Estimating Irrigation System Performance: A Key Step in Water Management

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1) Review the concepts of irrigation performance at field scale

2) Professional irrigation system evaluations
   ✓ What parameters are measured in the field?
   ✓ What information can we obtain?
   ✓ How to correct problems that are identified?

3) Recommendations
IRRIGATION EFFICIENCY @ FIELD SCALE

What fraction of the total water applied to a field is beneficially used by the crop

\[
I.E. = \frac{\text{Water used by the crop for } E.T. + \text{ Other Uses}}{\text{Total water applied onto the field}}
\]
Beneficial is the water used for crop production & health

- Canopy Transpiration (+ Plant Evaporation) = ET_c
- Spraying for pest control, application of fertilizers & nutrients (fertigation)
- Frost protection
- Canopy cooling
- Leaching salts + soil amendments

I.E. = Water used for crop production & health

Water Applied onto field

Water Applied to the field

- Replenish Soil Moisture Depleted since the last irrigation/rainfall event
- Soil Evaporation + Deep Percolation + Surface Runoff + Wind Drift
- Leakages (pipes or canals/ditches) + Out-of-control operation (valves/gates stuck-open, wrong commands, irrigation over-run, etc.)
- Water draining out of pipes and hoses after irrigation shut-off (pulsing on-off)
- Pipe flushing + Screen cleaning & Filters back-flush
- Pipe & hose chemical injection (keep the irrigation system functional)
Distribution Uniformity (D.U.) vs. Irrigation Efficiency (I.E)

Distribution Uniformity:
- is a number that describes how evenly water is distributed throughout the field.

Irrigation Efficiency:
- is the fraction of the applied water that is beneficially used by the crop.

**EXAMPLE**

1 gallon per tree
- D.U. = 100%; I.E. = 100%
- The plant will use every drop of water applied

500 gallons per tree
- D.U. = 100%; I.E. << 100%
- Trees will use a (small) percentage of the water applied
Vineyard B, 2015: Cumulative ET (mm/day) and cumulative precipitation + irrigation (mm/day) on North and South facing slopes (April 8-Oct 18)

(L. Wunderlich, D. Zaccaria, R. Snyder, K. Shackel)

S: 320 gal/vine (17.0 ac-inch)
N: 313 gal/vine (16.6 ac-inch)

N ave. 186 gal/vine (8.8 ac-inch)
S ave. 143 gal/vine (7.6 ac-inch)
Irrigation Efficiency

1) Application Mode
- Distribution Uniformity (DU)
- Adequacy of application (depth or volume infiltrated & stored)

2) Irrigation Losses
- Deep percolation
- Soil Evaporation
- Runoff
- Wind drift
Whether water is distributed evenly throughout the field or among plants (D.U.) mainly depends on proper system design, operation & maintenance.
If uniformity is not good, parts of the field must be over-irrigated so that the areas receiving less water in a given time will then be adequately irrigated. This over-irrigation can cause excessive deep percolation (water loss) => POOR Irrig. Efficiency
Adequacy of application refers to the depth or volume of water that infiltrates in the root zone and is available for plant use.

Whether an irrigation is adequate or not depends on the irrigation set-time & soil moisture status @ irrigation start.

**ADEQUACY OF APPLICATION**

Uniform, but average depth applied exceeds the soil water deficit (too much deep percolation).

**FIGURE 3**: Depiction of irrigation resulting in good DU but poor irrigation efficiency.

**FIGURE 4**: Depiction of irrigation sufficiently watering the entire field with good DU and irrigation efficiency.
CALCULATING DISTRIBUTION UNIFORMITY

\[ D.U. = \frac{\text{average flow of lowest 25\% emitters measured}}{\text{average flow of all emitters measured}} \]

EXAMPLE OF D.U. CALCULATION IN A VINEYARD

<table>
<thead>
<tr>
<th>Flow Rate (gph)</th>
<th>Circled Flow Rate (gph)</th>
<th>Flow Rate (gph)</th>
<th>Circled Flow Rate (gph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.98</td>
<td>0.89</td>
<td>0.95</td>
<td>0.94</td>
</tr>
<tr>
<td>0.99</td>
<td>1.05</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>1.15</td>
<td>0.70</td>
<td>1.05</td>
<td>1.01</td>
</tr>
<tr>
<td>0.98</td>
<td>0.97</td>
<td>0.96</td>
<td>0.94</td>
</tr>
</tbody>
</table>

The total number of emitters measured: 16
(=> 25\% * 16 emitters = 4 emitters)

The average flow of all emitters measured: 0.97 gph

The average flow of the lowest 25\% emitters measured: 0.87 gph

The Distribution Uniformity = 0.87/0.97 = 90\%
PROFESSIONAL SYSTEM EVALUATIONS

OBJECTIVES:

✓ Global (system) D.U.
✓ Identify main problems & corrections

STANDARDIZED SYSTEM D.U. (SWRCB)
WHAT DOES SYSTEM EVALUATION TELL US?

✓ What is the distribution uniformity (DU) of my system?
✓ What are the main problems to be corrected
✓ How much water does my system apply per hour (application rate)?
✓ How long shall I run the system to replace the water used by the crop?
WHAT PARAMETERS ARE MEASURED IN THE FIELD?

FLOWRATE

PRESSURE
What are the main factors affecting system D.U.?

1. **Pressure difference between emitters** (friction losses, elevation differences, etc.) cause flow differences \( q = k P^x \)

2. **Other causes**: emitter clogging, wear (gypsum), manufacturing variations (variation in size of orifices and flowrates due to the manufacturing process)

3. **Unequal drainage**: after system shut-off some emitters may continue to drain for some time while most of emitters have stopped discharging water (sloping blocks, pulsing irrigation on/off)

4. **Uneven spacing**: non-uniformity caused by having a different number of emitters per unit area in the field (2 or more different plant spacings)
system $DU_{lq} = \text{pressure difference } DU_{lq} \times \text{uneven spacing } DU_{lq} \times \text{unequal drainage } DU_{lq} \times \text{“Other” } DU_{lq}$
THE ITRC PROCEDURE ENCOMPASSES 4 SETS OF MEASUREMENTS

1. **Flow rate at 16-20 emitters** close to the pump and filters at 2 different values of the pressure

   \[ q = k P^x \]

   \[ P_8 \text{ PSI} \quad P_{16} \text{ PSI} \]

   \[ x = \log \left( \frac{\text{average low flow rate/average high flow rate}}{\text{log (low pressure/high pressure)}} \right) \]
2. DU related to pressure differences - it requires:

- **Pressure along individual hoses** (head, halfway down, tail-end)
- **Pressure between individual hoses along a single manifold – 2 hoses**: (closest to inlet, and most distant from inlet)
- **Pressure at head of each manifold – 6 manifolds** (including closest and most distant from the pump)

\[
q = k P^x
\]
3. DU related to “other causes” (clogging, wear, manufacturing variations)
Requires measuring emitter flow rates from 3 locations in the field

1. The middle of a hose hydraulically close to the water source (16 emitters)
2. The middle of a hose in the middle of a manifold near the middle of the field (16 emitters)
3. The end of a hose at the end of the most distant manifold (28 emitters)

\[
D.U. = \frac{\text{average flow of lowest 25\% emitters measured}}{\text{average flow of all emitters measured}}
\]
<table>
<thead>
<tr>
<th>Collection time:</th>
<th>0.5</th>
<th>minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose pressure at emitters:</td>
<td></td>
<td>psi</td>
</tr>
<tr>
<td>Collected volume:</td>
<td></td>
<td>mL</td>
</tr>
<tr>
<td>#1</td>
<td>258</td>
<td>mL</td>
</tr>
<tr>
<td>#2</td>
<td>304</td>
<td>mL</td>
</tr>
<tr>
<td>#3</td>
<td>290</td>
<td>mL</td>
</tr>
<tr>
<td>#4</td>
<td>320</td>
<td>mL</td>
</tr>
<tr>
<td>#5</td>
<td>288</td>
<td>mL</td>
</tr>
<tr>
<td>#6</td>
<td>305</td>
<td>mL</td>
</tr>
<tr>
<td>#7</td>
<td>312</td>
<td>mL</td>
</tr>
<tr>
<td>#8</td>
<td>220</td>
<td>mL</td>
</tr>
<tr>
<td>#9</td>
<td>310</td>
<td>mL</td>
</tr>
<tr>
<td>#10</td>
<td>320</td>
<td>mL</td>
</tr>
<tr>
<td>#11</td>
<td>315</td>
<td>mL</td>
</tr>
<tr>
<td>#12</td>
<td>307</td>
<td>mL</td>
</tr>
<tr>
<td>#13</td>
<td>305</td>
<td>mL</td>
</tr>
<tr>
<td>#14</td>
<td>312</td>
<td>mL</td>
</tr>
<tr>
<td>#15</td>
<td>297</td>
<td>mL</td>
</tr>
<tr>
<td>#16</td>
<td>304</td>
<td>mL</td>
</tr>
</tbody>
</table>

The average flow rate was 9.0287 gph.
The average application rate was 0.0362 in/hr.
The Flow DU for this location was 91.0248 %

<table>
<thead>
<tr>
<th>Collection time:</th>
<th>19.5</th>
<th>minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hose pressure at emitters:</td>
<td></td>
<td>psi</td>
</tr>
<tr>
<td>Collected volume:</td>
<td></td>
<td>mL</td>
</tr>
<tr>
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</tr>
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<td>#2</td>
<td>305</td>
<td>mL</td>
</tr>
<tr>
<td>#3</td>
<td>317</td>
<td>mL</td>
</tr>
<tr>
<td>#4</td>
<td>220</td>
<td>mL</td>
</tr>
<tr>
<td>#5</td>
<td>285</td>
<td>mL</td>
</tr>
<tr>
<td>#6</td>
<td>282</td>
<td>mL</td>
</tr>
<tr>
<td>#7</td>
<td>284</td>
<td>mL</td>
</tr>
<tr>
<td>#8</td>
<td>283</td>
<td>mL</td>
</tr>
<tr>
<td>#9</td>
<td>245</td>
<td>mL</td>
</tr>
<tr>
<td>#10</td>
<td>294</td>
<td>mL</td>
</tr>
<tr>
<td>#11</td>
<td>180</td>
<td>mL</td>
</tr>
<tr>
<td>#12</td>
<td>282</td>
<td>mL</td>
</tr>
<tr>
<td>#13</td>
<td>295</td>
<td>mL</td>
</tr>
<tr>
<td>#14</td>
<td>300</td>
<td>mL</td>
</tr>
<tr>
<td>#15</td>
<td>290</td>
<td>mL</td>
</tr>
<tr>
<td>#16</td>
<td>287</td>
<td>mL</td>
</tr>
<tr>
<td>#17</td>
<td>284</td>
<td>mL</td>
</tr>
<tr>
<td>#18</td>
<td>291</td>
<td>mL</td>
</tr>
<tr>
<td>#19</td>
<td>292</td>
<td>mL</td>
</tr>
<tr>
<td>#20</td>
<td>295</td>
<td>mL</td>
</tr>
<tr>
<td>#21</td>
<td>286</td>
<td>mL</td>
</tr>
<tr>
<td>#22</td>
<td>283</td>
<td>mL</td>
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<tr>
<td>#23</td>
<td>263</td>
<td>mL</td>
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<tr>
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<td>255</td>
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<tr>
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<td>289</td>
<td>mL</td>
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<tr>
<td>#26</td>
<td>294</td>
<td>mL</td>
</tr>
<tr>
<td>#27</td>
<td>291</td>
<td>mL</td>
</tr>
<tr>
<td>#28</td>
<td>298</td>
<td>mL</td>
</tr>
</tbody>
</table>

The average flow rate was 8.9101 gph.
The average application rate was 0.0357 in/hr.
The Flow DU for this location was 87.7764 %
4. DU related to Unequal Drainage (emitters continue draining after system shut-off => downhill edges of the field, pulsing irrigation on/off)

Requires observation of emitters within the field
(how long some emitters continue draining after most emitters stopped)

Unequal Drainage D.U. = \[
\left(\frac{\text{extra min. of operation of some emitters}}{\text{average set duration (min)}}\right) x (\text{fraction of the field with unequal drainage})
\]

uneven spacing DU = \[
\frac{\text{lowest weekly depth applied}}{\text{average weekly weighted depth applied}}
\]
system \( DU_{lq} = \) pressure difference \( DU_{lq} \times \) uneven spacing \( DU_{lq} \times \) unequal drainage \( DU_{lq} \times \) “Other” \( DU_{lq} \)

Distribution Uniformity................................................................. 85%

How your system rates:

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Fair</th>
<th>Good</th>
<th>Very Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>74 or below</td>
<td>75-79</td>
<td>80-84</td>
<td>85-89</td>
<td>90 and up</td>
</tr>
</tbody>
</table>
ADDITIONAL INFORMATION
FROM SYSTEM EVALUATION

DRIP/MICRO EVALUATION: PROBLEMS NOTED

Ref. #
5 The field DU is considered poor

Pressure problems
Manifold inlet pressure variation is a significant problem
Possible causes of manifold inlet pressure variation include:

6 Lack of pressure regulation;
consider installing manifold pressure regulators

Hose inlet pressure variation is a significant problem
Possible causes of hose inlet pressure variation include:

9 Defective regulators
10 Inlet pressure lower than pressure regulator’s operating range

12 Some pressures found in the field were very low

Other problems noted
27 Fertilizer injector located downstream of filter
31 High pressure losses at pump station
34 Small wetted soil area

Pressure problems
Hose inlet pressure variation is a significant problem
Possible causes of hose inlet pressure variation include:

8 Lack of pressure regulation;
consider installing hose pressure regulators

Other problems noted
27 Fertilizer injector located downstream of filter
30 No flow meter

Hose screen plugged
With organic matter
Main causes of clogging include:

- Suspended material in the irrigation water
- Chemical precipitation in emitters
- Biological growths in emitters
- Root intrusion
- Soil ingestion
SOME RECOMMENDATIONS

Have a professional system evaluation at least every 2-3 years
DU tends to decrease over time

Know your system application rate & DU
⇒ Key elements for irrigation efficiency

(Time to run the system = water to be applied/application rate)

Monitor the system periodically to spot and correct problems

(Check mainly flowrate and pressure at critical points)
Correct problems soon after they are identified
HIGH EFFICIENCY REQUIRES SIGNIFICANT EFFORT IN ROUTINE MAINTENANCE

- Checking for leaks (farm equipment & animals)
- Back-flushing filters (manually or automatically)
- Periodically flushing main, submain and laterals (in that order)
- Chlorinating for organic material: continuous (1-2 ppm) or periodic (10-50 ppm)
- Acidifying (lowering Ph. < 7-5) to avoid/remove precipitates
- Cleaning or replacing clogged emitters and other components

Publication available at:
### Table X – Average DU and IE from 990 mobile lab evaluations in the Central Valley (Hanson et al. 1995)

<table>
<thead>
<tr>
<th>Irrigation method/system</th>
<th>Sample Size</th>
<th>Average DU (%)</th>
<th>Average IE (%)</th>
</tr>
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<tbody>
<tr>
<td>Hand move/solid-set sprinklers</td>
<td>164</td>
<td>62</td>
<td>69</td>
</tr>
<tr>
<td>Continuous-move sprinklers</td>
<td>57</td>
<td>75</td>
<td>81</td>
</tr>
<tr>
<td>Undertree sprinklers</td>
<td>28</td>
<td>79</td>
<td>81</td>
</tr>
<tr>
<td>Microirrigation</td>
<td>481</td>
<td>70</td>
<td>76</td>
</tr>
<tr>
<td>Furrow irrigation</td>
<td>157</td>
<td>81</td>
<td>66</td>
</tr>
<tr>
<td>Border irrigation</td>
<td>72</td>
<td>84</td>
<td>80</td>
</tr>
</tbody>
</table>

### Average DU of Micro-Irrigation systems (ITRC, 2004)

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th># of Fields evaluated</th>
<th>Average $DU_{Uq}$</th>
<th>Coefficient of variation of the DU values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drip</td>
<td>133</td>
<td>.86</td>
<td>.127</td>
</tr>
<tr>
<td>Microspray</td>
<td>196</td>
<td>.81</td>
<td>.123</td>
</tr>
<tr>
<td>Total or average</td>
<td>329</td>
<td>.83</td>
<td>.12</td>
</tr>
</tbody>
</table>
Application Efficiency (A.E) vs. Irrigation Efficiency (I.E.)

Application Efficiency:

\[ A.E. = \frac{\text{Water stored in the soil root zone}}{\text{Total water applied onto the field}} \]

Irrigation Efficiency:

\[ I.E. = \frac{\text{Water beneficially used by the crop}}{\text{Total water applied onto the field}} \]

single irrigation event

entire irrigation season
DIFFERENCES BETWEEN IRRIGATION METHODS

SURFACE IRRIGATION METHODS
DU and infiltrated water mainly depend on soil infiltration rate and slope (water travels onto the fields)

SPRINKLER & MICRO-IRRIGATION
DU and infiltrated water mainly depend on system’s characteristics (water travels through the pipe system and is applied in the vicinity of plants)
Low performance (DU) is due to:

- Inadequate design and installation (new systems)
- Lack of proper maintenance (aging systems)
- Variations in system pressure
- Improper set of control valves (reduced pressure)
- Plugged hose screens (reduced pressure)
- Debris accumulated at end of mains and sub-mains (reduced pressure)
- Leaks (drop in pressure)
- Emitter plugging (reduced pressure & flow)

Table X – Average DU and IE from 990 mobile lab evaluations in the Central Valley (Hanson et al. 1995)

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</table>
Sprinkler & Micro-irrigation Methods

Applied water = Root zone storage + Runoff + Deep percolation

To Increase Irrigation Efficiency:

1) Improve DU
2) Minimize Runoff, Wind-drift and Deep Percolation

IRRIGATION SYSTEM EVALUATION

✓ What is the distribution uniformity (DU) of my system?
✓ What are the main problems to be corrected
✓ How much water does my system apply per hour (application rate)?
✓ How long shall I run the system to replace the water used by the crop?
INEFFICIENT IRRIGATION OFTEN LEADS TO:

- Higher costs (labor, water, nutrients, pumping)
- Leaching nutrients, fertilizers and pesticides;
- Uneven plants development;
- Crop yield lower than potential or alternate bearing