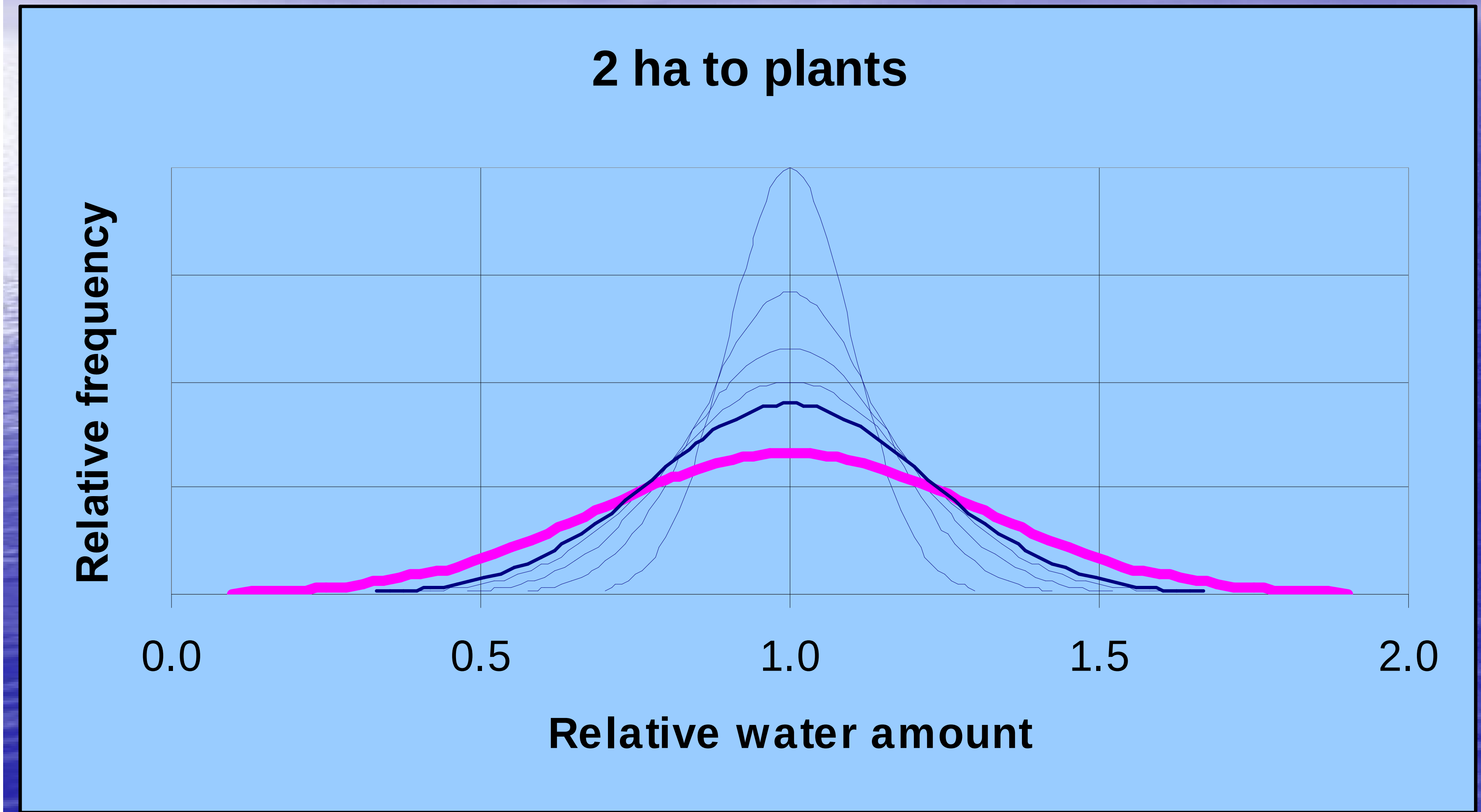


Example of Actual Measurements

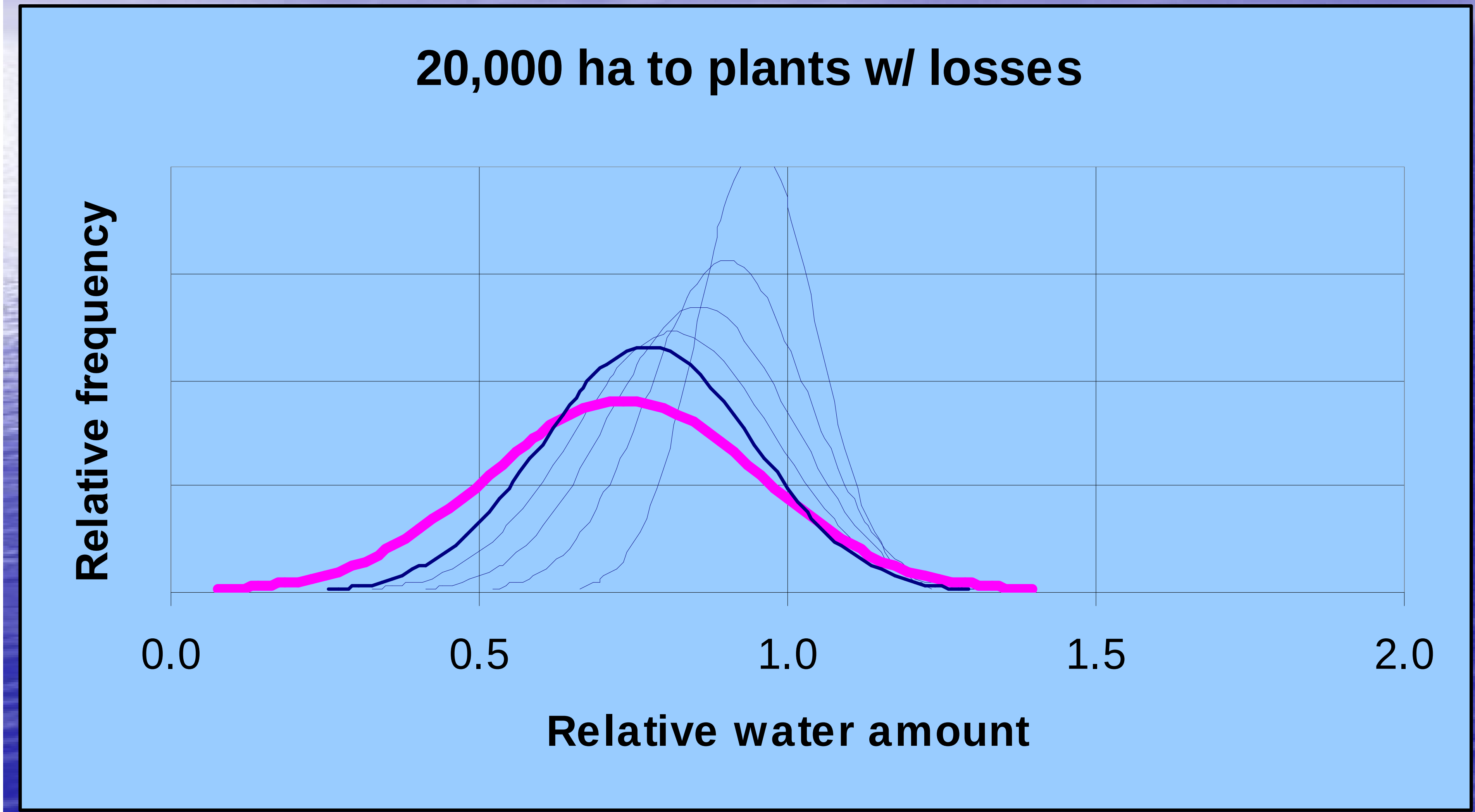


Water Distribution is the result of Chaos

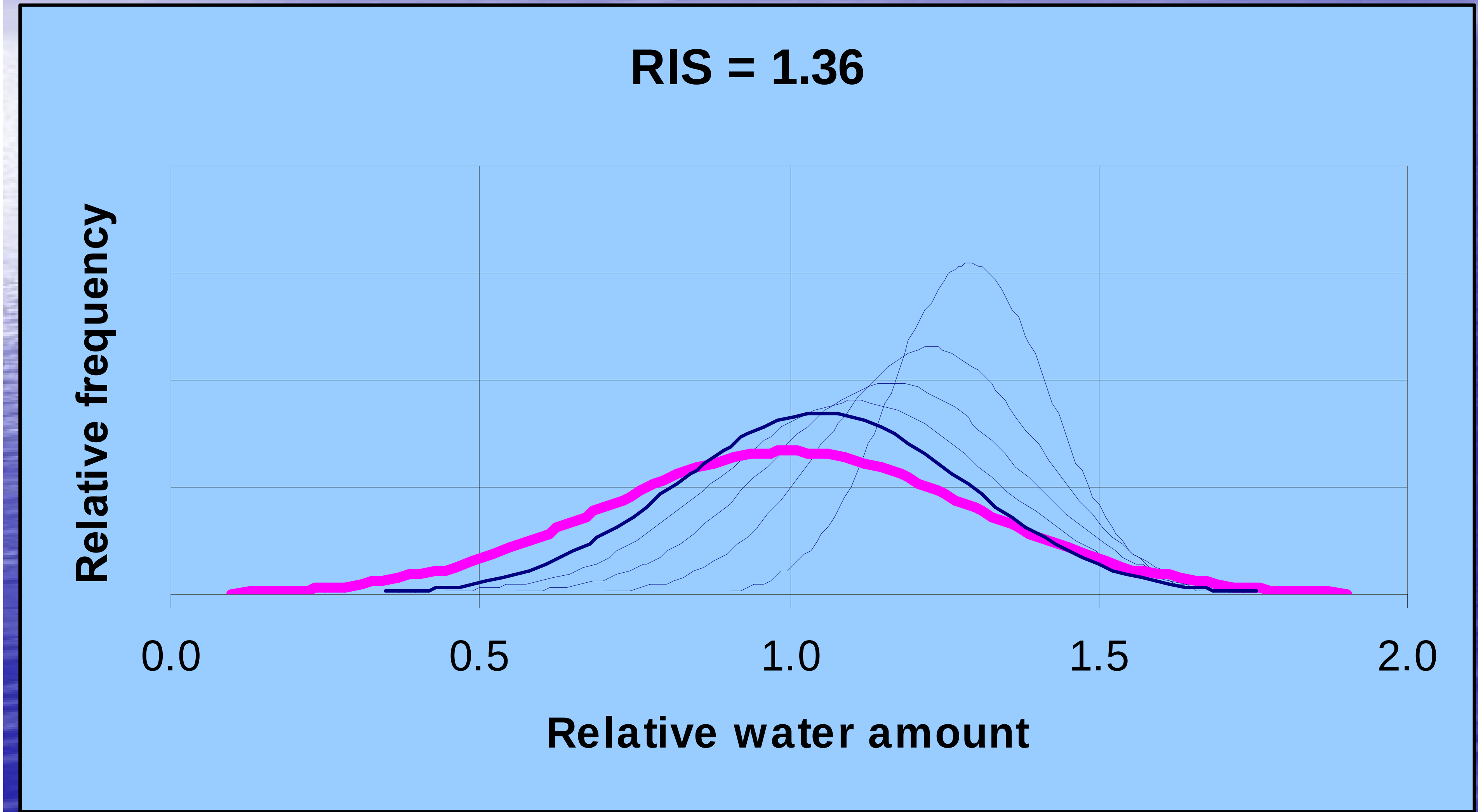
Distribution from one level to the next



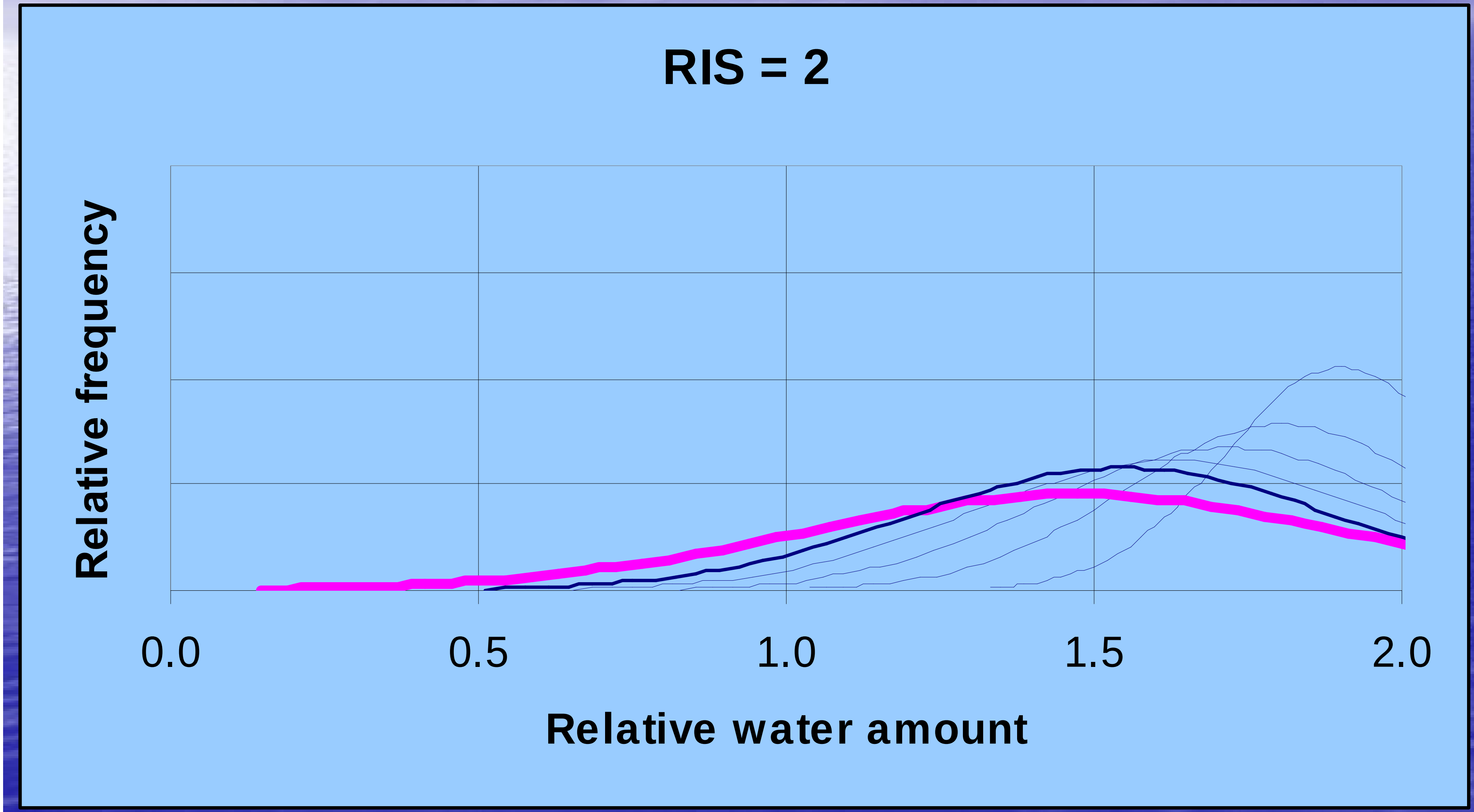
Project scale distribution of water to plants can be related to productivity



Providing extra water to make up for system losses



Providing extra water to make up for poor water distribution

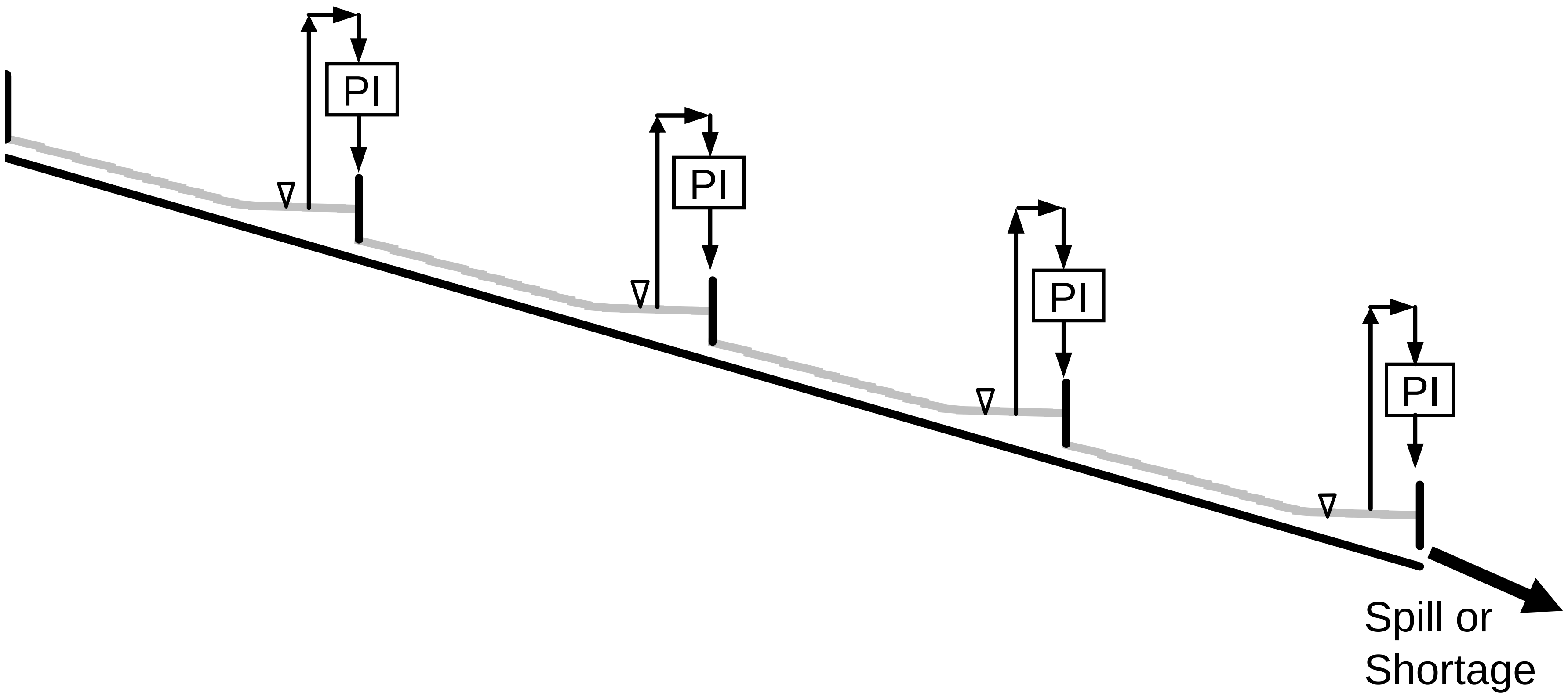


Chaos Rules

- Most canals are operated manually!
  - Operators adjust manual gates to distribute flow between off-takes and check structures.
  - At a division point,
    - The water level will rise or fall until outflow equals inflow.
    - Flow distribution depends upon the **relative** setting of the gates.
- Unsteady Flow causes Chaos
  - Gate changes cause downstream flows to vary.
  - Upstream changes arrive gradually downstream,
  - Flow to users varies over time.
  - This is independent of flow measurement errors.

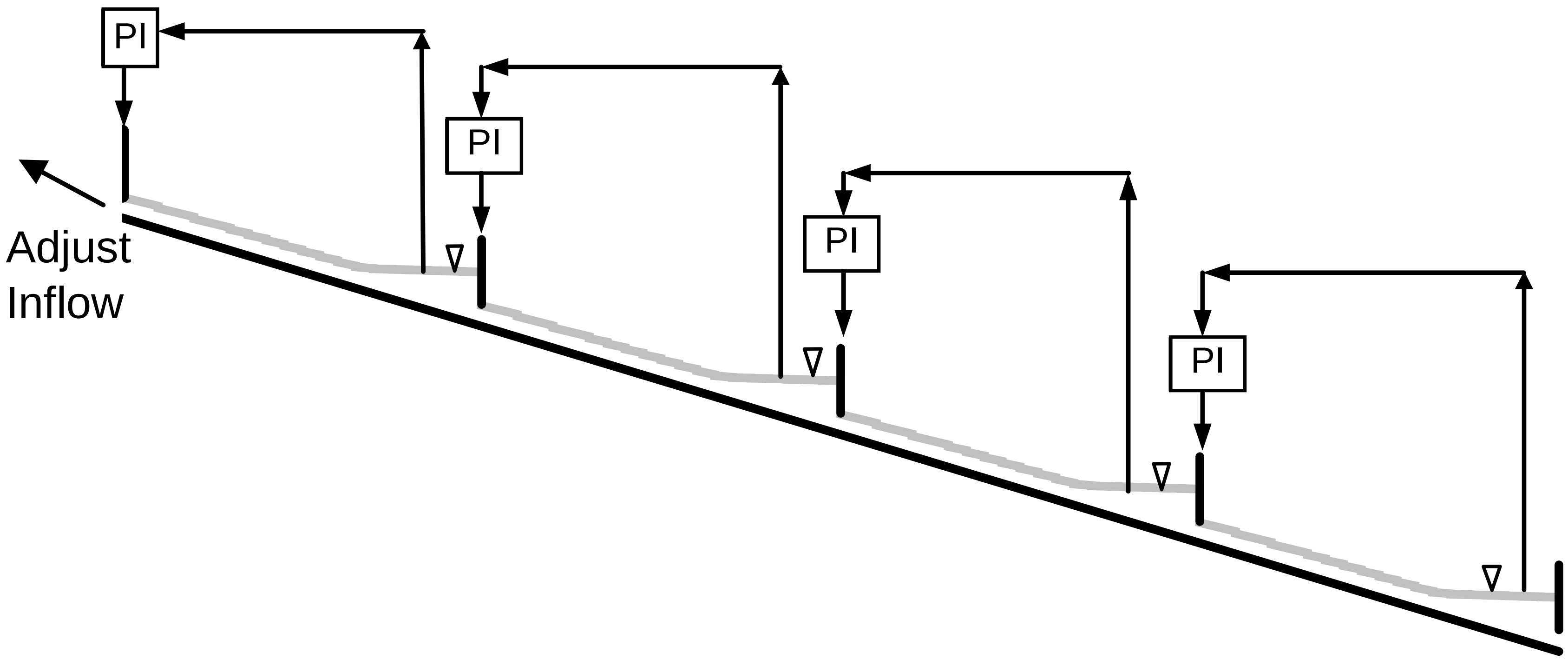
Upstream Control

Control is rapid, but
Errors go to downstream end



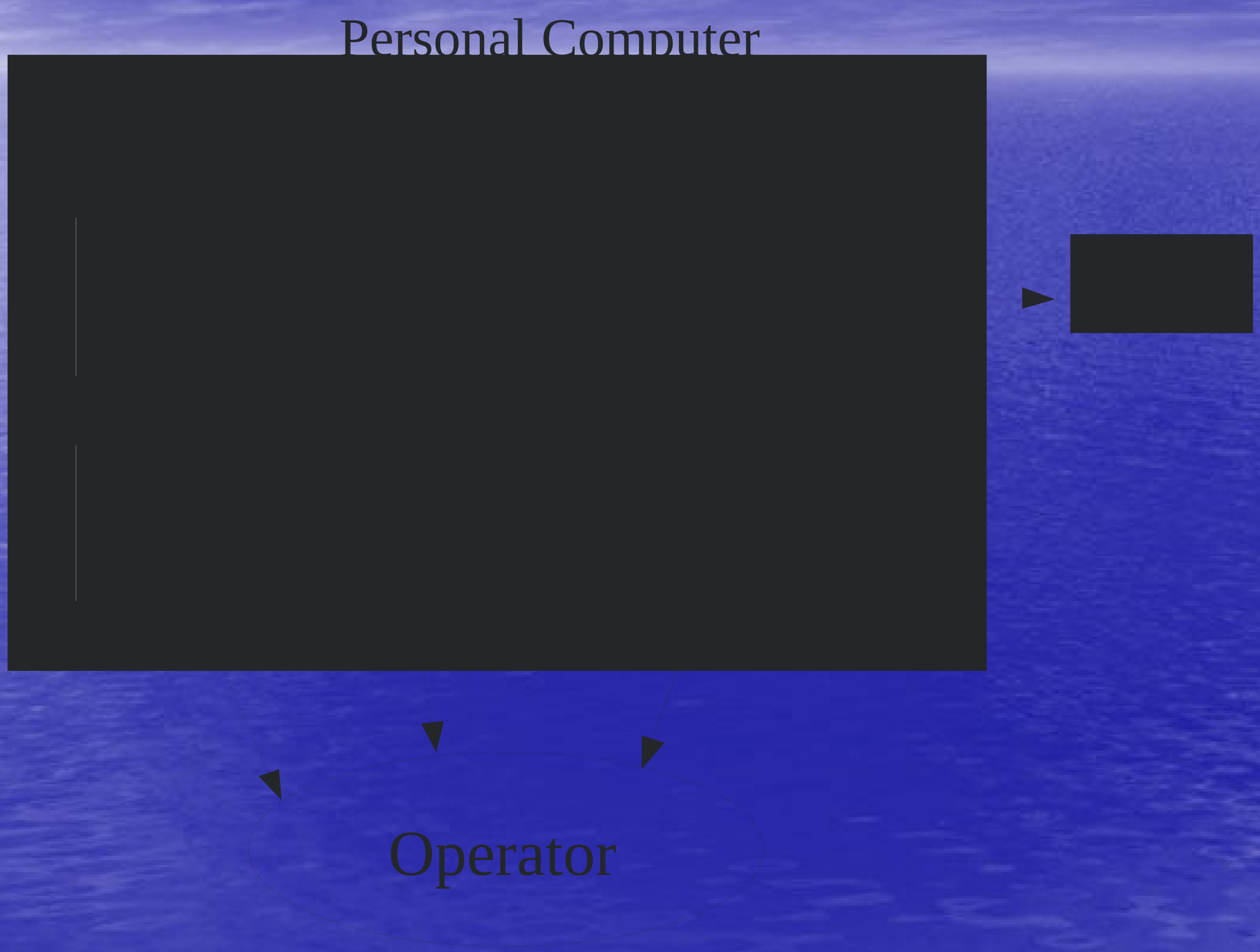
Downstream Control

Delays can be long, but
Errors go to upstream end

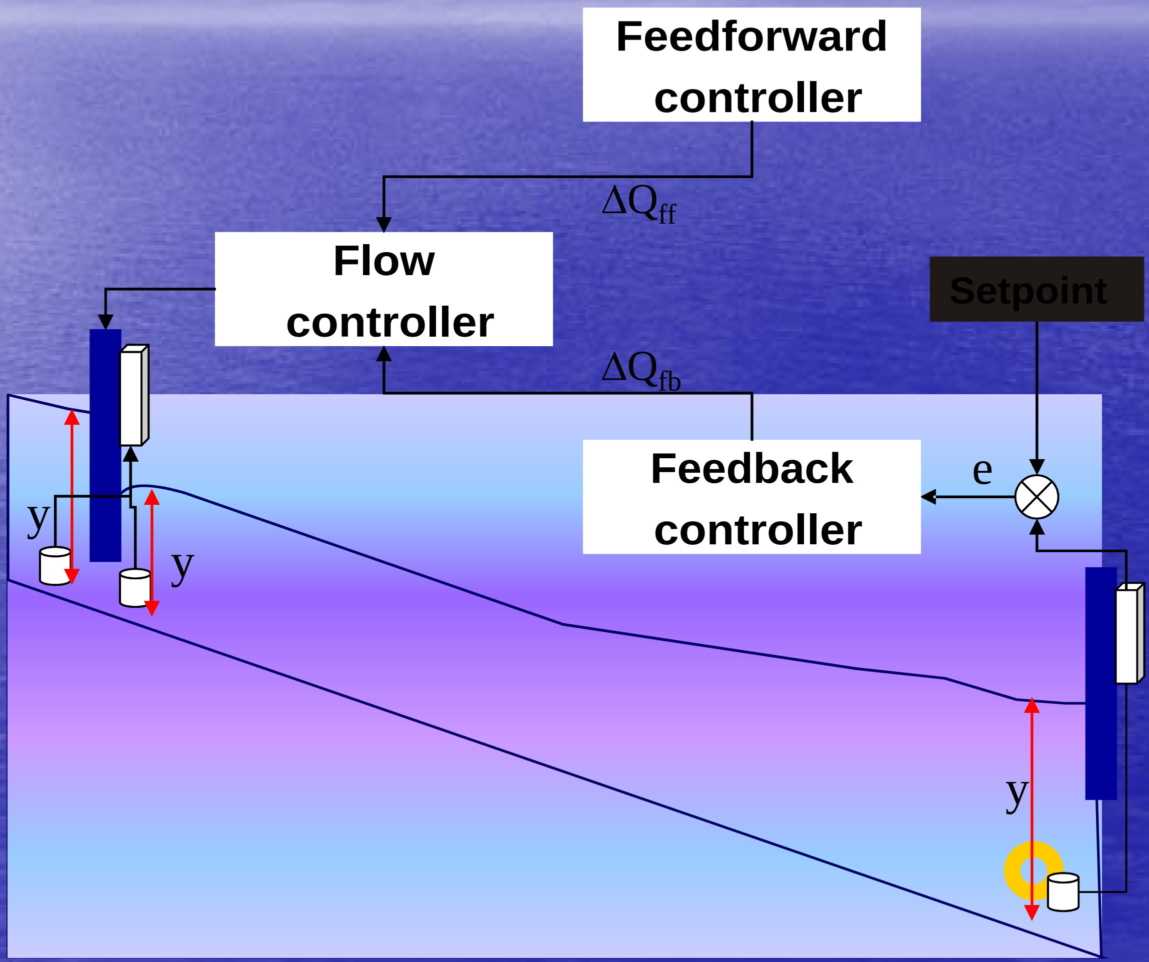


Software for Automated Canal Management

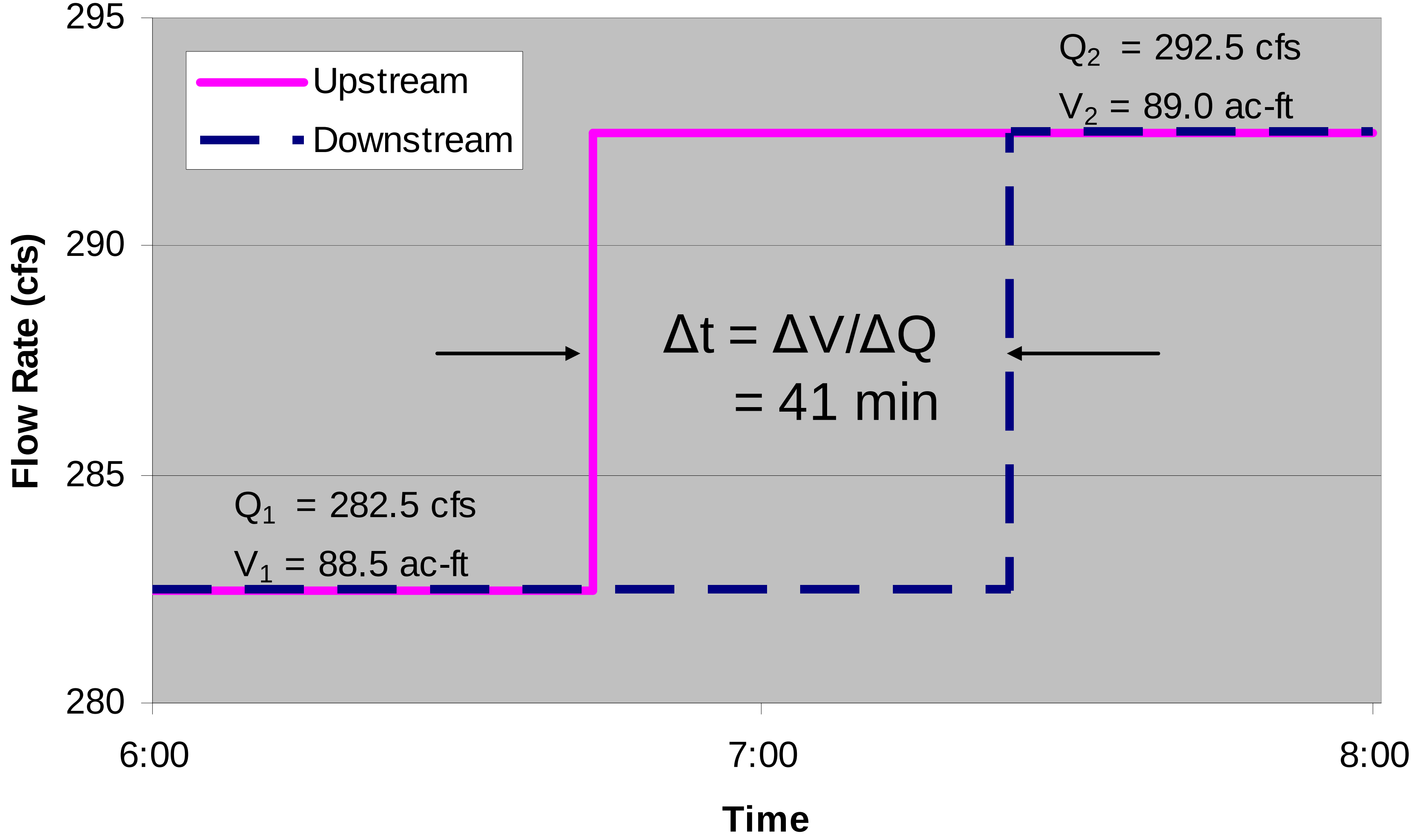
SacMan



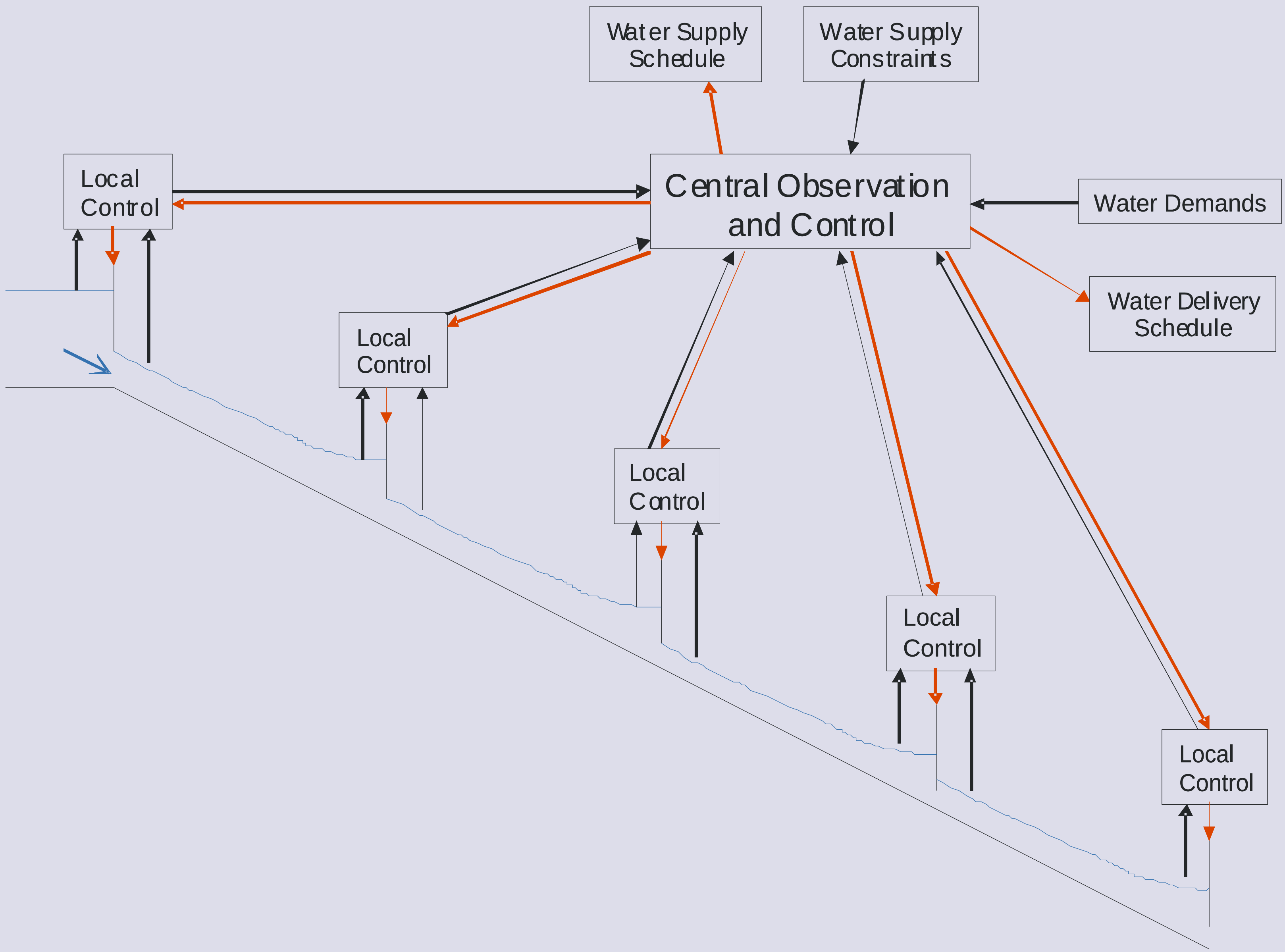
Components of control logic



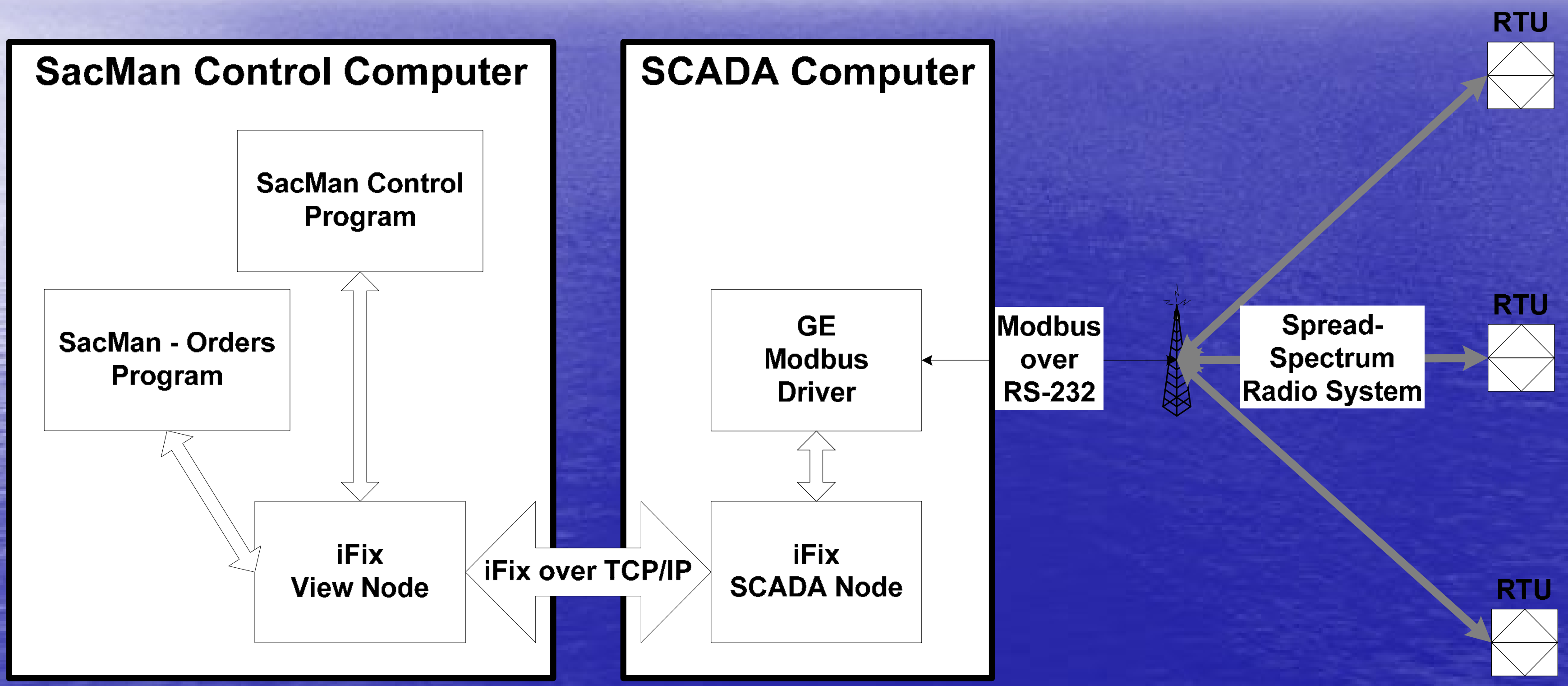
Volume Compensation Feed-Forward Routing - delay time, $\Delta\tau = \Delta V / \Delta Q$



Canal Automation Scheme



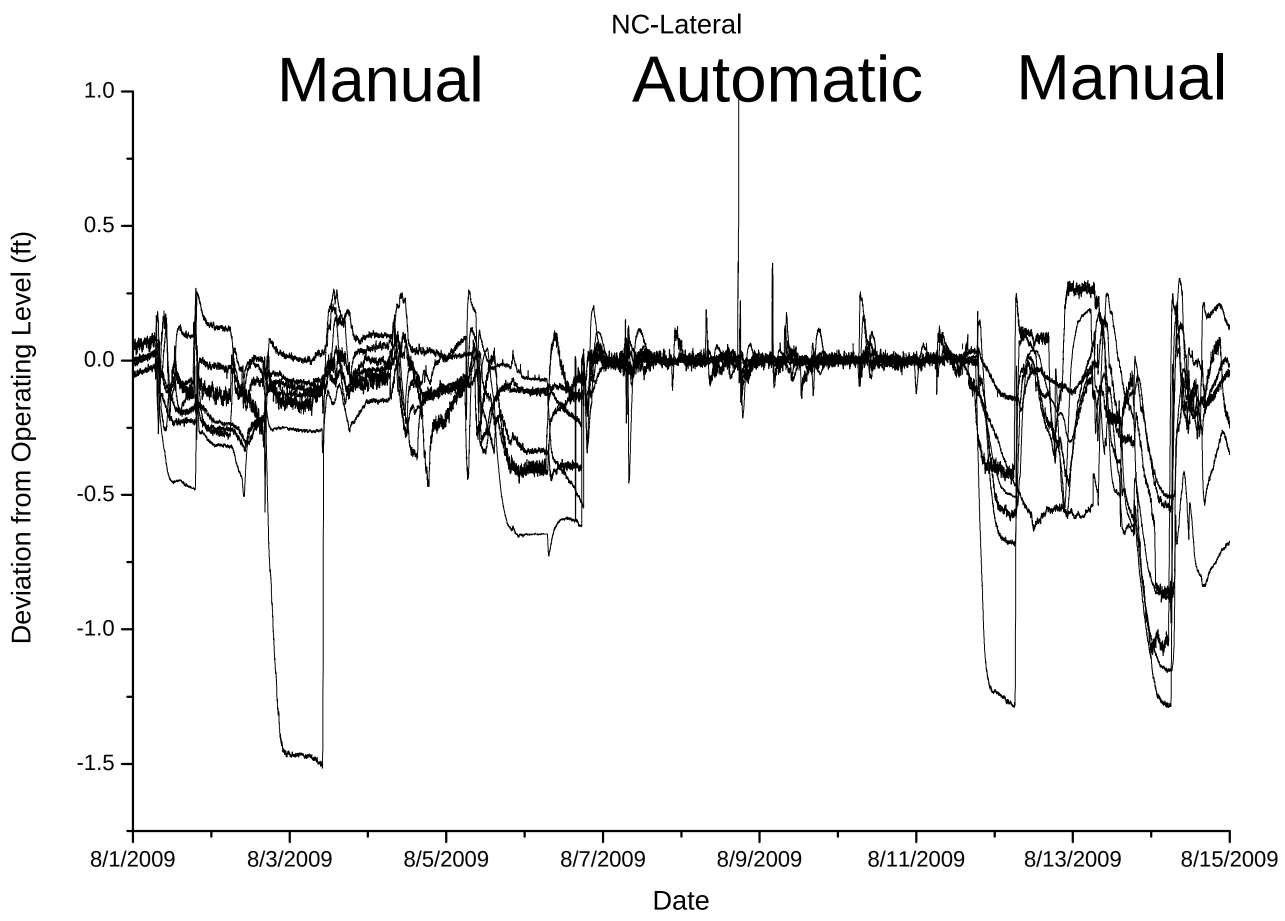
SacMan Implementation



Canal Automation with SacMan

- Water orders are entered into computer
- Computer routes flow changes through canal system based on volume compensation
- Canal operator opens turnout gate at prescribed time
- Water level errors are corrected with feedback control (new technology works!)
- Headgate and check gate flow controllers maintain flow balances
- Main canal pool volumes are varied to balance secondary canal volume errors

Automatic Controls remove Chaos from Distribution System

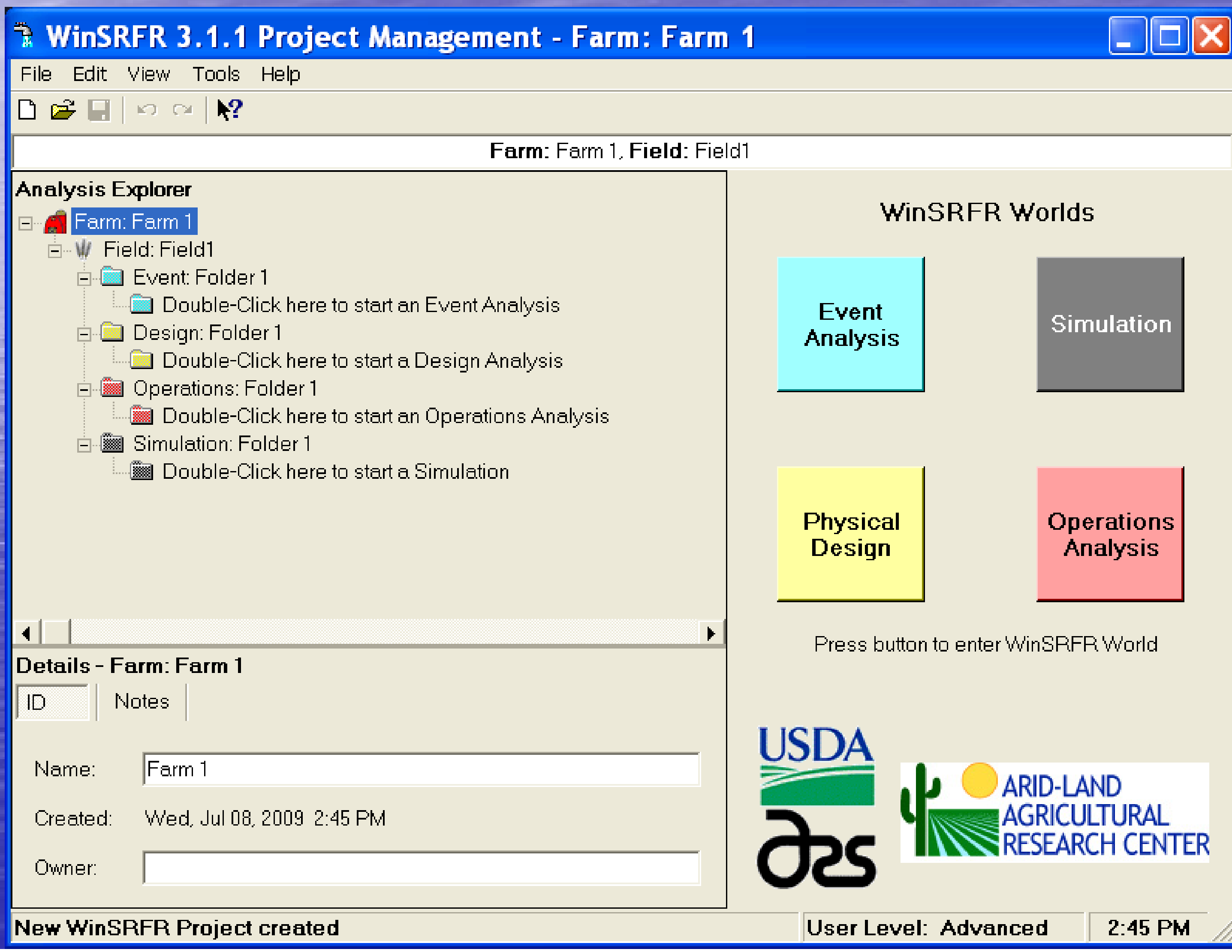


Technology for improving control for surface irrigation

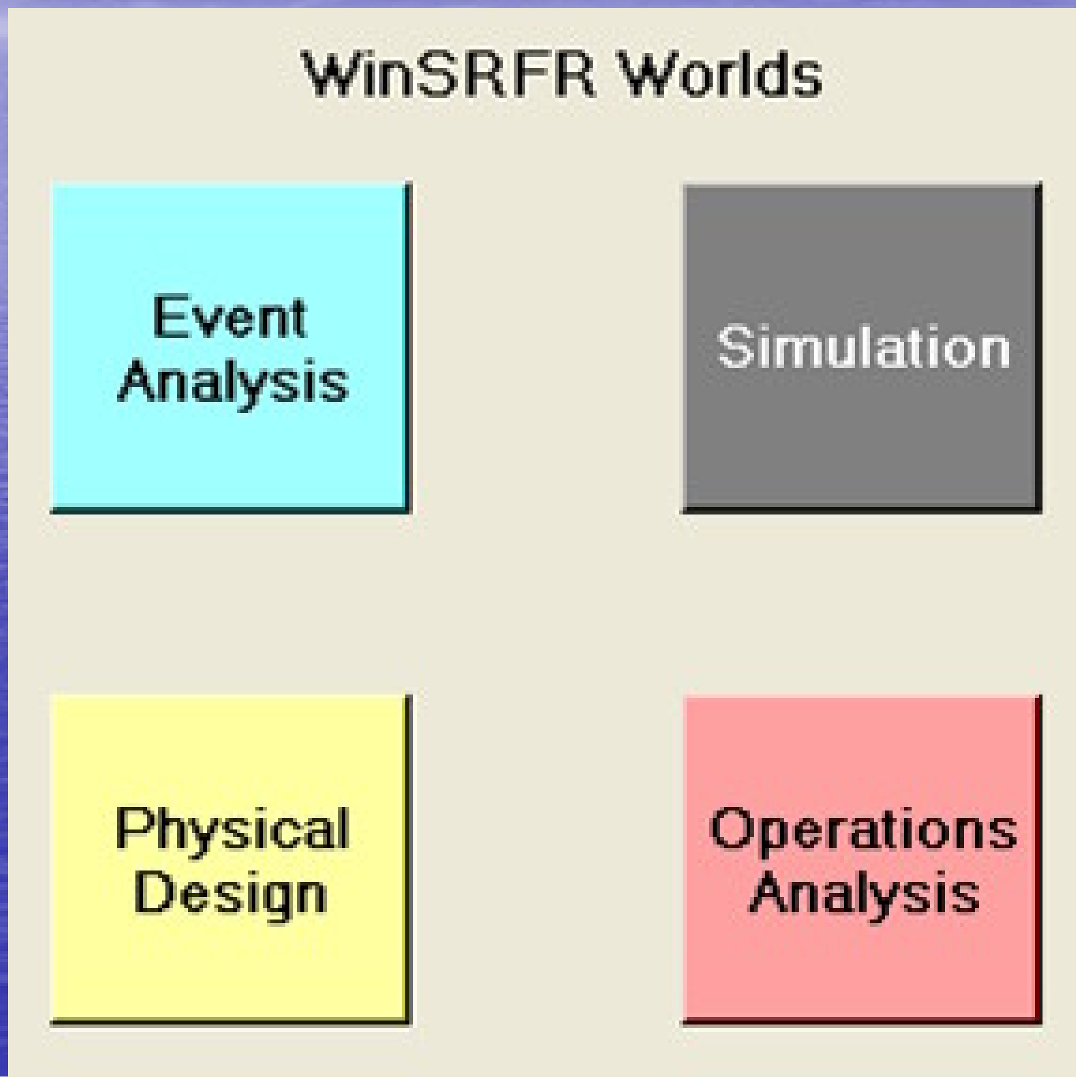
Laser-guided land grading is essential for improving surface irrigation

WinSRFR

Software for surface irrigation analysis



Different analyses are performed in different WinSRFR Worlds



- Event Analysis World
  - Evaluate irrigation events
  - Determine infiltration parameters
- Simulation World
  - conduct simulations
- Physical Design World
  - Determine field dimensions
- Operations Analysis World
  - Determine flow rate and operating rules
    - Time-based cutoff
    - Distance-based cutoff

Surface flow model simplifications

- Full hydrodynamic

$$\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{2Q}{gA^2}\frac{\partial Q}{\partial x}+\left(1-Fr^2\right)\frac{\partial y}{\partial x}=S_0-S_f$$

- Zero-inertia
  (equilibrium model)

$$\frac{\partial y}{\partial x}=S_0-S_f$$

- Kinematic-wave
  (normal depth model)

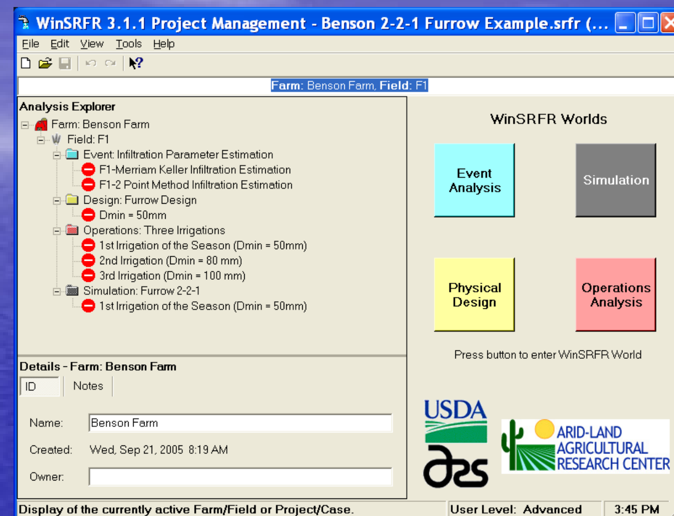
$$S_0=S_f$$

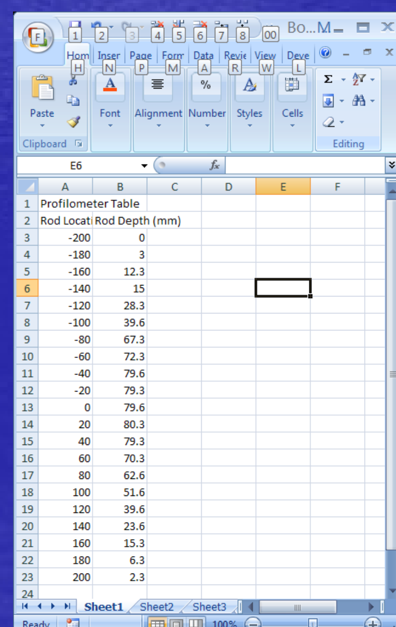
- Volume balance
  (assumed average surface depth model)

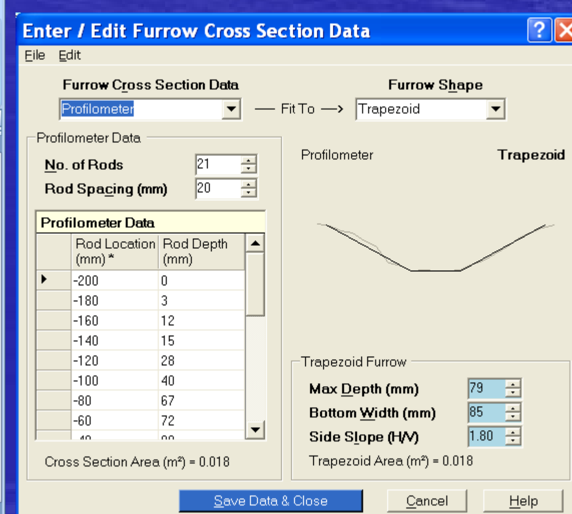
$$V_y=(A_n\cdot s_y)\cdot x_A$$

WinSRFR: Data Exchange

- Create scenarios from existing WinSRFR scenarios
- Exchange data with Windows applications







Simulation World

Given

- Field geometry
  - Length
  - Cross section
  - Bottom description (slope or elevations)
- Soil and crop hydraulic properties
  - Infiltration
  - Hydraulic resistance
- Management variables
  - Inflow as a function of time
  - Downstream boundary condition

Find

- Evolution of surface and subsurface flows
  - Q(x,t)
  - A(x,t)
  - Z(x,t)
- Performance measures
  - Application efficiency (AE)
  - Distribution uniformity (DU)
  - Adequacy (AD)
  - Runoff and deep percolation fractions (RO% and DP %)

Event Analysis World

<u>Given</u>

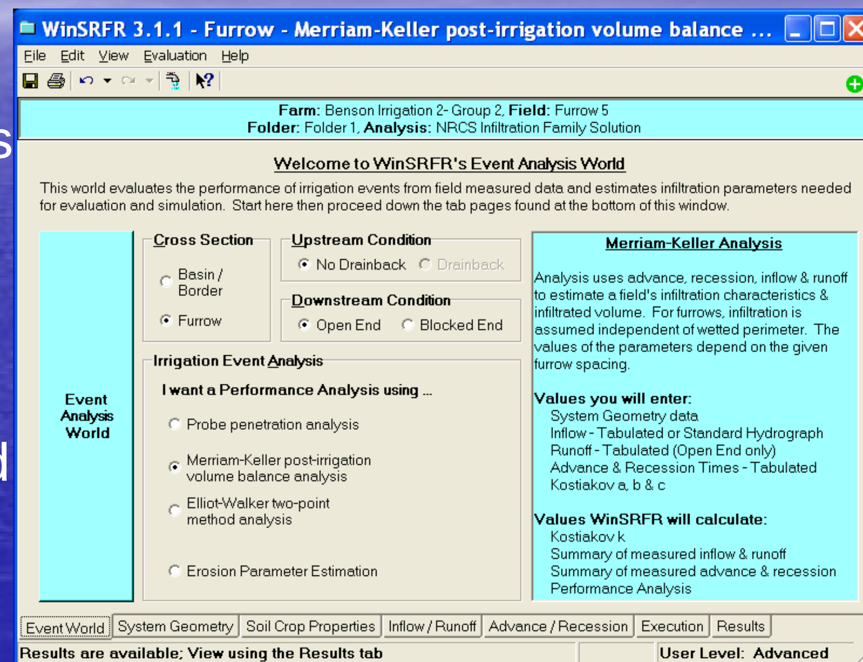
- Field geometry
  - Length
  - Cross section
  - Bottom description (slope or elevations)
- Management variables
  - Inflow as a function of time
  - Downstream boundary condition
- Observed outputs
  - Advance/recession
  - Runoff
  - Water penetration profile

<u>Find</u>

- Performance measures
  - Application efficiency (AE)
  - Distribution uniformity (DU)
  - Adequacy (AD)
  - Runoff and deep percolation fractions (RO% and DP %)
- Infiltration parameters (resistance parameters in future versions)

Event Analysis Options

- Irrigation performance evaluation
  - Probe penetration analysis
- Infiltration parameter estimation
  - Merriam-Keller PIVB
  - Elliott-Walker 2-pt method
- Erosion parameters estimation
  - Erodibility and critical shear)



Design World

Given

- Field geometry
  - Cross section
  - Slope or bottom elevation
- Soil and crop hydraulic properties
  - Infiltration
  - Hydraulic resistance
- Management variables
  - Available flow rate
  - Downstream boundary condition

Find

- Length/width or length/discharge combinations that will attain feasible and practical levels of performance

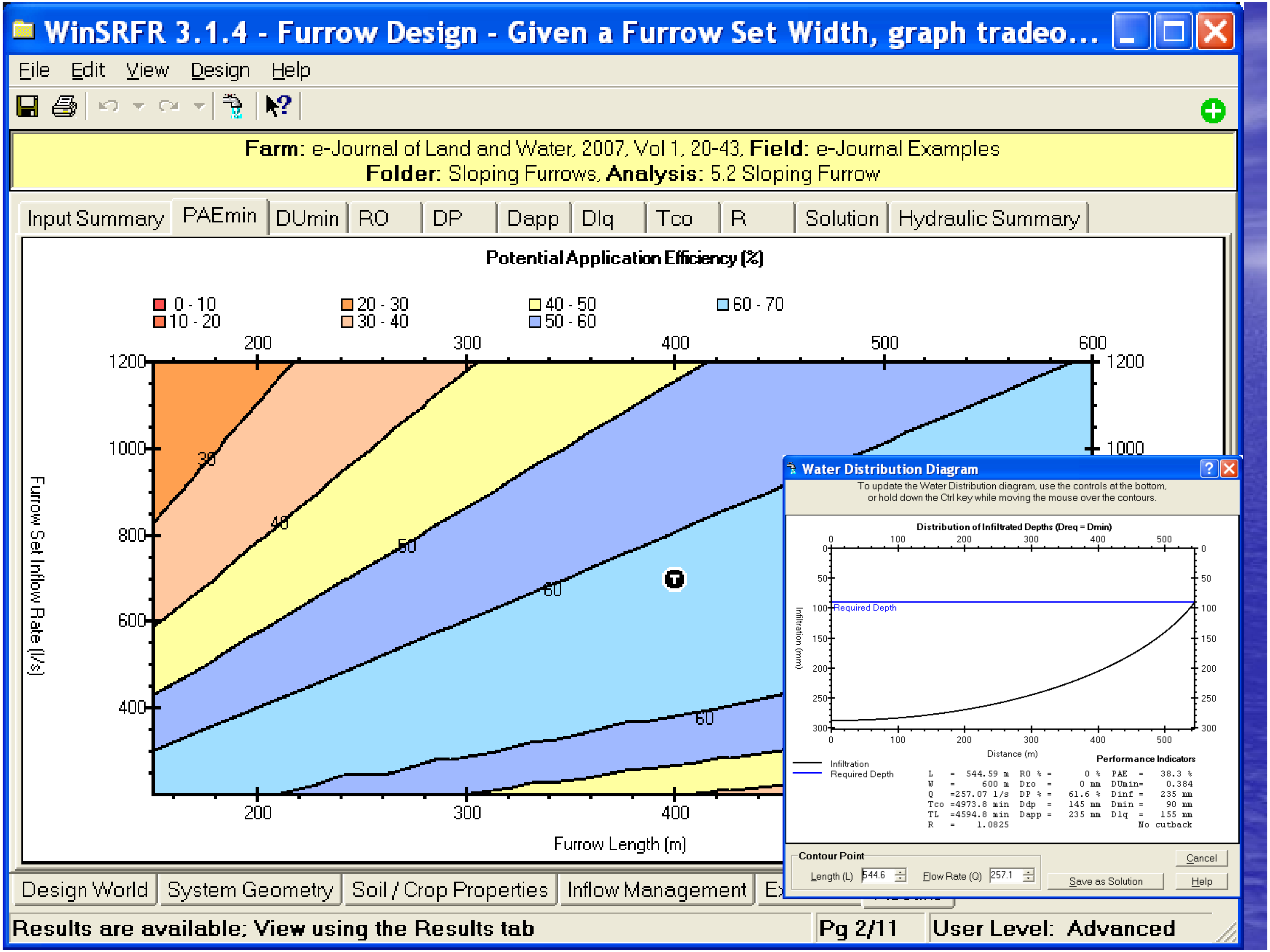
Operational Analysis World

Given

- Field geometry
  - Cross section
  - Slope or bottom elevation
  - Field dimensions
- Soil and crop hydraulic properties
  - Infiltration
  - Hydraulic resistance
- Management variables
  - Downstream boundary condition

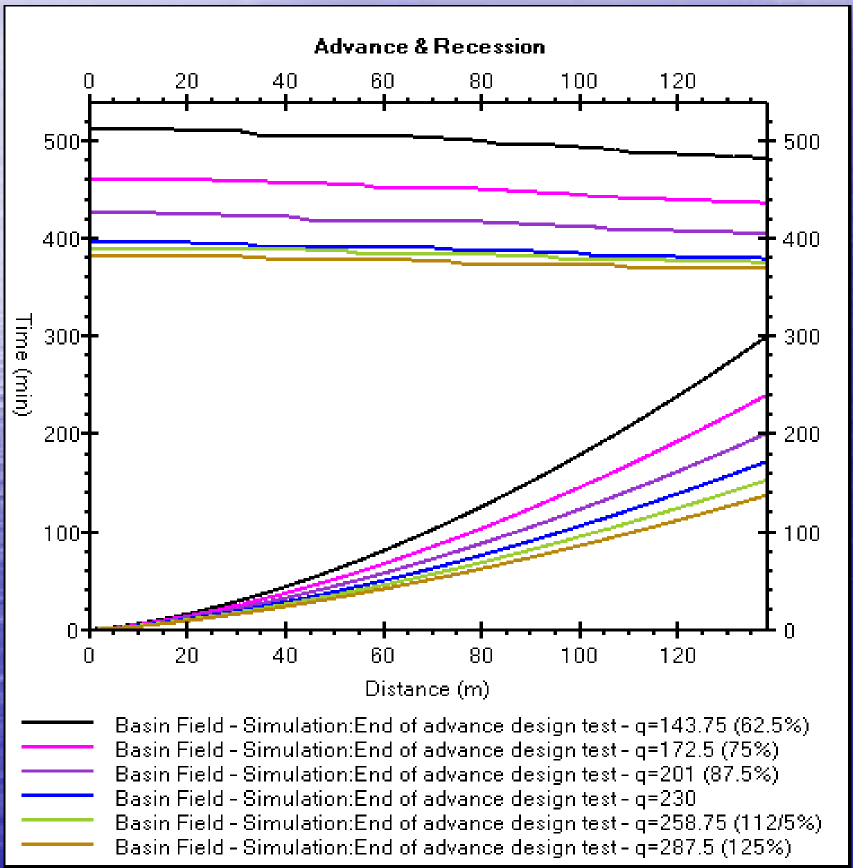
Find

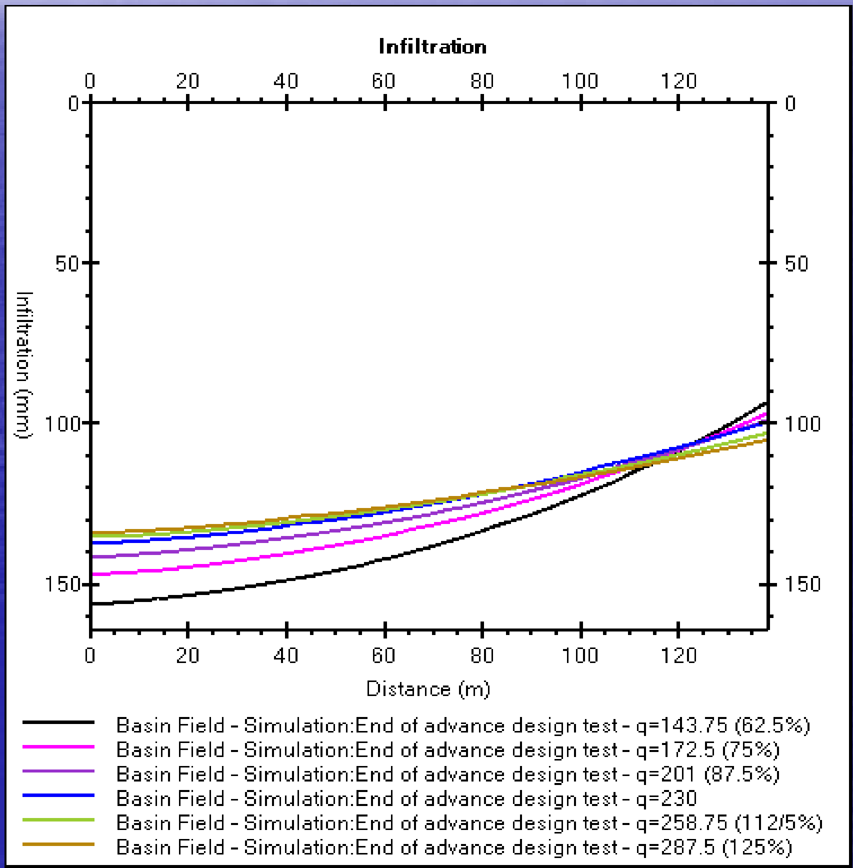
- Unit discharge and cutoff time combination(s) that will attain feasible and practical levels of performance



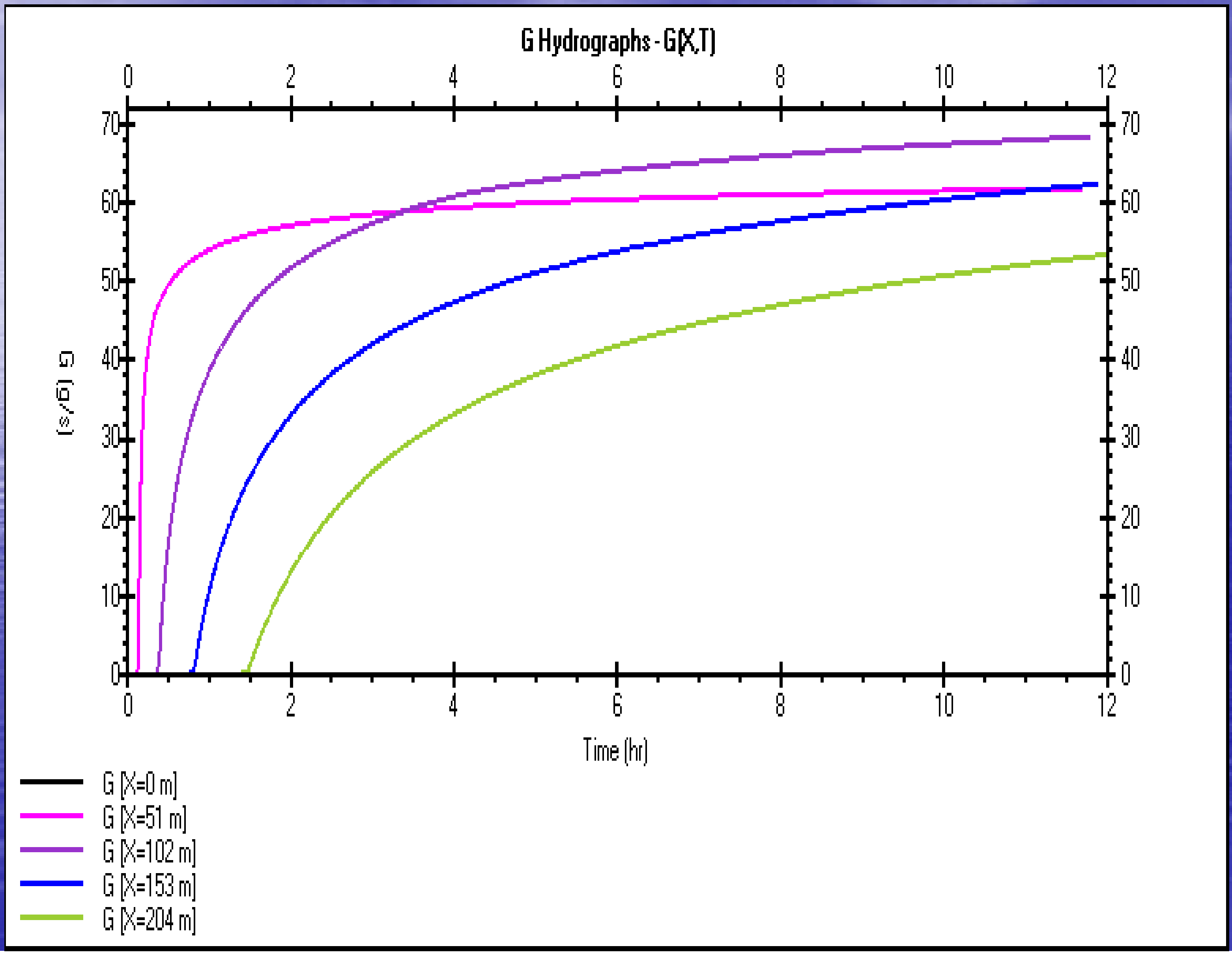
WinSRFR 3.1.4 - Furrow Design - Given a Furrow Set Width, graph tradeo...
File Edit View Design Help
Farm: e-Journal of Land and Water, 2007, Vol 1, 20-43, Field: e-Journal Examples
Folder: Sloping Furrows, Analysis: 5.2 Sloping Furrow
Input Summary
PAEmin
DUmin
RO
DP
Dapp
Dlq
Tco
R
Solution
Hydraulic Summary
Potential Application Efficiency (%)
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
Furrow Set Inflow Rate (l/s)
Furrow Length (m)
Water Distribution Diagram
To update the Water Distribution diagram, use the controls at the bottom, or hold down the Ctrl key while moving the mouse over the contours.
Distribution of Infiltrated Depths (Dreq = Dmin)
Required Depth
Infiltration (mm)
Distance (m)
Infiltration
Required Depth
Performance Indicators
L = 544.59 m RO % = 0 % PAE = 38.3 %
W = 600 m Dro = 0 mm DUmin= 0.384
Q =257.07 l/s DP % = 61.6 % Dinf = 235 mm
Tco =4973.8 min Ddp = 145 mm Dmin = 90 mm
TL =4594.8 min Dapp = 235 mm Dlq = 155 mm
R = 1.0825 No cutback
Contour Point
Length (L) 544.6
Flow Rate (Q) 257.1
Cancel
Save as Solution
Help
Design World
System Geometry
Soil / Crop Properties
Inflow Management
Results are available; View using the Results tab
Pg 2/11
User Level: Advanced

Performance of End-Of-Advance designed basin with varying inflows





Research model for prediction of erosion, sedimentation and fertigation



Summary

Improve water productivity through:

- Evaluation of water destinations
  - Where does the water end up?
- Better flow measurement
  - Design of flumes with WinFLume
- Improved control of water distribution
  - Canal automation with SacMan
- Improved design and operation of irrigation systems
  - WinSRFR and laser-guided land leveling for surface irrigation