Monitoring stormwater control measures

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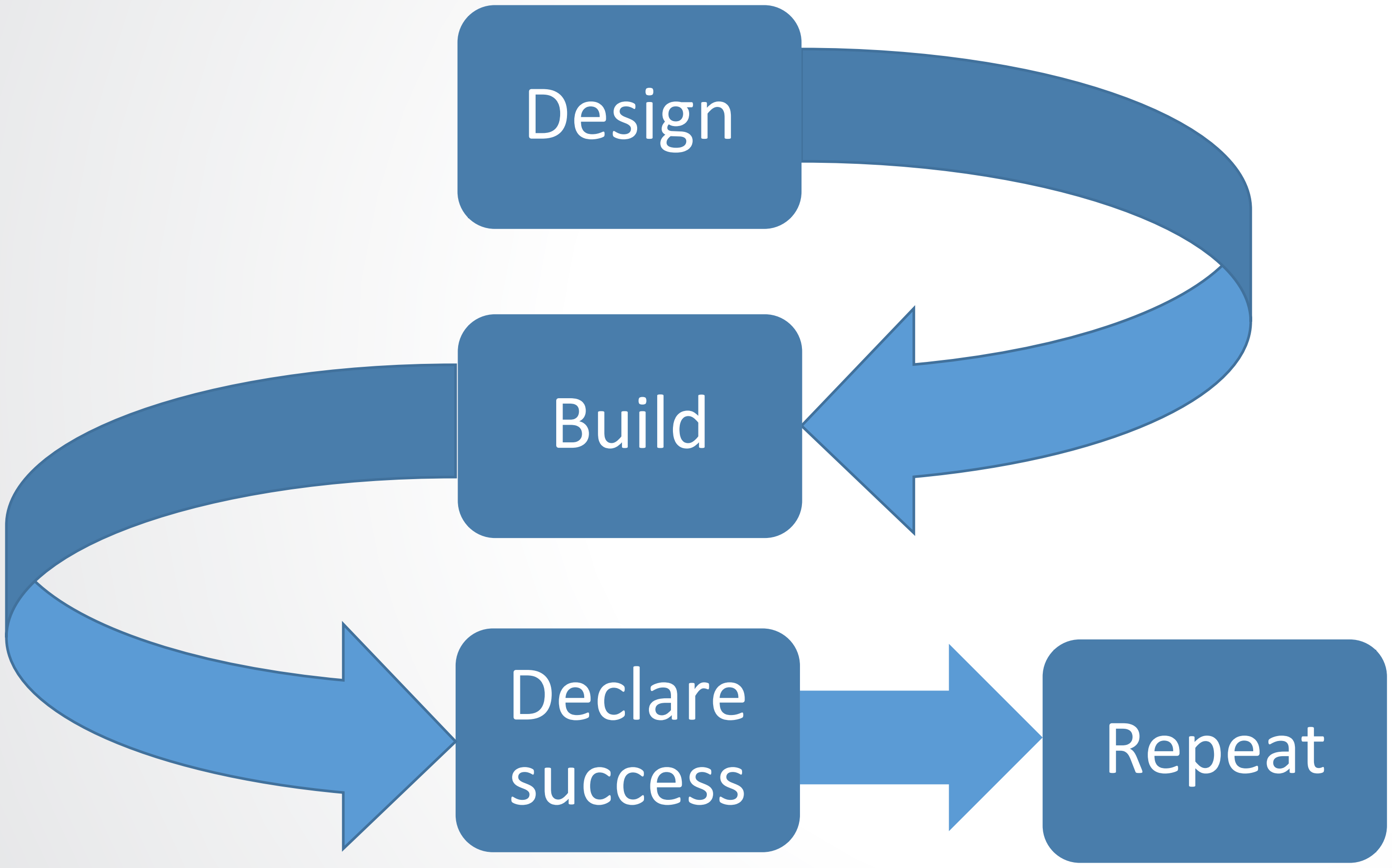
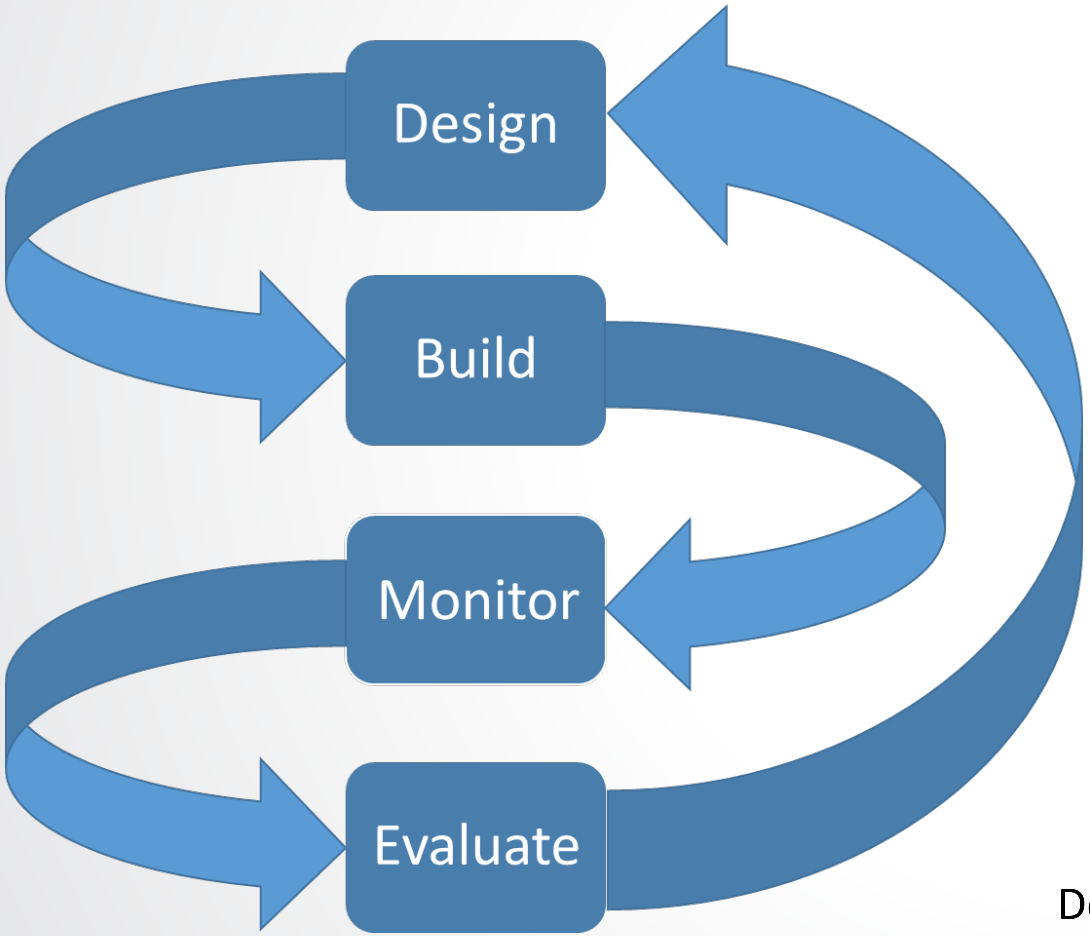
Engineer

EPA / ORD / CESER / WID

One approach



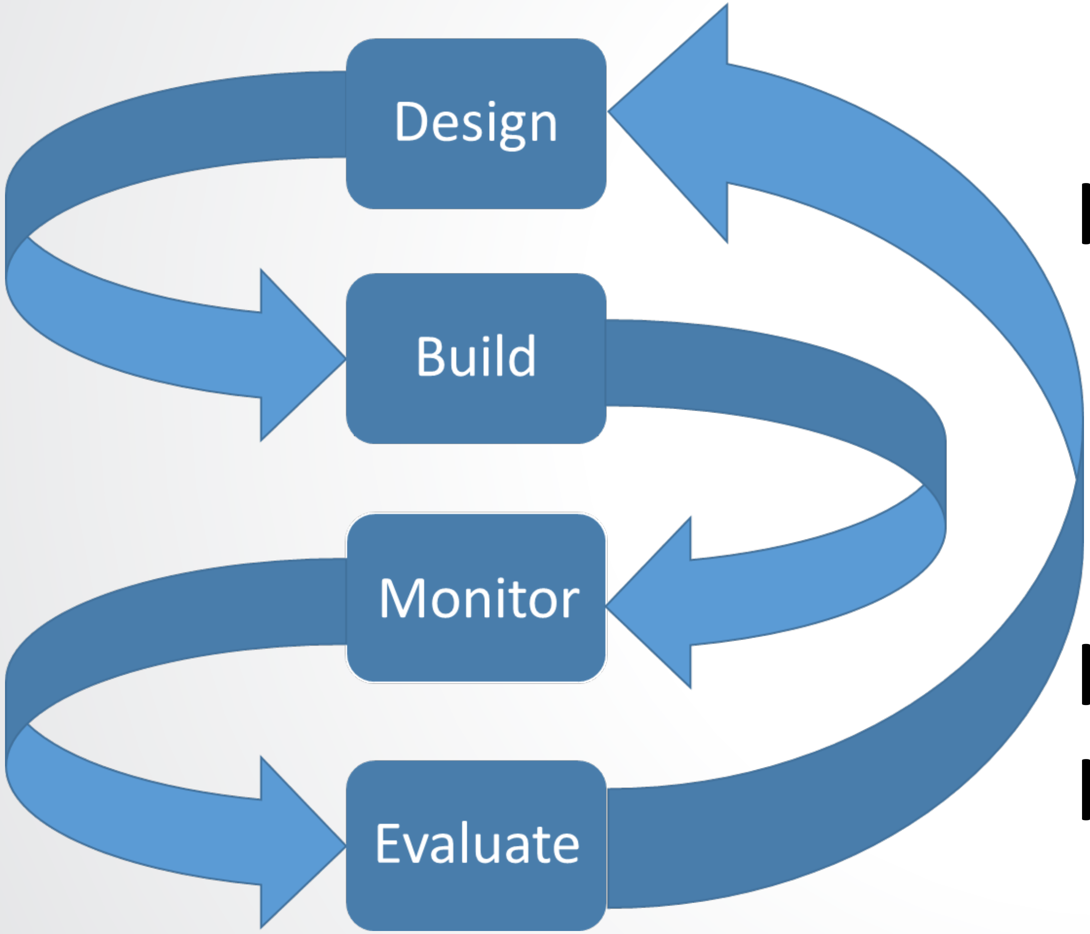
An alternate approach



Adaptive management aka "learning while doing"

Doremus, H., Precaution, Science, and Learning While Doing in Natural Resource Management, 82 WASH. L. REV. 547, 550 (2007).

Adaptive management



How to monitor?

What to measure?

How to measure?

How long to measure?

How good are the measurements?

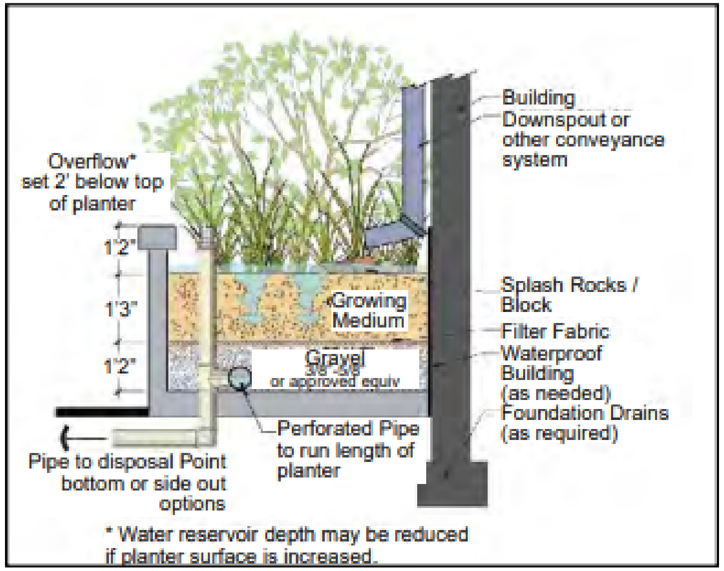
How to analyze measurements?

Why start with stormwater planters?

- They should be easy to monitor
  - Nearly closed system
  - Small by comparison to most other stormwater controls
  - Usually have a single inlet (plus direct rainfall) and single outlet (plus ET)
- Techniques and results should be transferable to other biofiltration systems

What is a stormwater planter?

- A flow-through stormwater control measure typically installed above ground to intercept rooftop runoff.
- Small footprint suitable for urban installations where space is limited and can meet ADA requirements.
- Ponding zone, media layer over aggregate with underdrain
- Usually vegetated
- Often (but not always) do not exfiltrate to locale soils
- Used in MS4 and CSO communities
- Variety of sizing guidelines

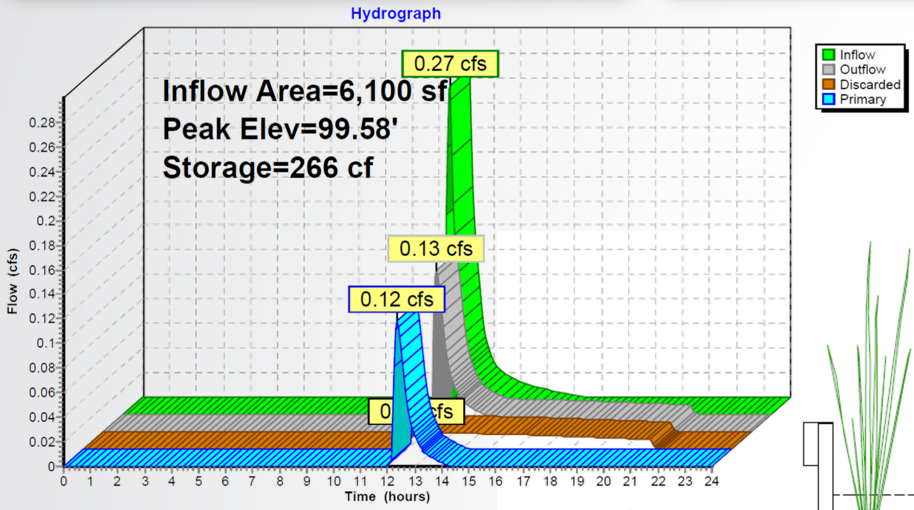


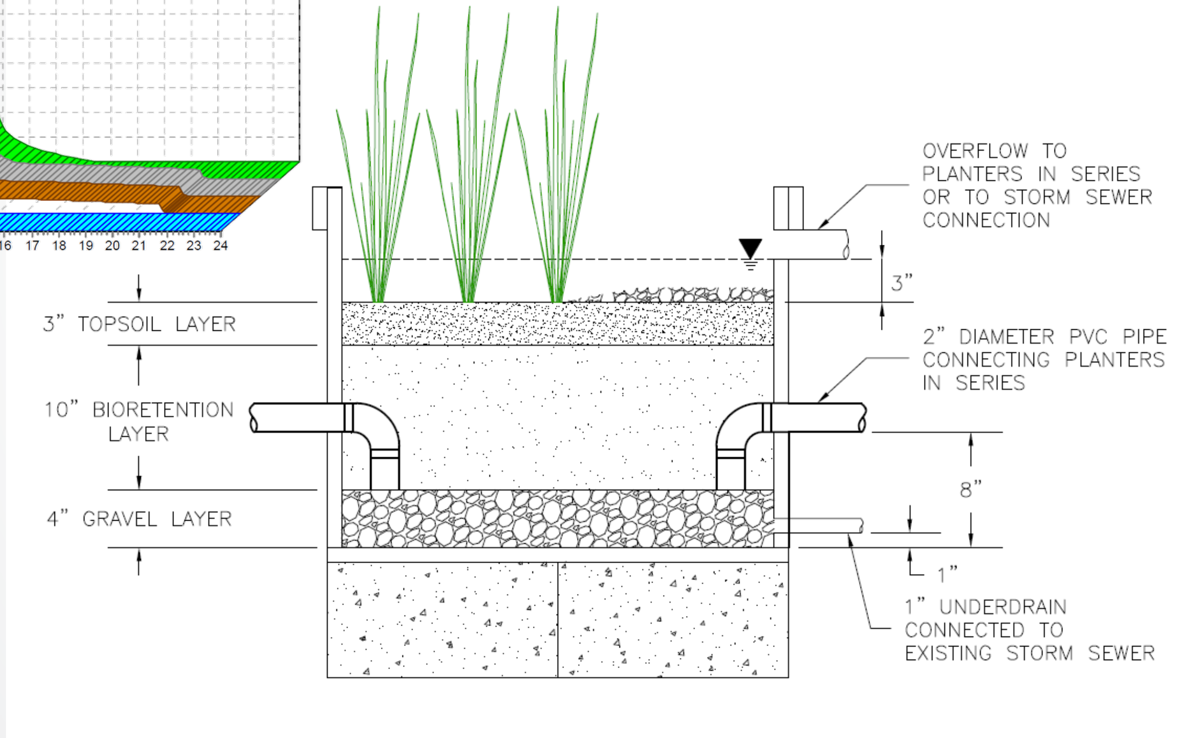
Source: City of Portland, Bureau of Environmental Services

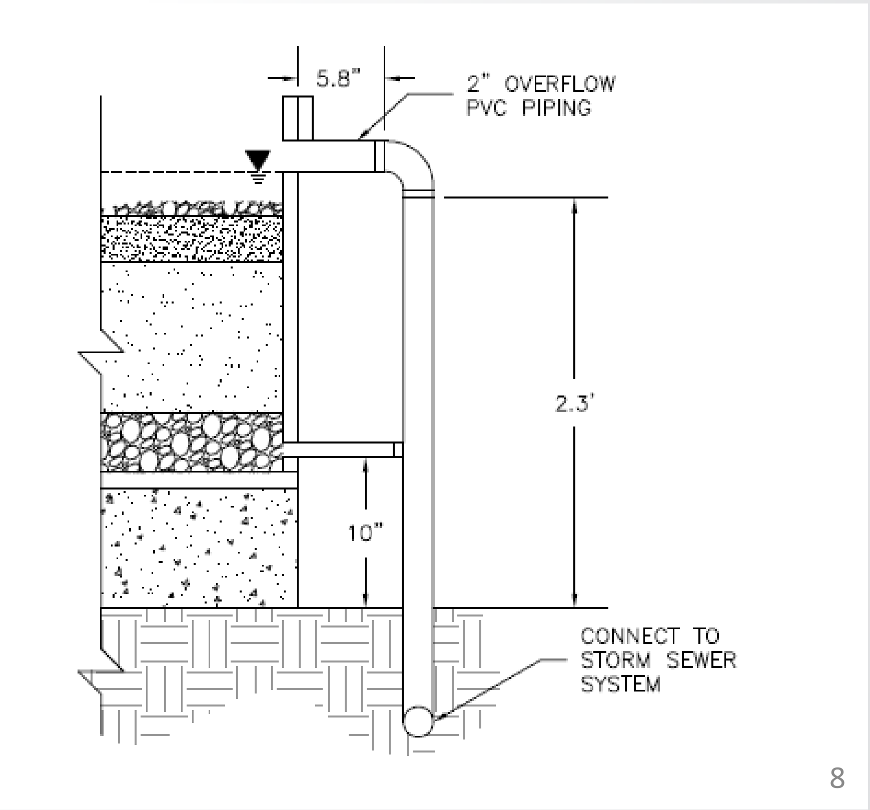
Measures of planter performance

- Complete capture frequency
- Captured volume
  - Water held after rain event less water held at start of the event
  - Inlet volume less outlet volume
- Discharge delay
  - Time difference from first inlet flow to first outlet flow
  - Time difference between inlet and outlet flow centroids
- Peak flow attenuation
  - Based on ratio of maximum discharge flowrate to maximum inlet flowrate
- Fraction of media used

Plan A: Camden, NJ

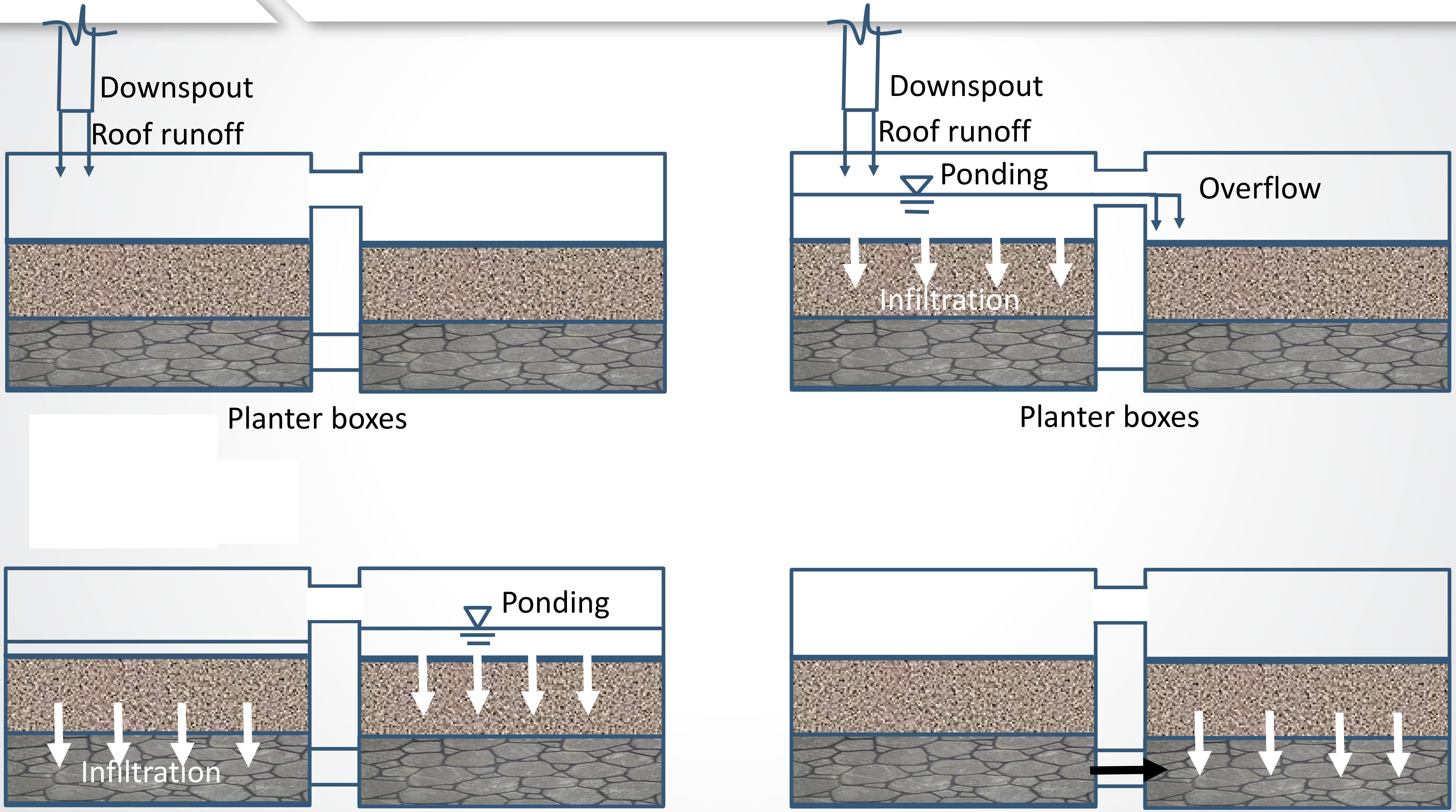






Camden County Municipal Utilities Authority, 2014

Conceptual operation



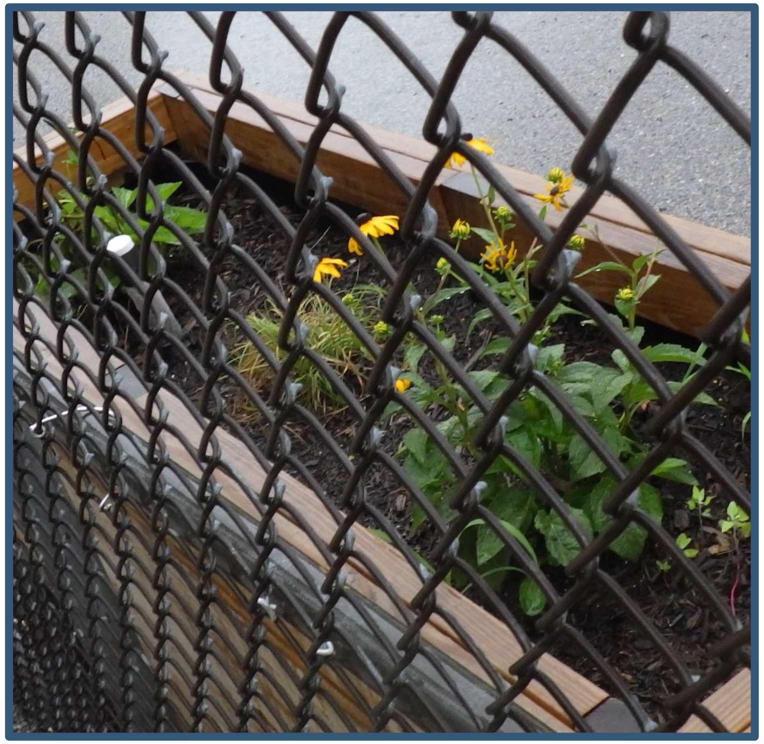
Modular plug-and-play design

Henry H. Davis school (8 boxes)

Only first box(es) received surface flow

Henry Davis school, Box 1

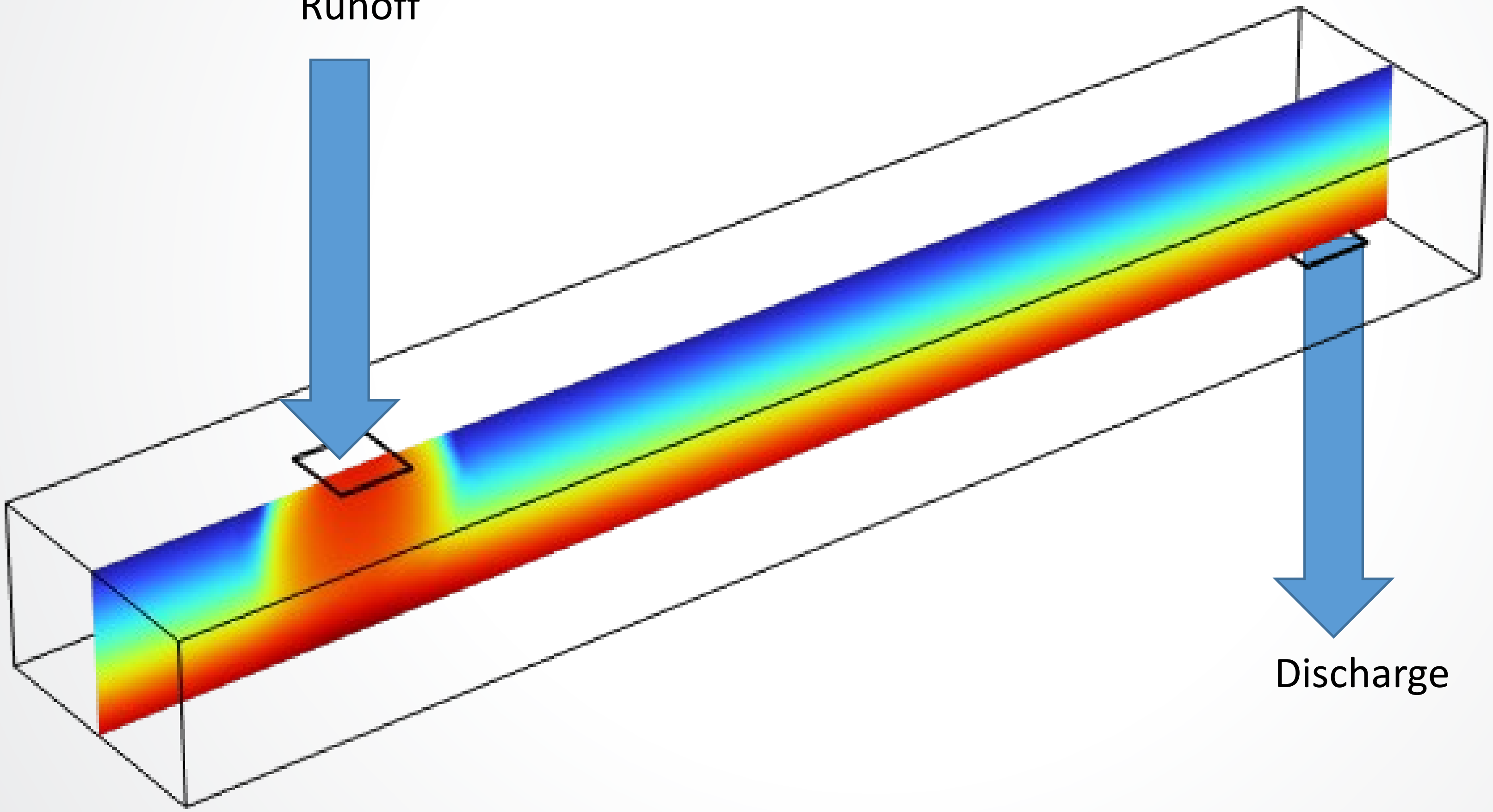
07/15/15 rain event, 0.79 inch



Henry Davis school, Box 8 (last)

Henry Davis school, Box 8,
Underdrain discharge

So, what's happening?



Media with "large" saturated hydraulic conductivity allows immediate infiltration to gravel layer.

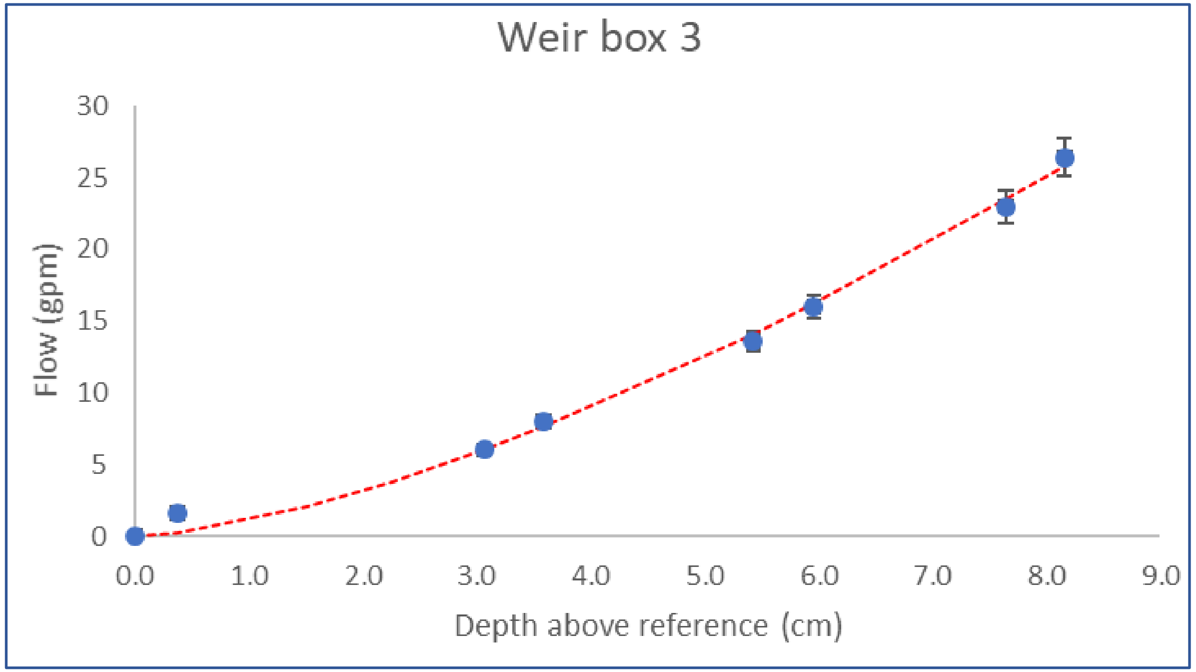
2-D COMSOL Model
K. Nissen

Plan B: Hoboken, NJ

- 4 flow-through planters with precast concrete bottom and sides
- 4.9-m long, 0.9-m wide, 1.2-m tall (inside dimensions)
- Sensors monitoring inflow, outflow, and the volumetric water content (VWC) of the media

Stevens Institute of Technology

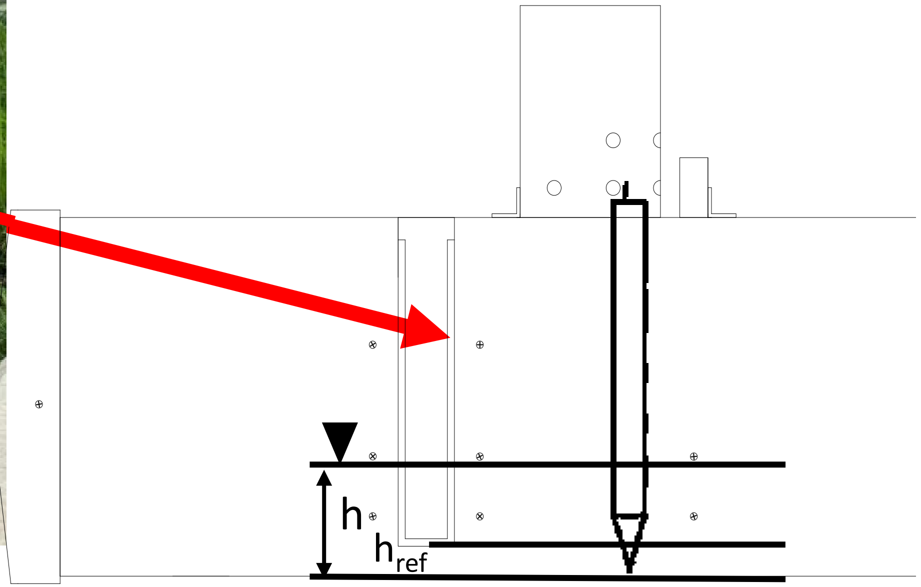
Inlet rating curve for sharp-crested rectangular weir



$$q(h) = C\left(h - h_{ref}\right)^{1.5}$$

Flowrates are calculated from water depth measurements made using verified pressure transducers and weir-specific laboratory-developed rating curves.

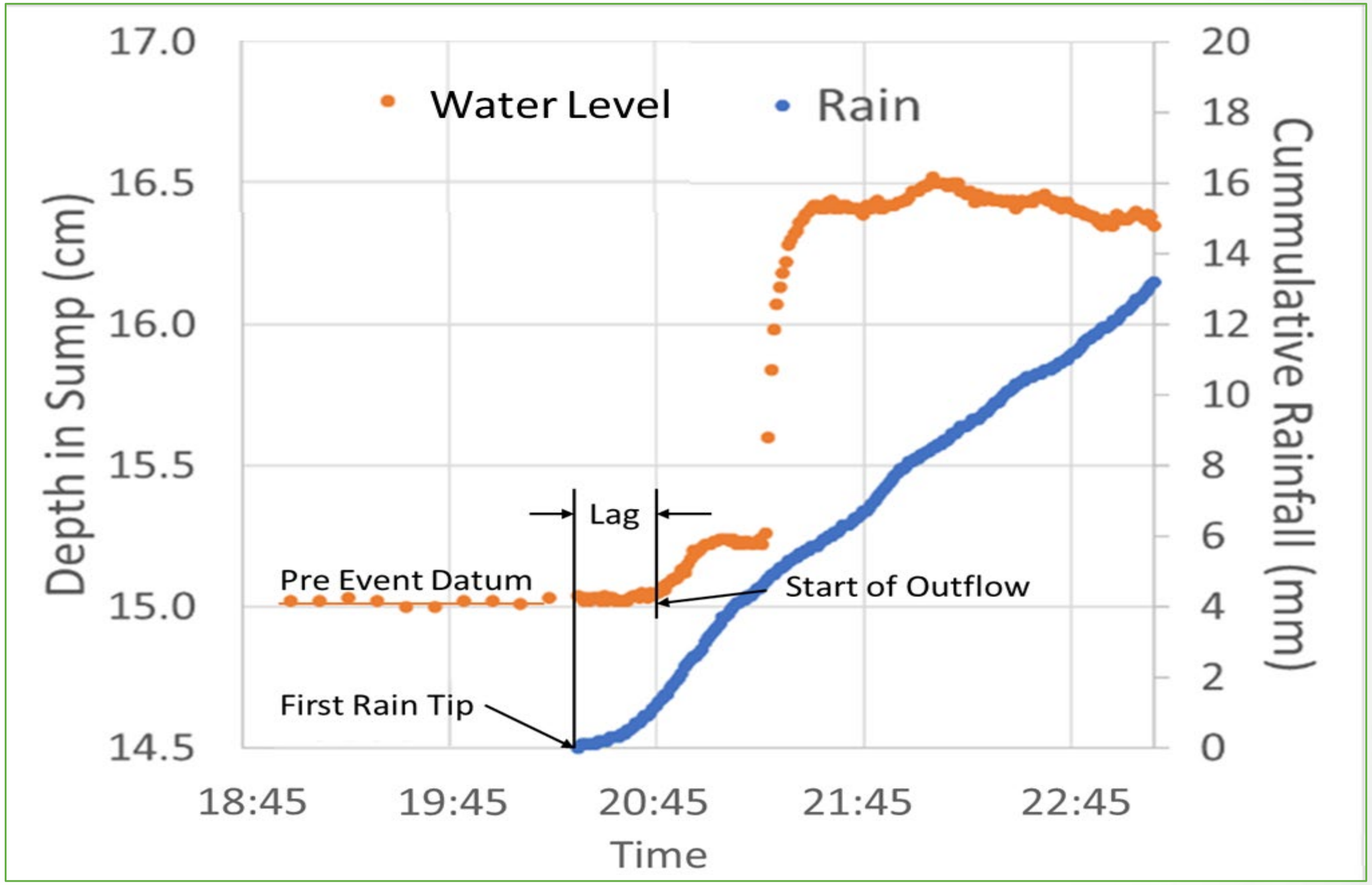
Inlet volume determined from weir monitoring



$$V = \sum_i q(h_i)\Delta t$$

Result: Lag

- **Median lag was 77 minutes**
- **Coefficient of variation of 1.67**
- **Controlling variables (multiple regression)**
  - **Approximate runoff volume in first half hour**
  - **Initial moisture deficit (antecedent dry period and media properties)**



Storm Variables

Independent Variables

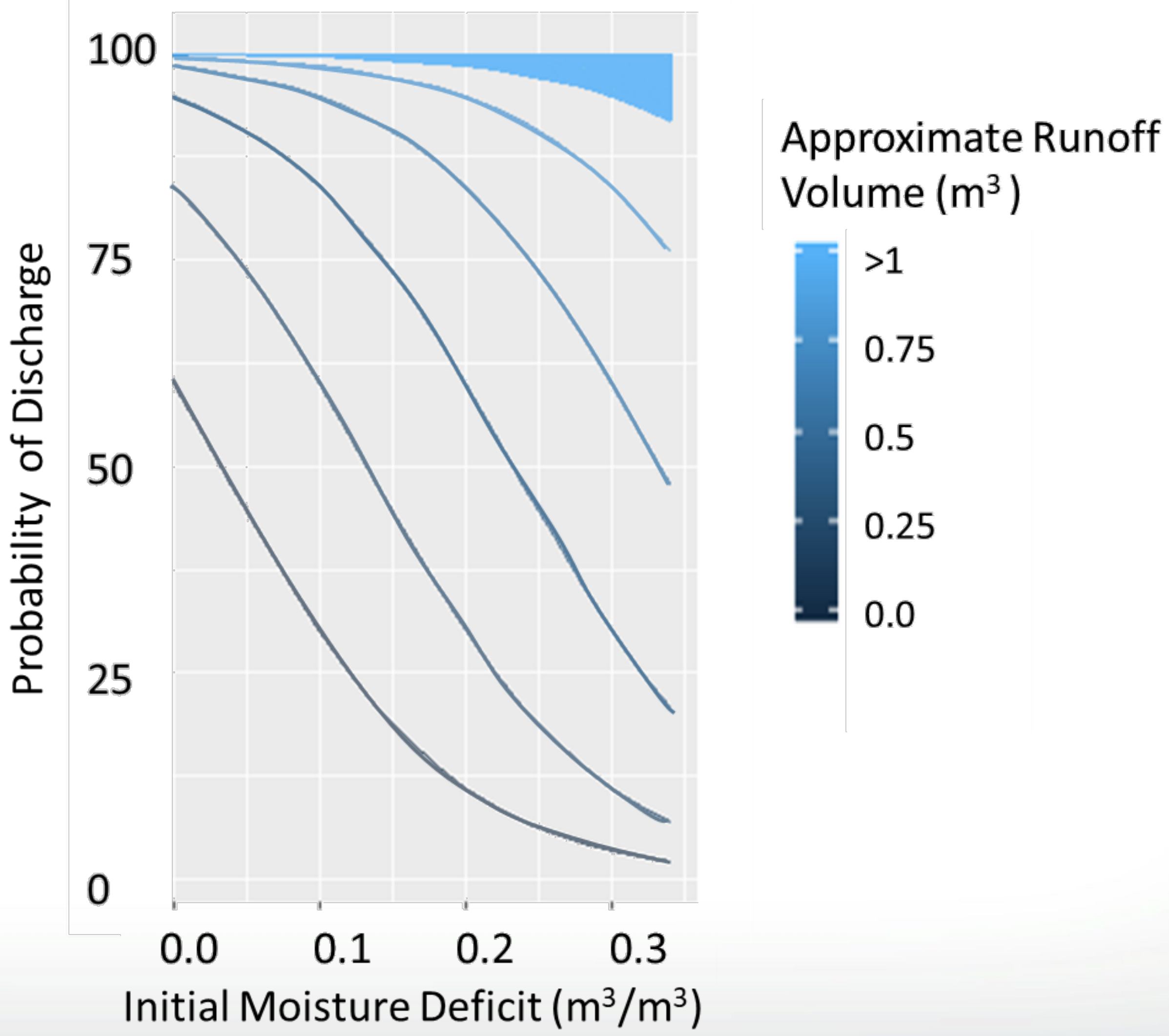
- Runoff volume (m^3)
- Runoff during first half hour (m^3)
- Initial moisture deficit (maximum volumetric water content less pre-event volumetric water content) (m^3 / m^3)

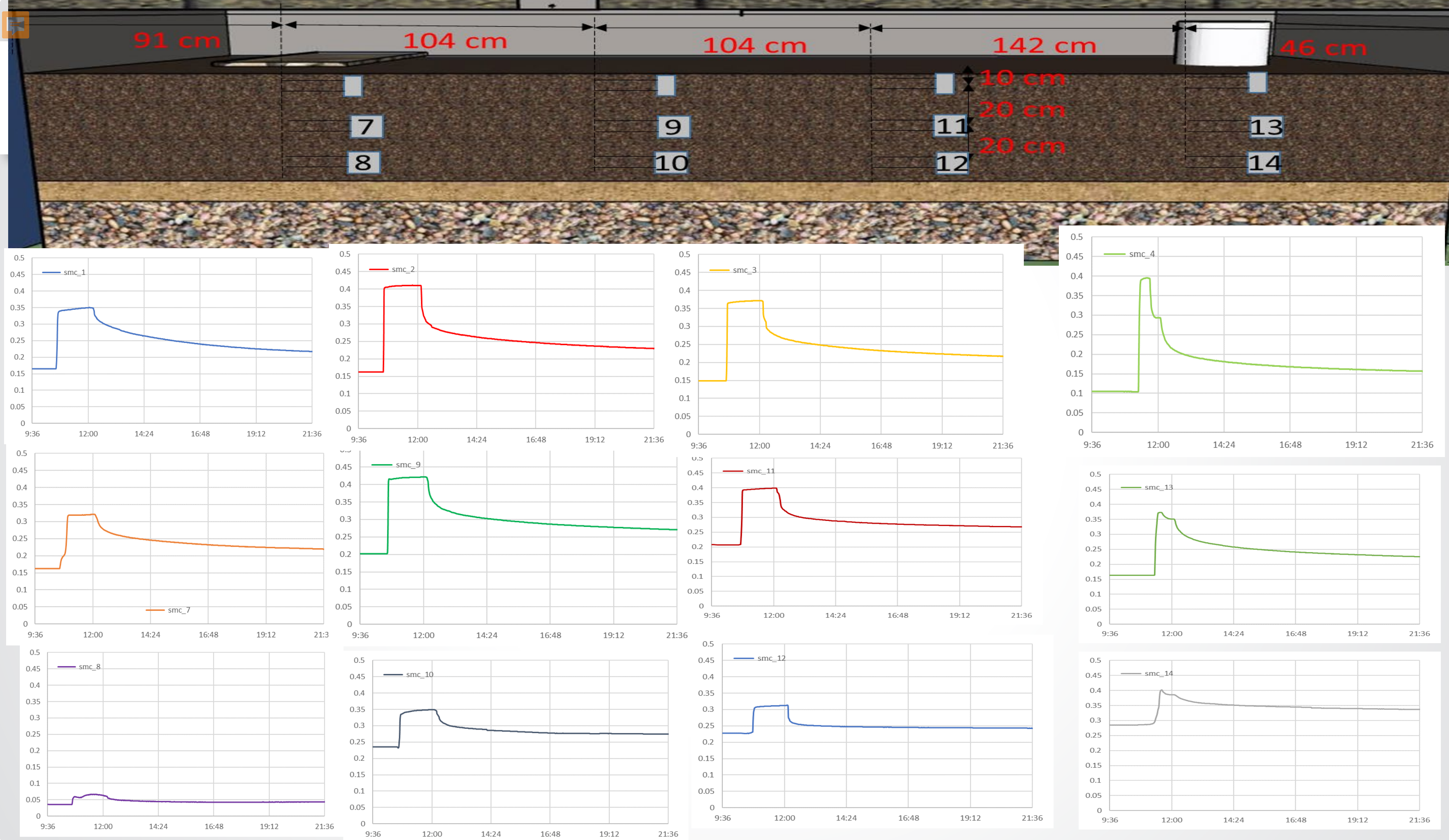
Response Variables

- Probability of Discharge (%)
- Lag (minutes)

Results: Discharge probability

- **Planters completely captured 40% of storms**
- **Controlling variables**
  - **Runoff volume**
  - **Initial moisture deficit (based on pre-event and saturated conditions**



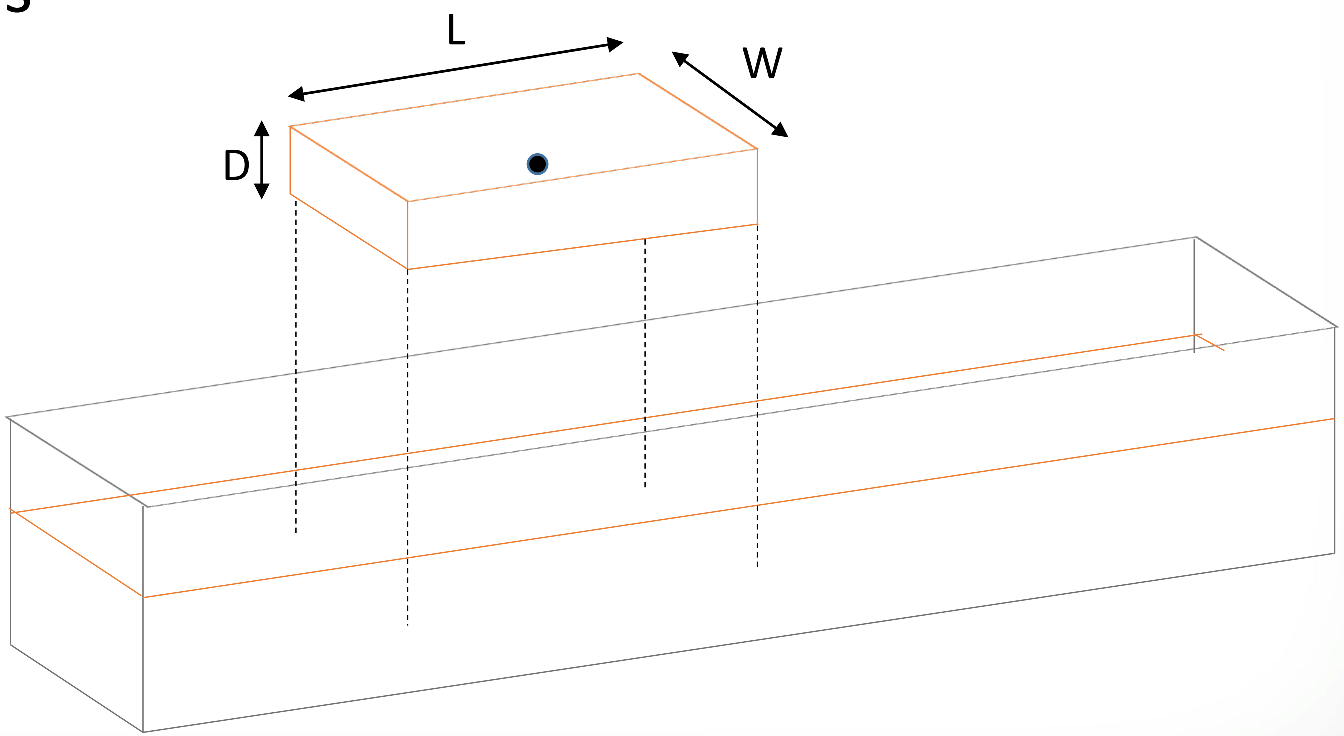

91 cm
104 cm
104 cm
142 cm
46 cm
10 cm
20 cm
20 cm
7
8
9
10
11
12
13
14
smc_1
smc_2
smc_3
smc_4
smc_7
smc_9
smc_11
smc_13
smc_8
smc_10
smc_12
smc_14
9:36
12:00
14:24
16:48
19:12
21:36

Volume represented by sensor

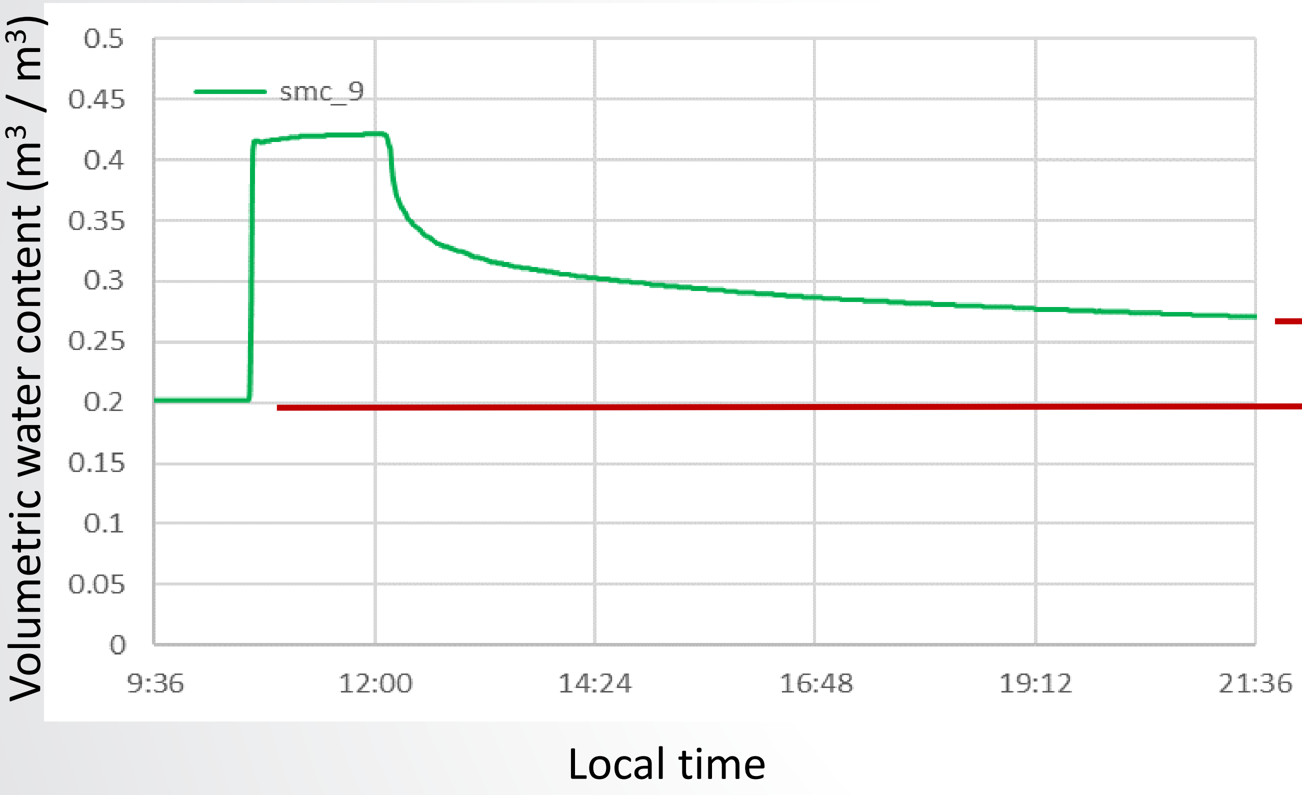
Each sensor represents a media volume determined by distance to the planter walls or half the distance to adjacent sensor.

For sensor 9,
L= 105.4 cm
W= 91.4 cm
D= 20.3 cm

Volume = 0.196 m^3



Retained runoff volume



Each WCR reflects the water held in the surrounding volume

0.279 m^3 water/ m^3 media

0.208 m^3 water/ m^3 media

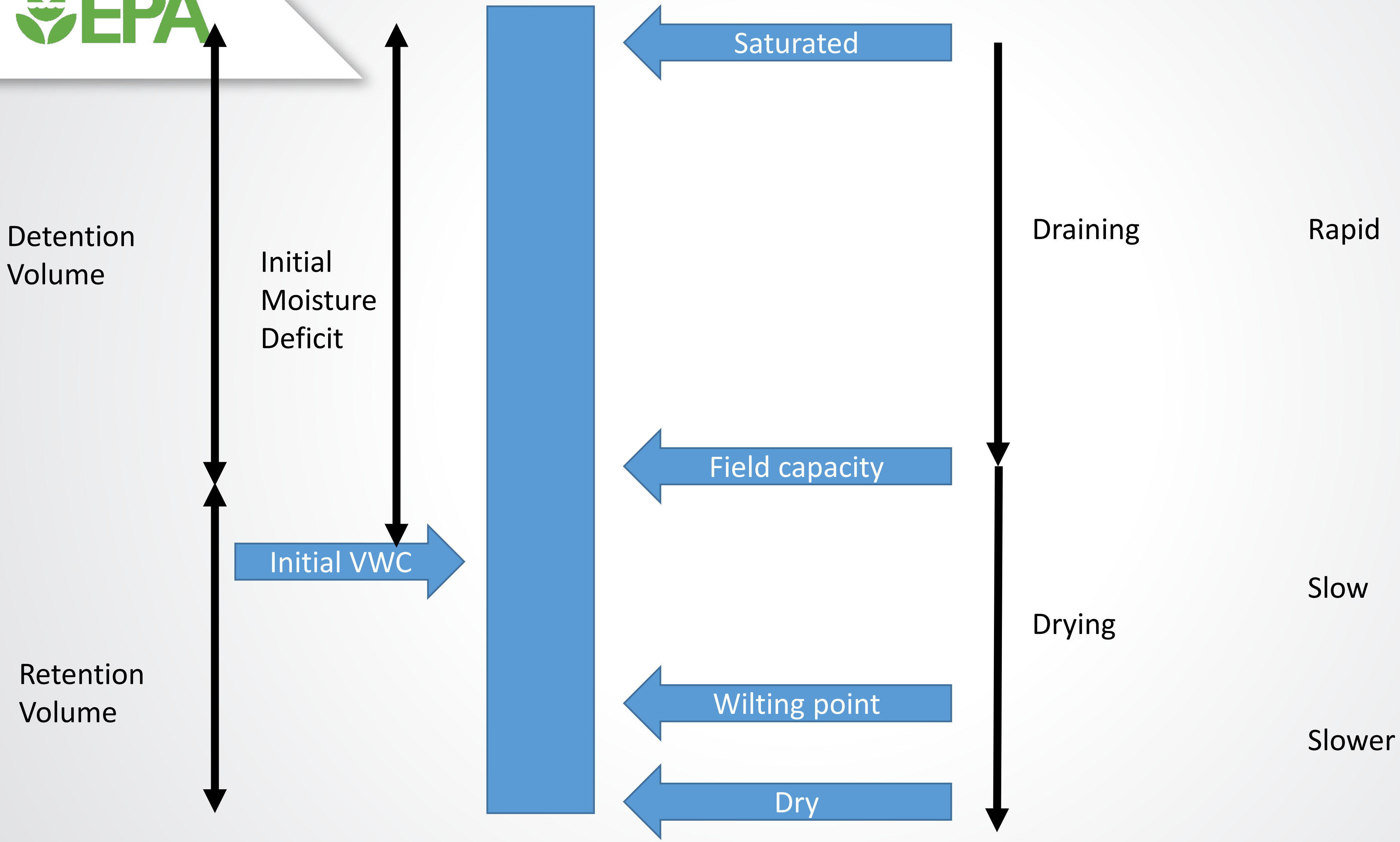
For sensor 9, the represented volume is 0.195 m^3 media (0.279-0.208)*0.196=0.0139 m^3 water gained in segment

$$Retained\ volume = V_f - V_0$$

$V_f = \sum_{i=1}^{12} V_{media,i} VWC_f$ = 588.5L

$V_0 = \sum_{i=1}^{12} V_{media,i} VWC_0$ = 452.6 L

$Total\ retained\ volume = V_f - V_0$ = 135.9 L



Detention Volume
Initial Moisture Deficit
Initial VWC
Retention Volume
Saturated
Field capacity
Wilting point
Dry
Draining
Drying
Rapid
Slow
Slower

Does the water balance balance?

- Volume in =Volume out + change in stored water
- Volume in = runoff + direct rainfall
- Volume out = underdrain discharge + Evapotranspiration
- Balance successful if difference between entering volume and exiting volume is less than the total measurement uncertainty.
  - Initially only about a quarter of the rain events balanced
  - Operational changes increased balanced events to about three quarters
    - Orientation of pressure transducers
    - Filling sumps to the reference depth before rain events to establish h_{ref}

Plan C: Riverside, CA

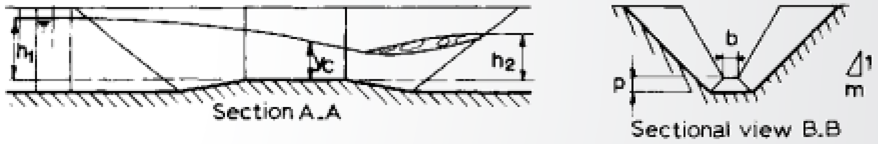
Cooperative among Riverside County Flood Control and Water Conservation District, EPA ORD, Southern California Coastal Water Research Project

- 2 larger planters (about 2 m x 12 m).
- Runoff from larger drainage area 300 to 600 m^2 .
- Increased instrument density.
- Selective water quality monitoring.

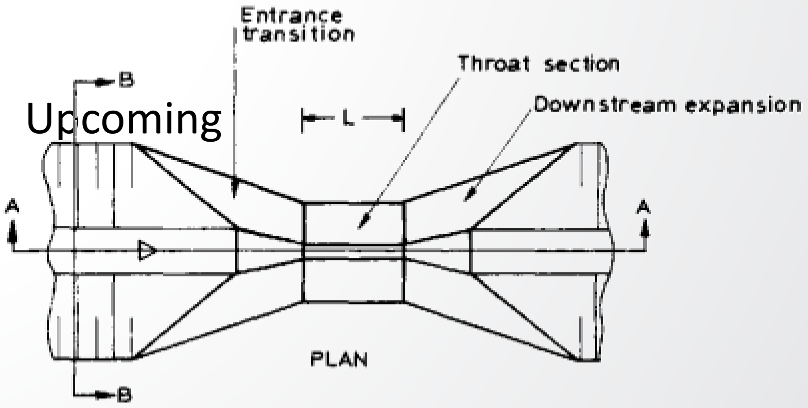
Sample product

- Demonstrate method(s) to quantify BMP influent and effluent flowrates
  - Develop rating curves for sharp-crested compound weirs
    - Method
    - Data to collect
    - Analyses
    - Use
  - Develop rating curves for trapezoidal weirs
    - Method
    - Data to collect
    - Analyses
    - Use

Done

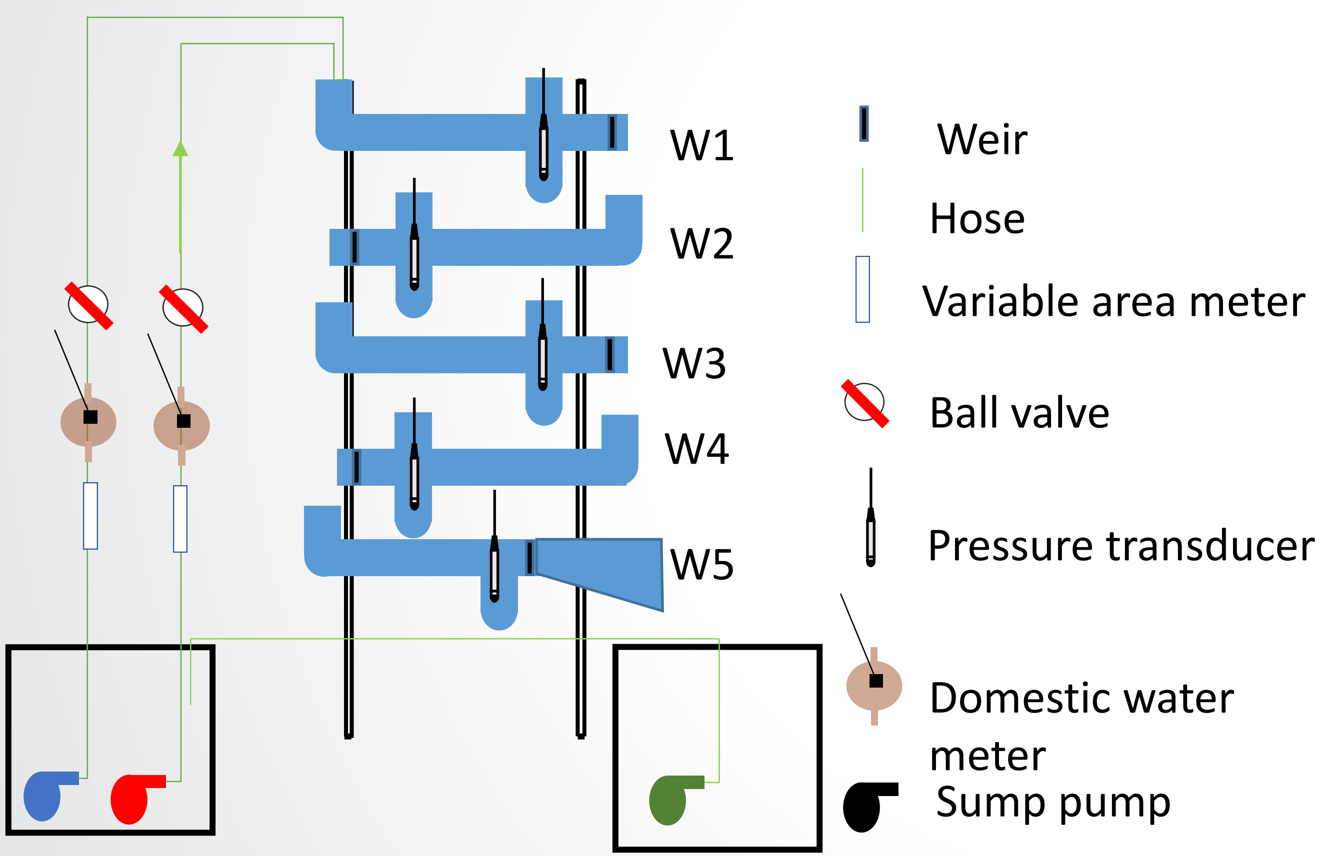


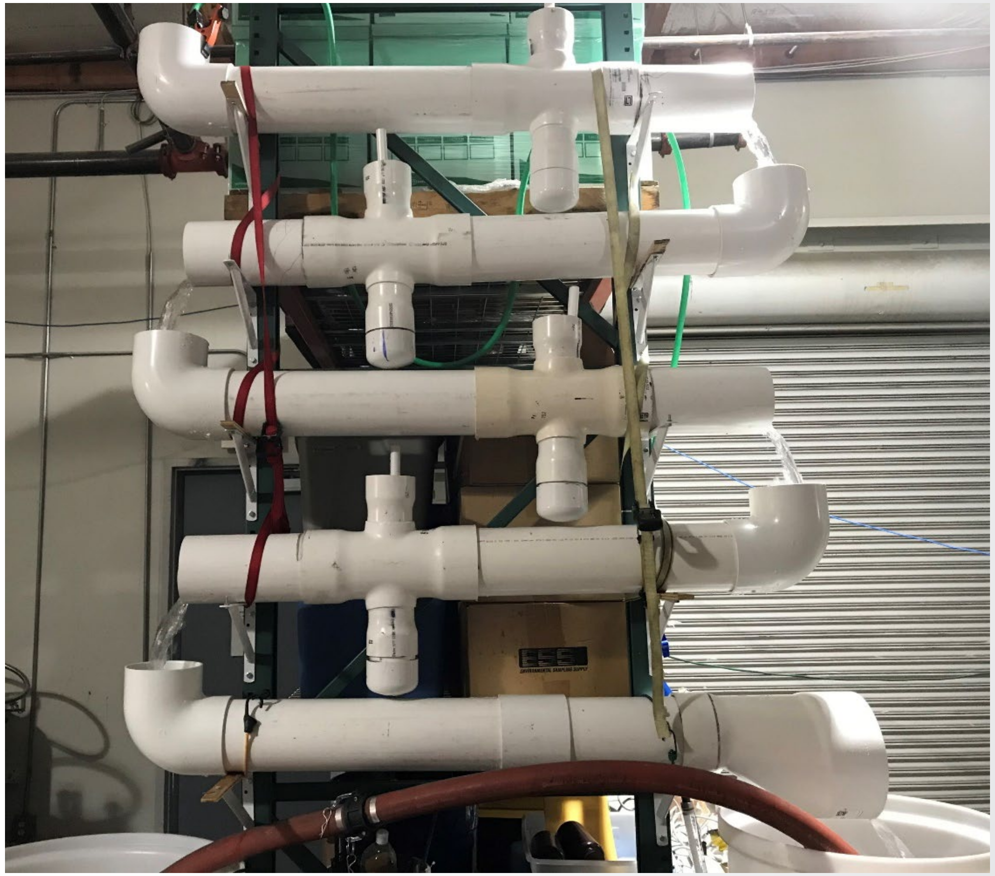
Upcoming



TRAPEZOIDAL FLUME

Develop rating curves simultaneously.

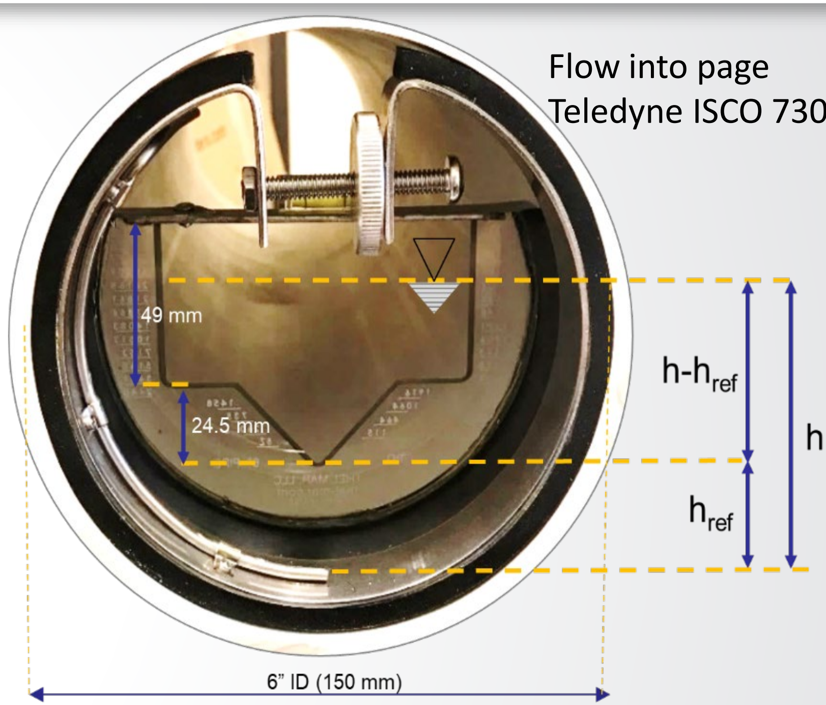




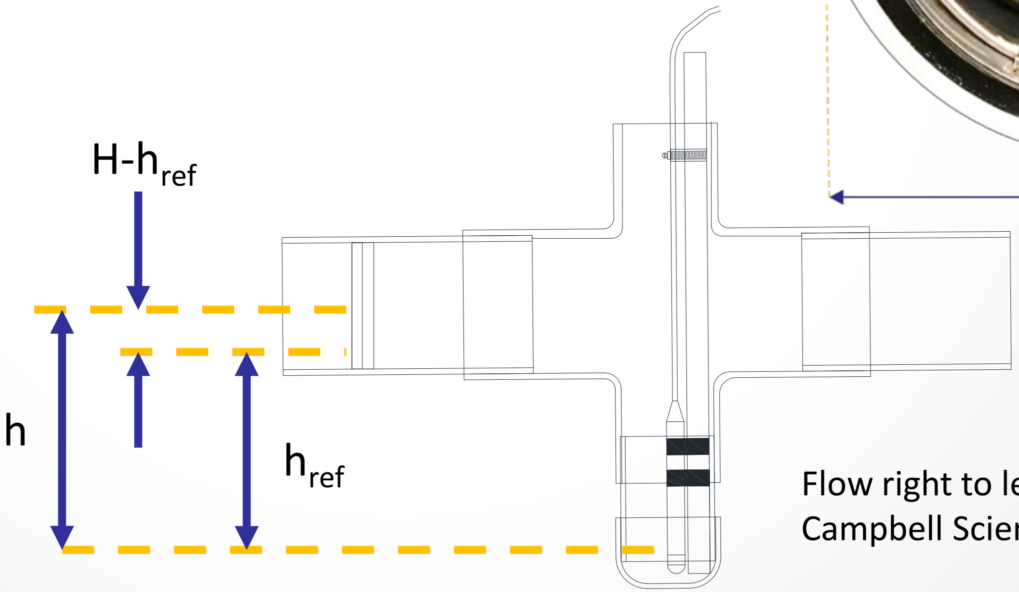
SCCWRP
Costa Mesa, CA

Total flow depth is not head.

We measures total depth, not the pressure head, using the Teledyne ISCO and the Campbell Scientific systems.



Flow into page
Teledyne ISCO 730

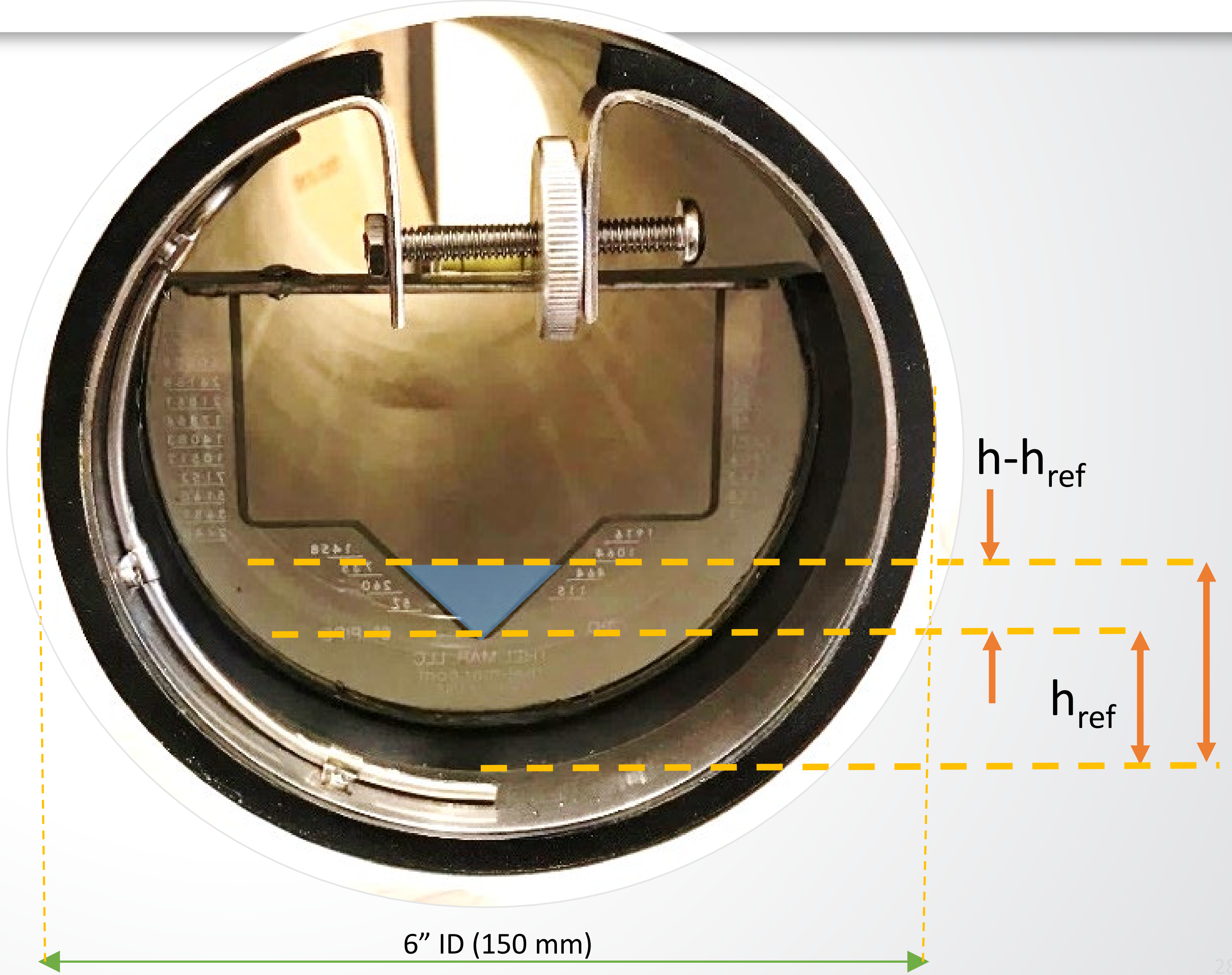


Flow right to left
Campbell Scientific CS451

Small flows remain in the Vee

Well established general relationship from theory and practice. For 90-degree angle

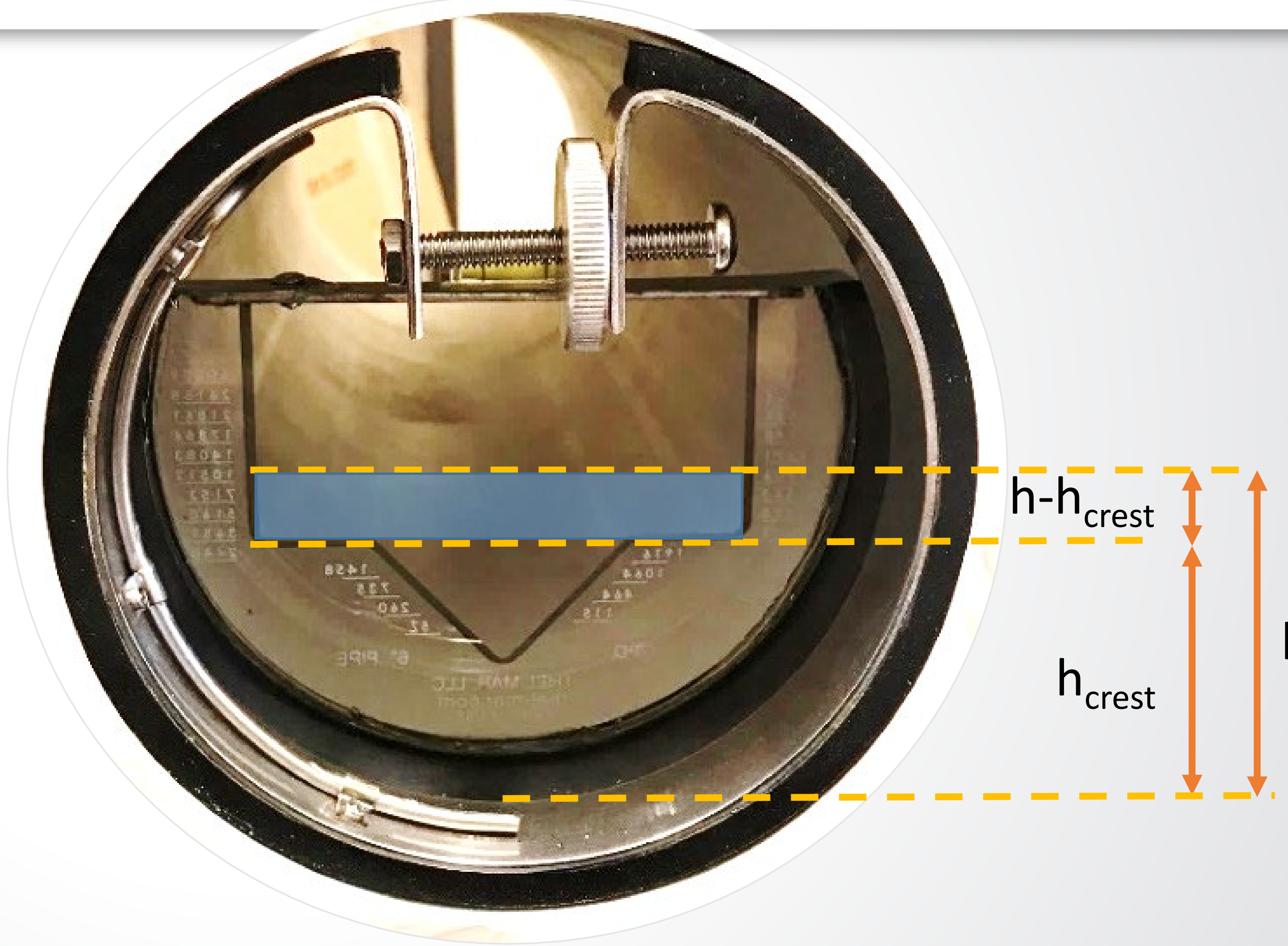
$$q_{vee} = C_1\left(h - h_{ref}\right)^{\frac{5}{2}}$$



Larger flows require a rectangular weir.

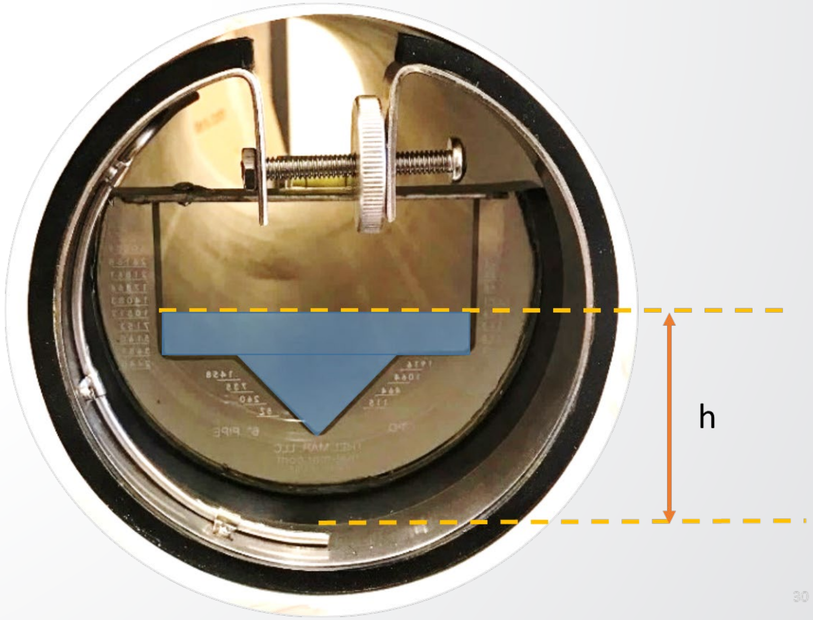
Well established general relationship from theory and practice. For rectangular weir

$$q_{rect} = C_2(h - h_{crest})^{\frac{3}{2}}$$



Total flow is sum of triangular and rectangle flows

$$q_{total} = q_{vee}^{max} + q_{rect}$$



Approach Flow Conditions

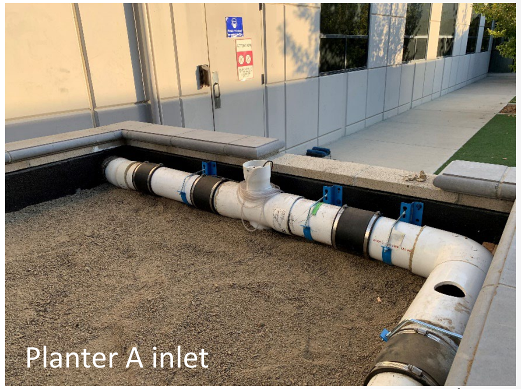
What we want

"In general, the approaching flow should be subcritical. The flow should be fully developed, mild in slope, and free of curves, projections, and waves... By analogy [to pipe flow] and using a minimum of 10 pipe diameters of straight approach, open channel flow would require 40 hydraulic radii of straight, unobstructed, unaltered approach. "

(USBR (2001) Water measurement Manual, P. 5-2)

What we have

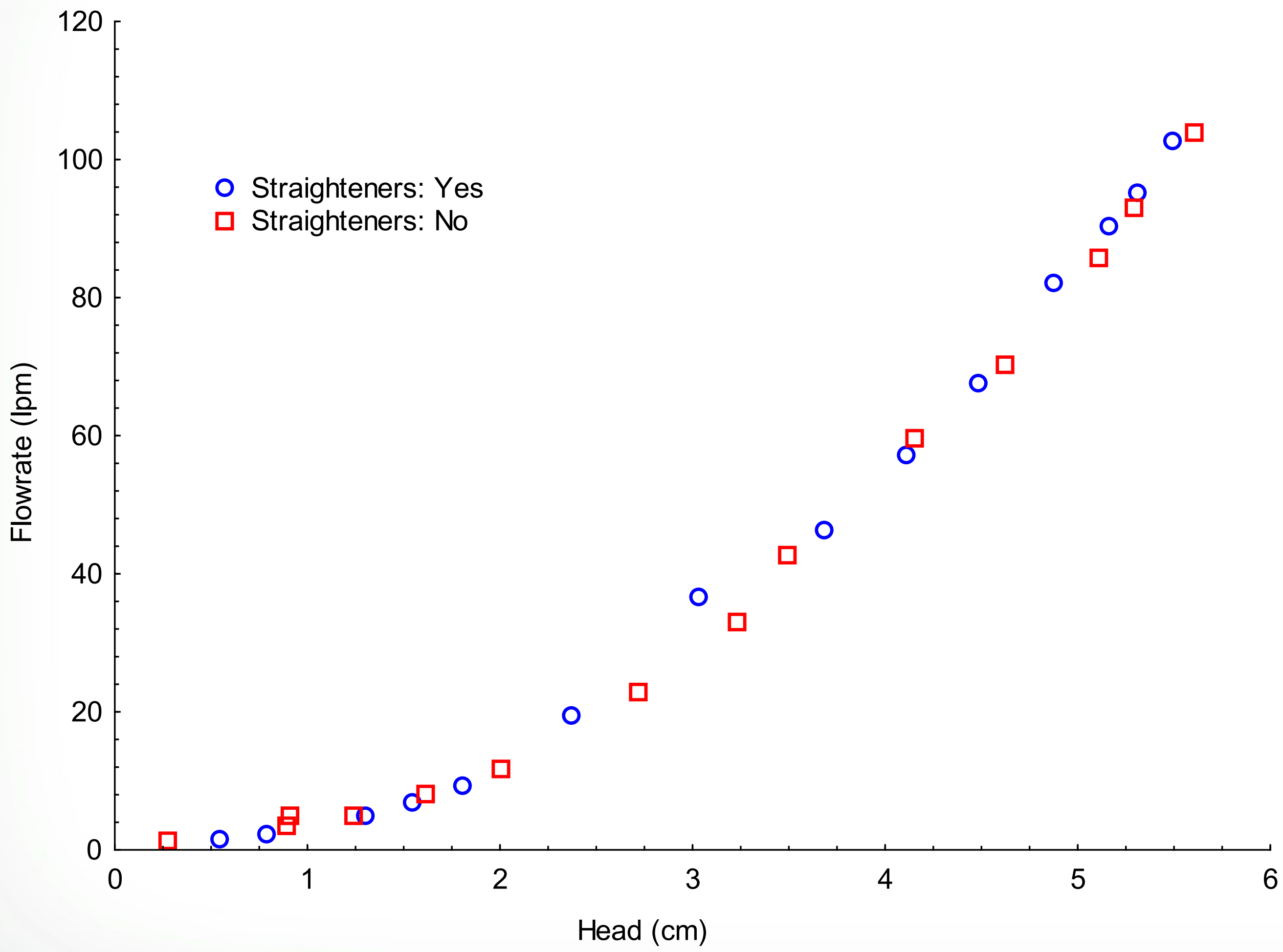
- A 2-story drop to a 90-degree Ell
- About 30 inches of mostly straight pipe run
- Many pipe fittings



Riverside, CA

Riverside, CA


Edison, NJ



No difference in rating curves. No reduction in constant flow standard deviation. No benefit.
Question of debris tolerance is circumvented.

Measurement matrix

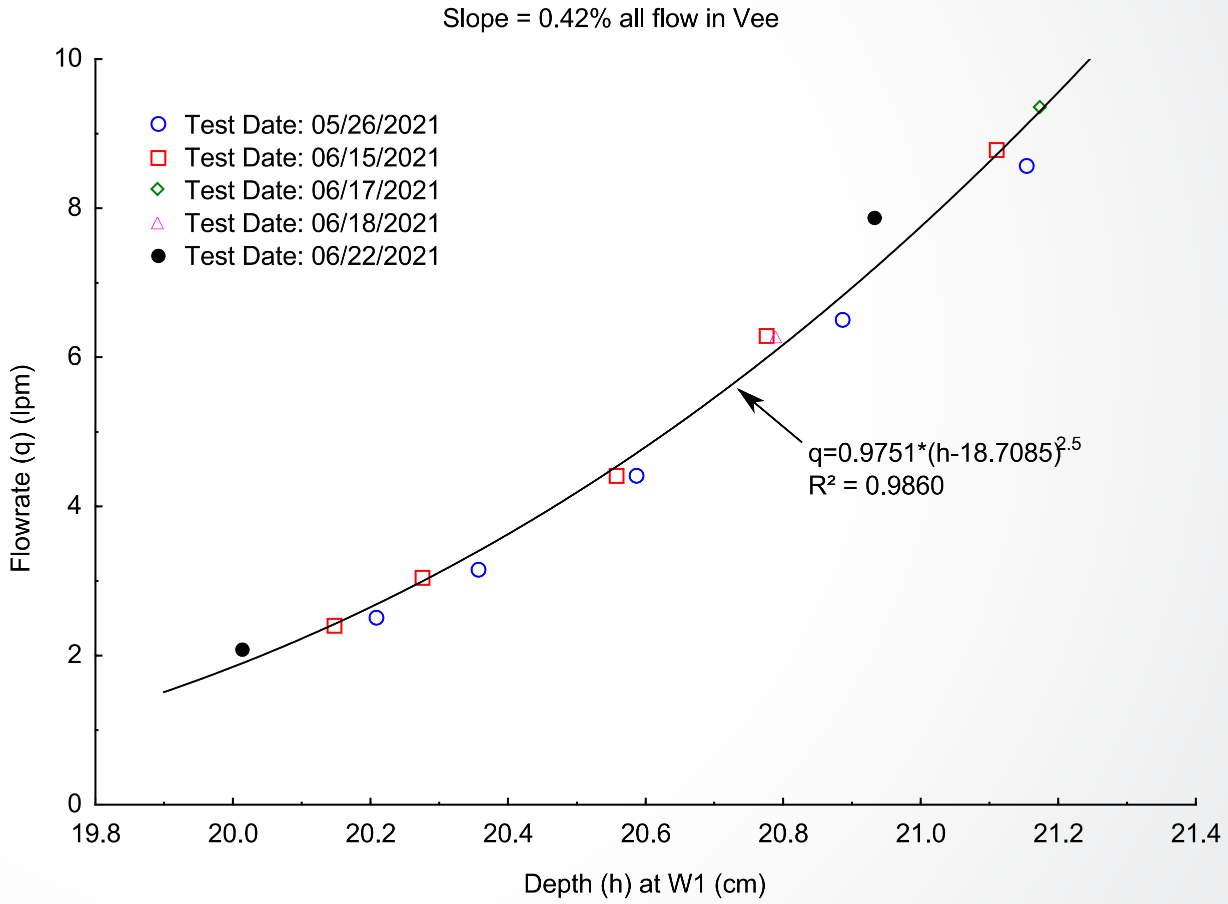
Slope	W
2.92%	

Slope	W
2.08%	

Slope	W
0.84%	

Slope	Weir	Value	ISCO 730	Campbell Scientific CS451
0.42%	W1	C_1		
		C_2		
		h_{ref}		
		h_{crest}		
	W2	C_1		
		C_2		
		h_{ref}		
		h_{crest}		
	W3	C_1		
		C_2		
		h_{ref}		
		h_{crest}		
	W4	C_1		
		C_2		
		h_{ref}		
		h_{crest}		
	W5	C_1		
		C_2		
		h_{ref}		
		h_{crest}		

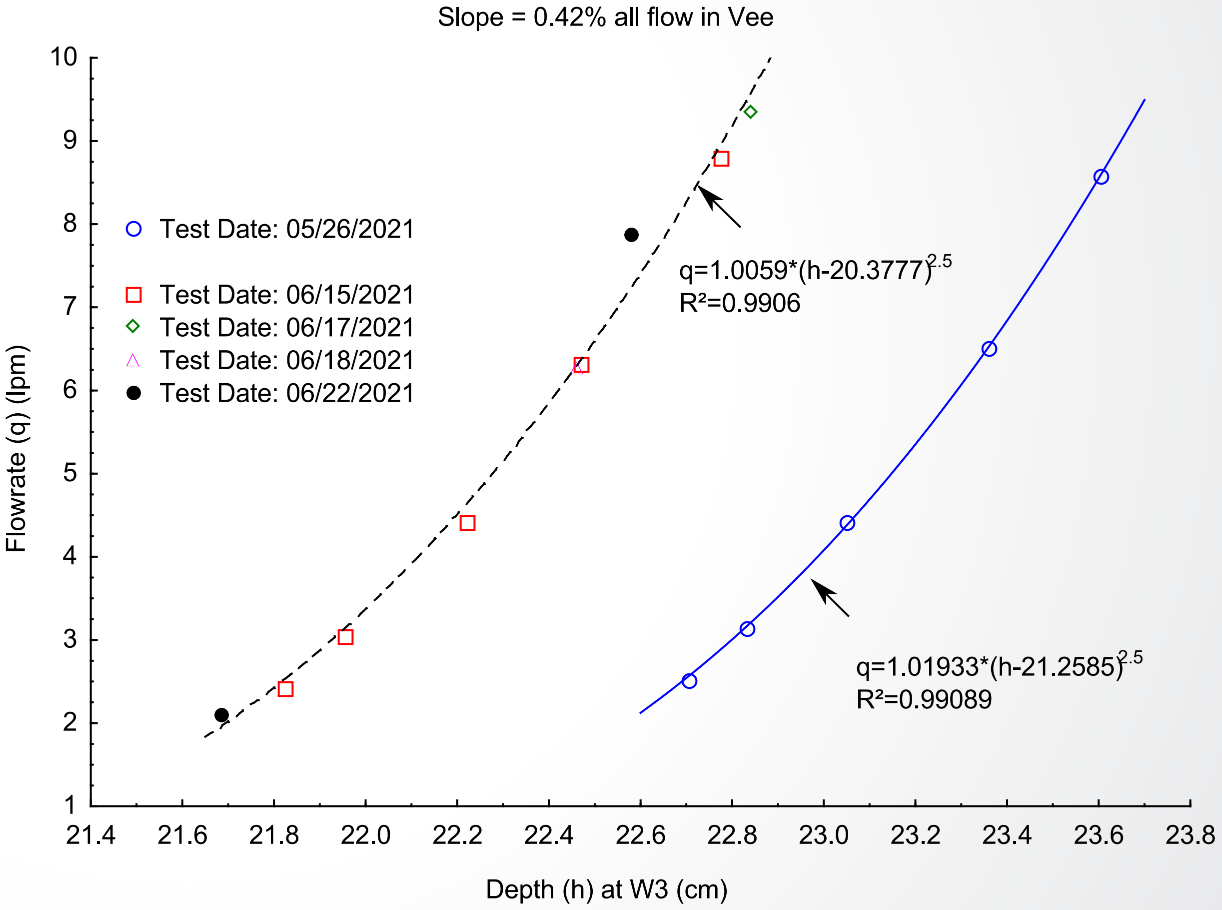
Non-linear regression gives the constants



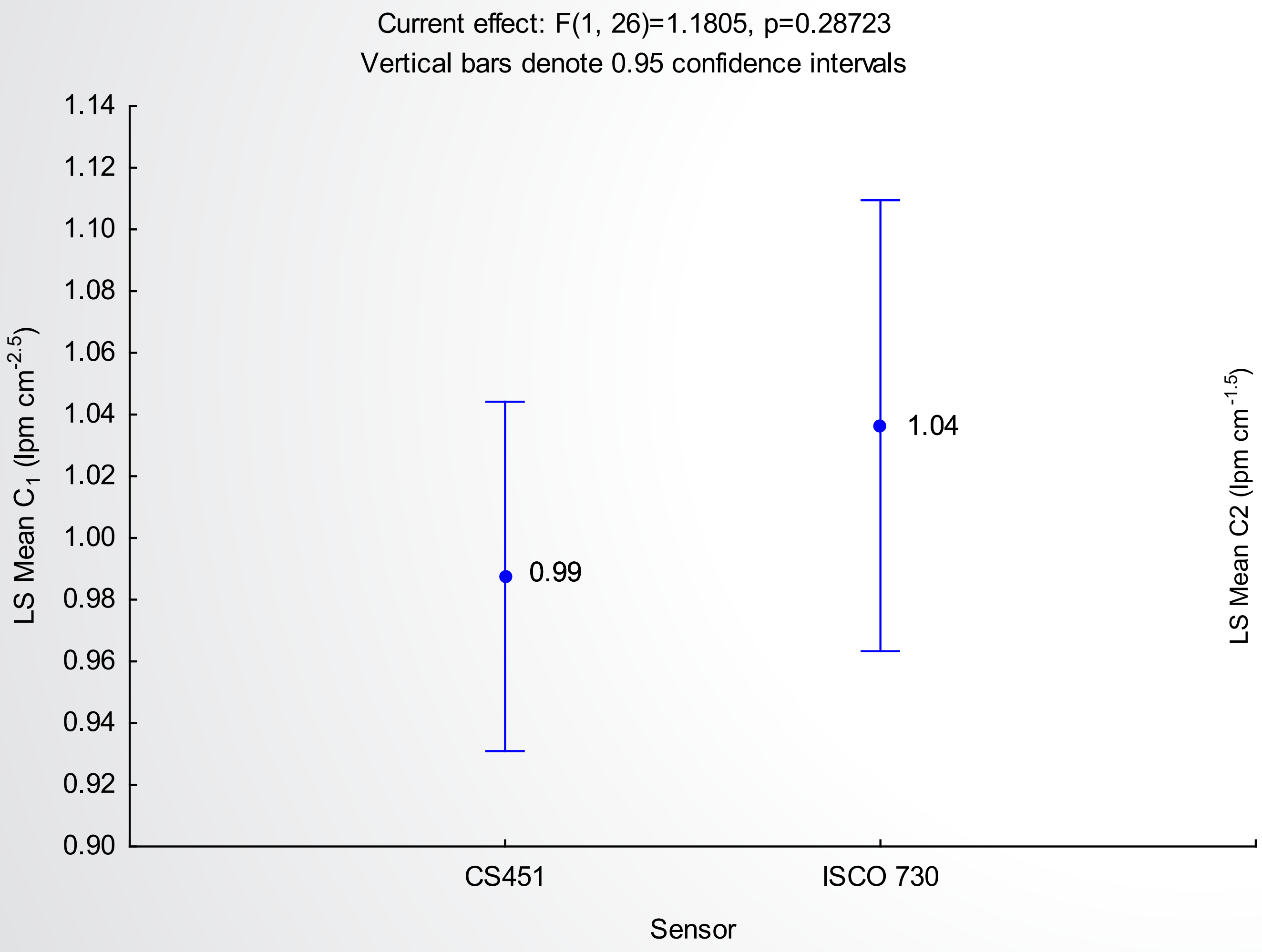
Moving sensor is a problem.

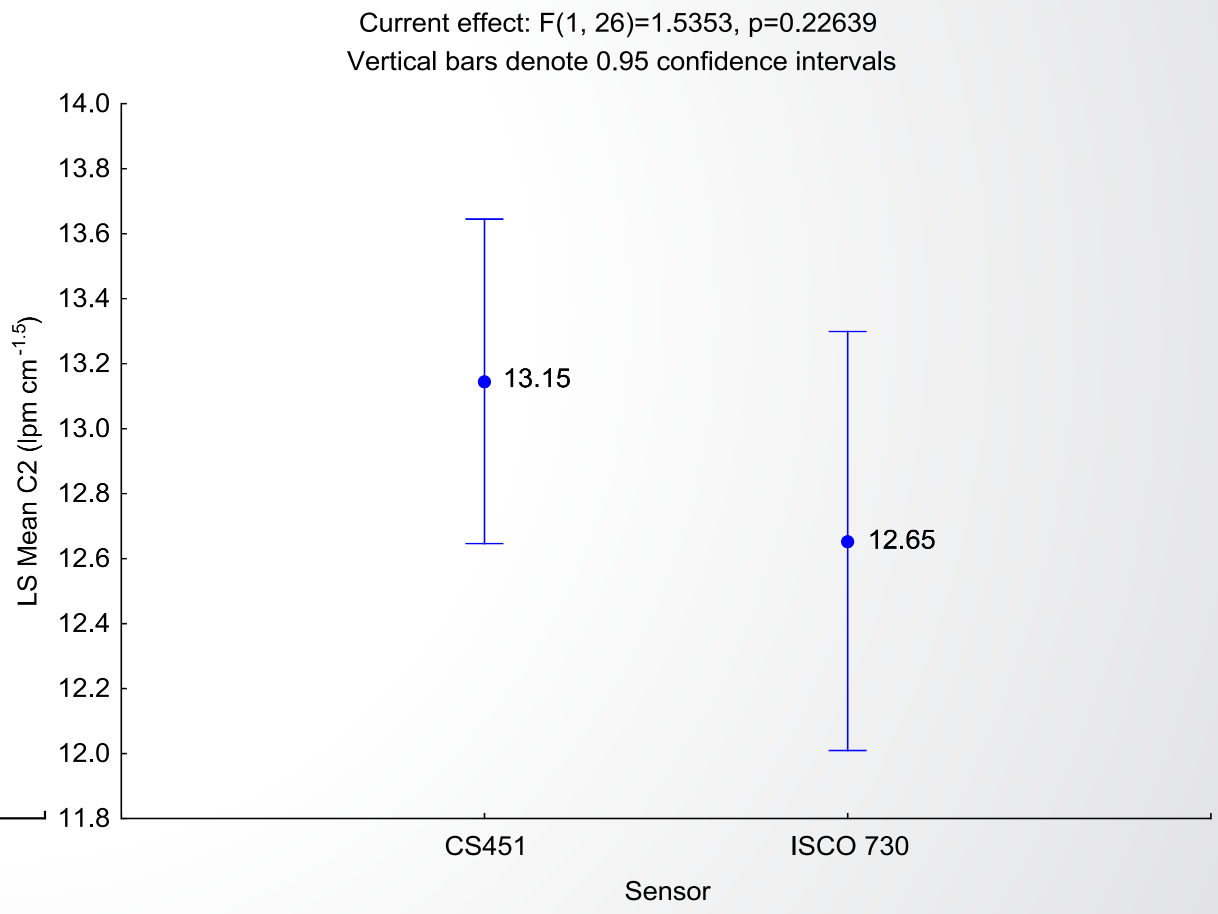
CS451 sensor at W3 moved about 9 mm between 5/26 and 6/15

May 26, q(22.6 cm)=2.10 lpm
June 15 q(22.6 cm)= 7.50 lpm

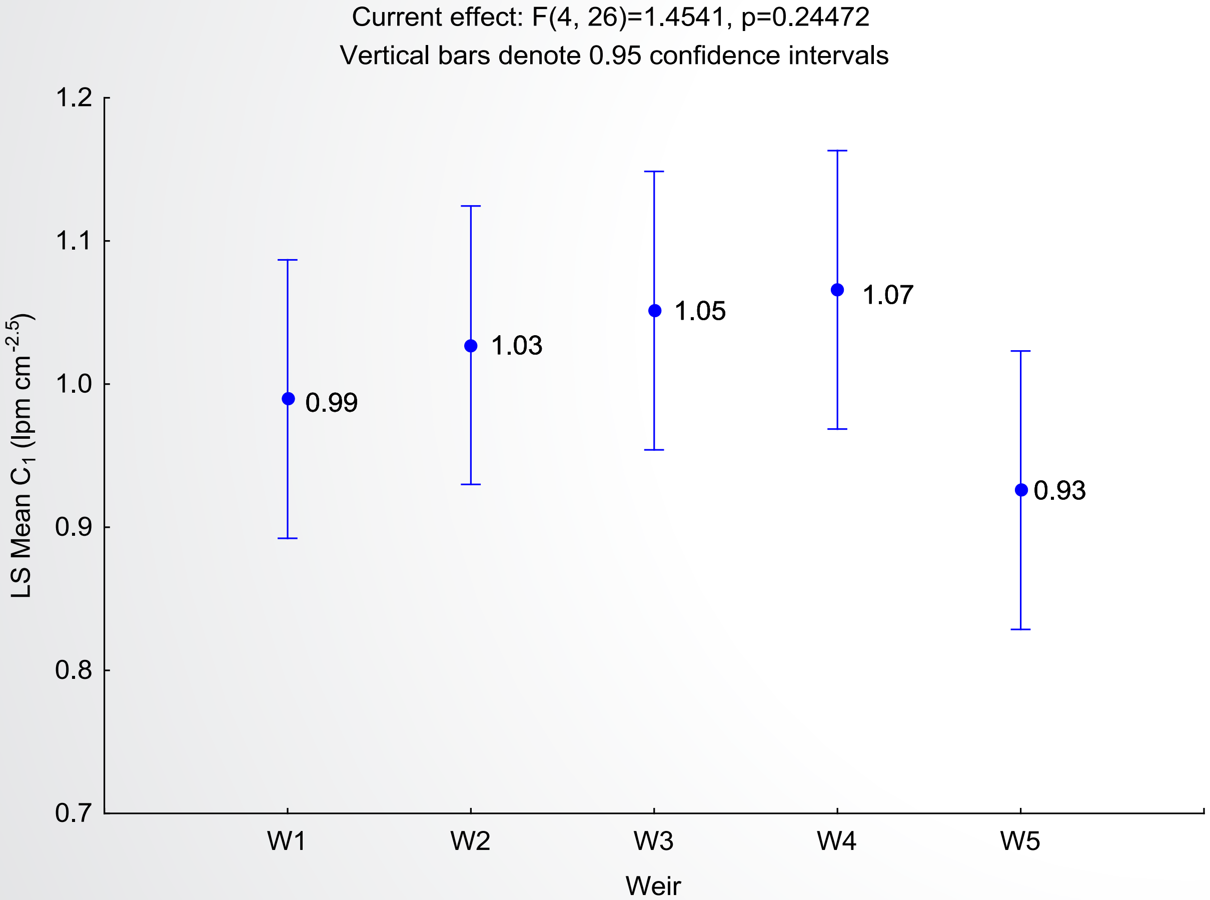


There was not a statistical difference between the two measurement techniques

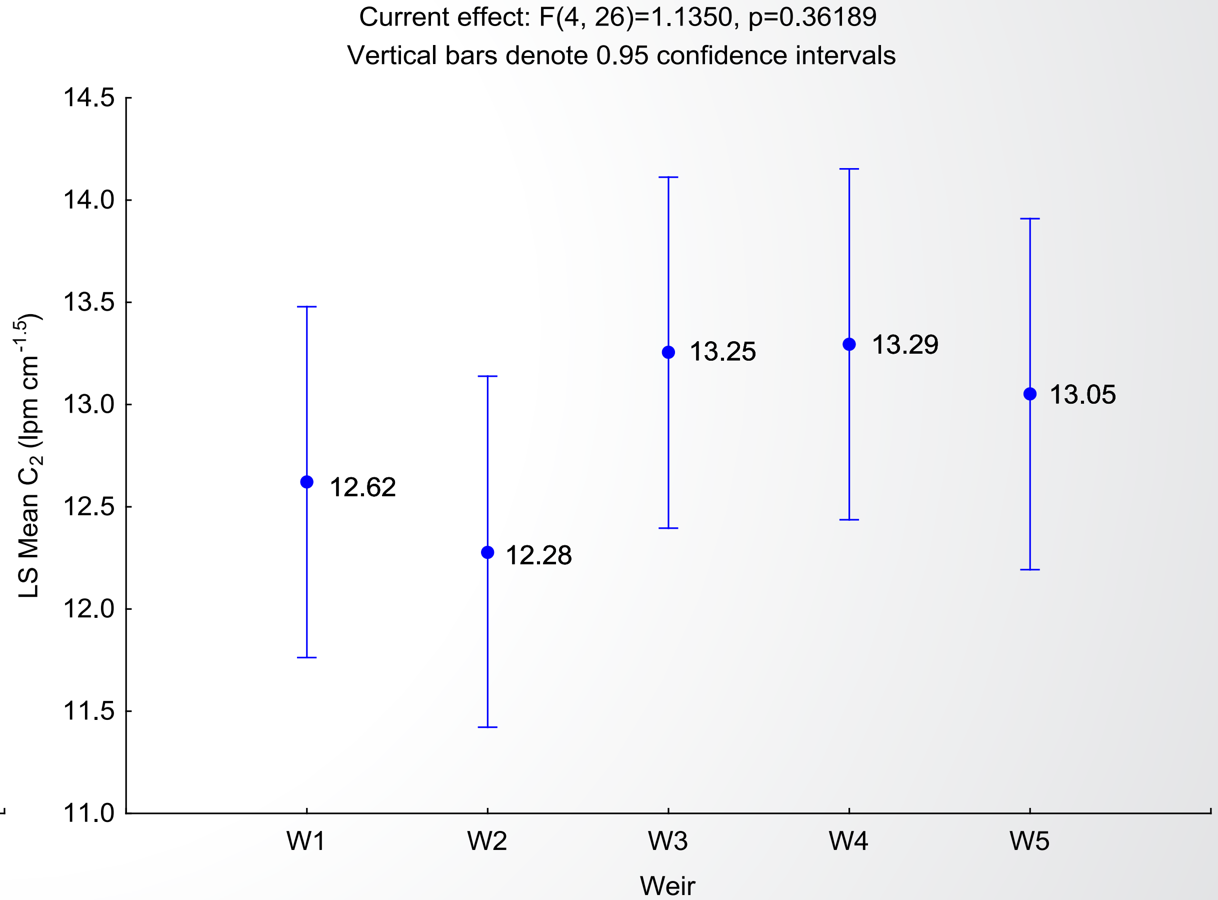




There was no significant difference in constants among the weirs.

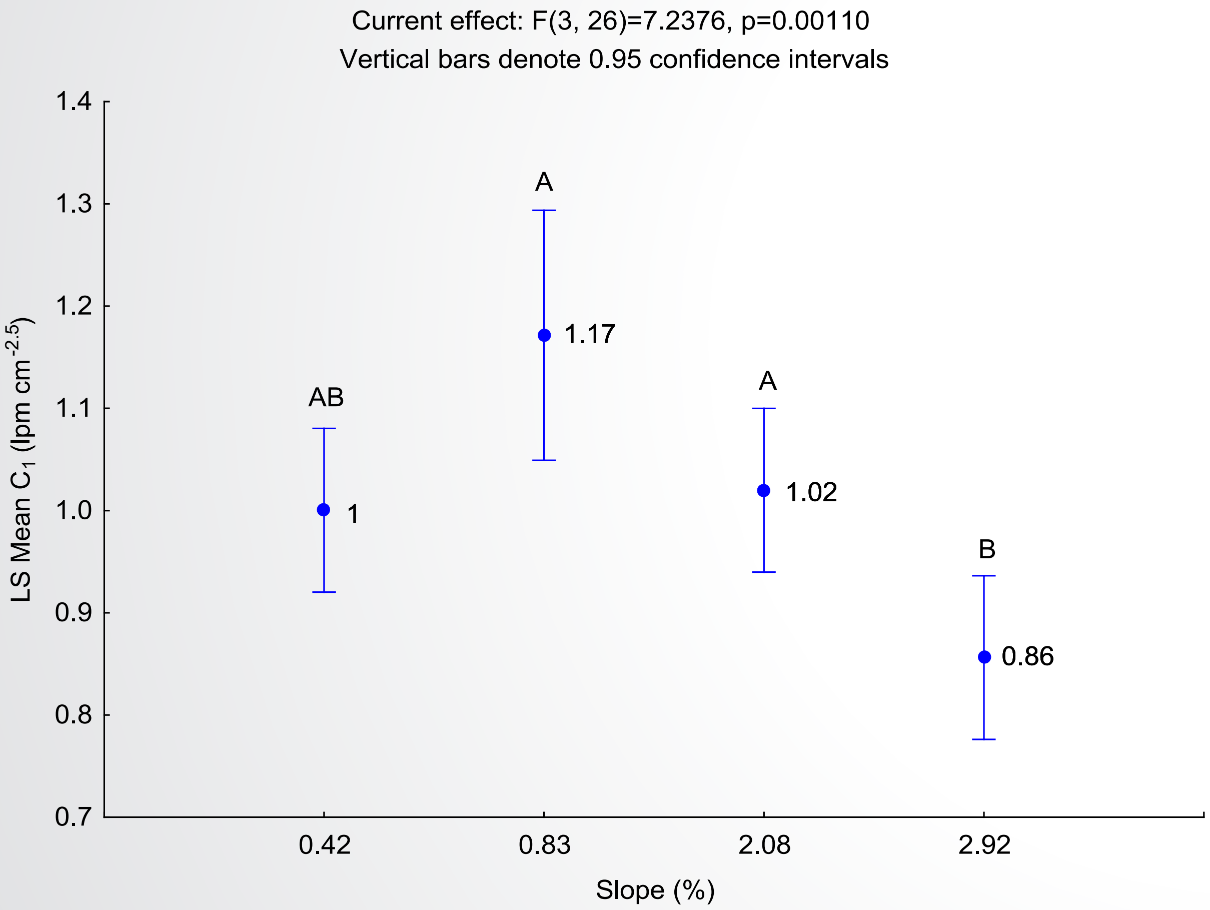


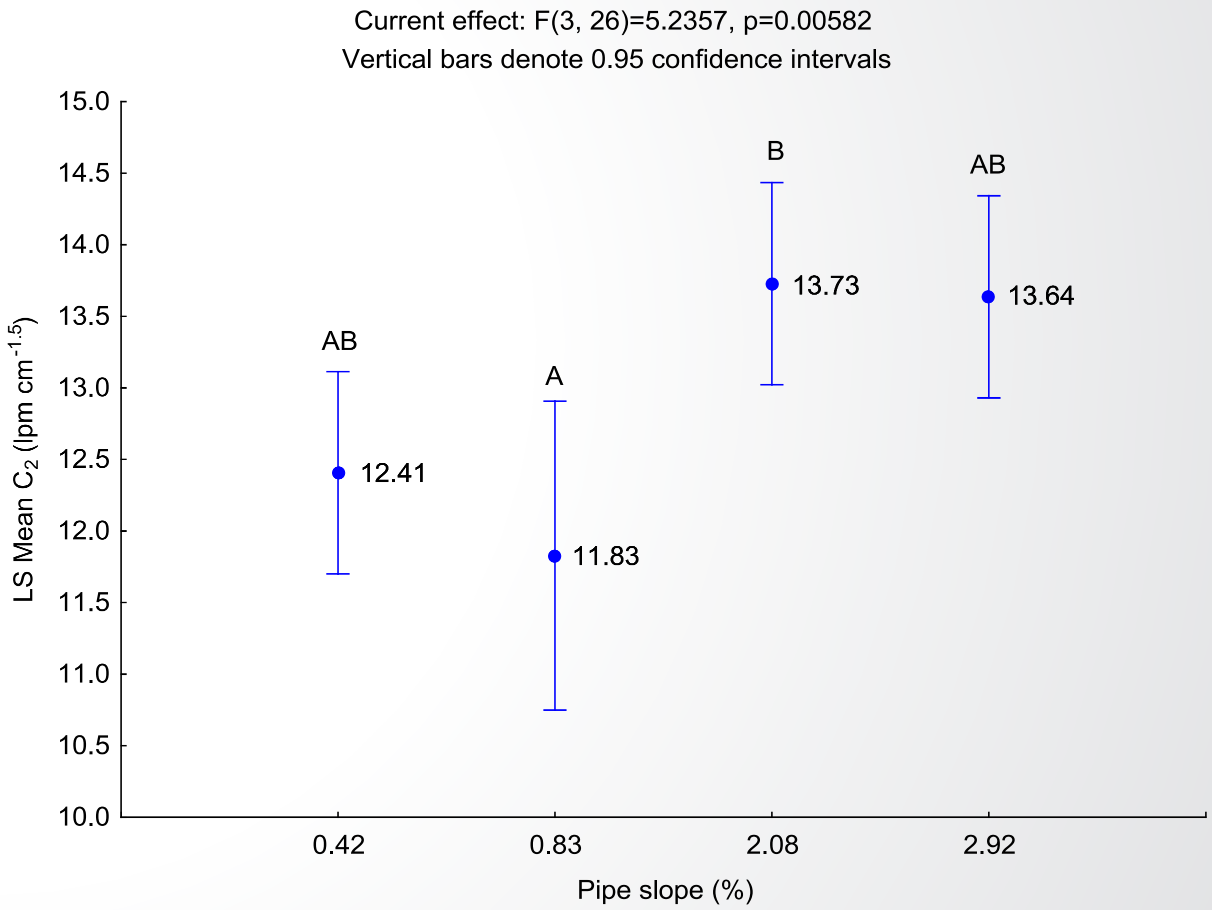
Vee section



Rectangular section

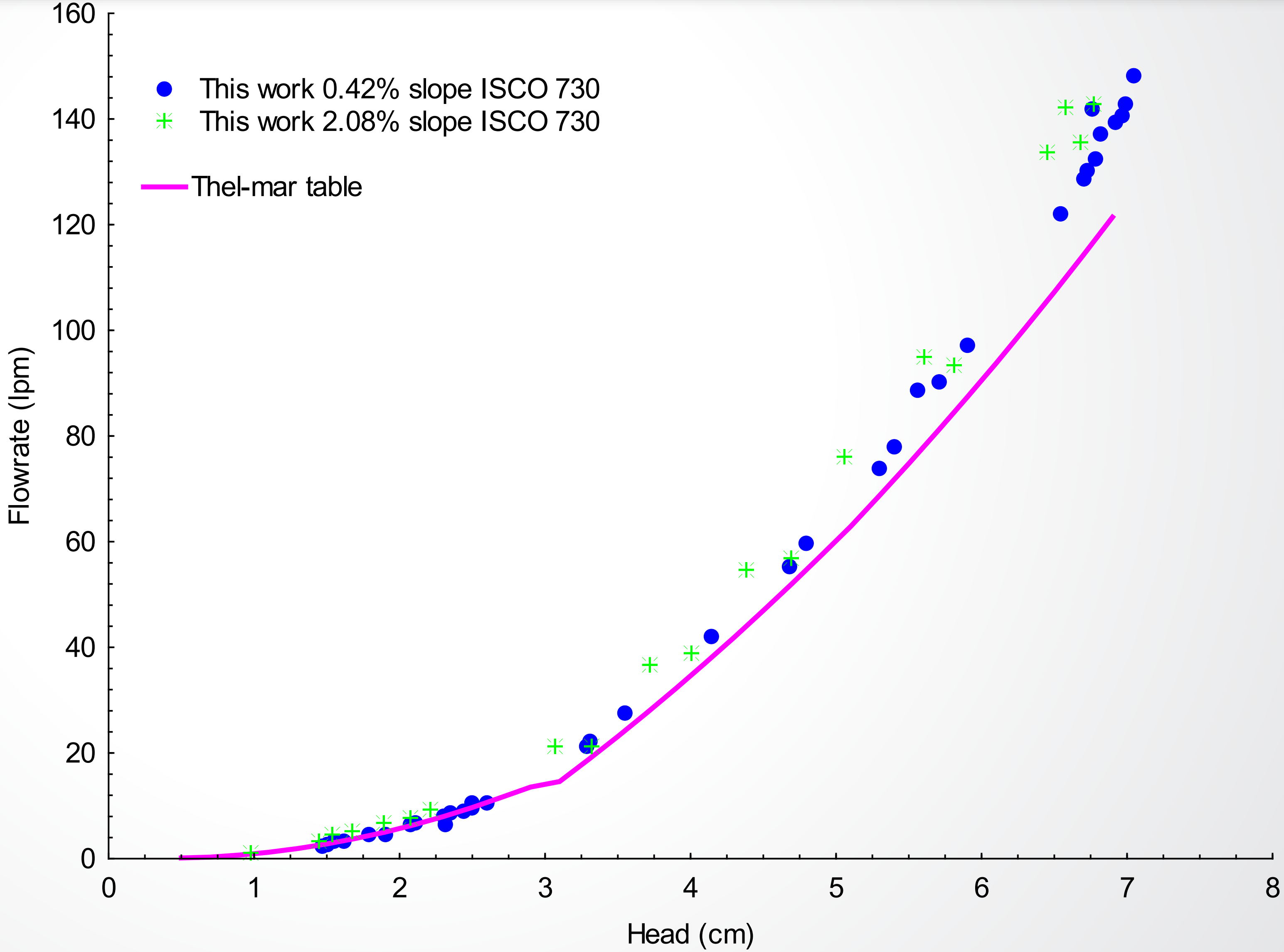
There is a statistical difference among the tested slopes (0.42 to 2.92%)





Measured and tabulated flows do not match.

Difference between tabulated and measured flow is large with deeper flow depths.



Suggestions

- Do not rely on tabulated values
- Develop rating curve as near the installed slope as possible.
- Secure measurement sensors
- Flow straighteners did not affect data quality

Thanks for listening.

The research described in this presentation has been funded in part by the U.S. Environmental Protection Agency (EPA) under contract EP-C-17-009 to PARS Environmental Services with portions of the research conducted by EPA. The Southern California Coastal Water Research Project, and the Riverside County Flood Control and Water Conservation District under a memorandum of understanding for cooperative research. It has been subjected to review by the Office of Research and Development and approved for publication. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.