Research on stormwater planters

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Cincinnait, OH

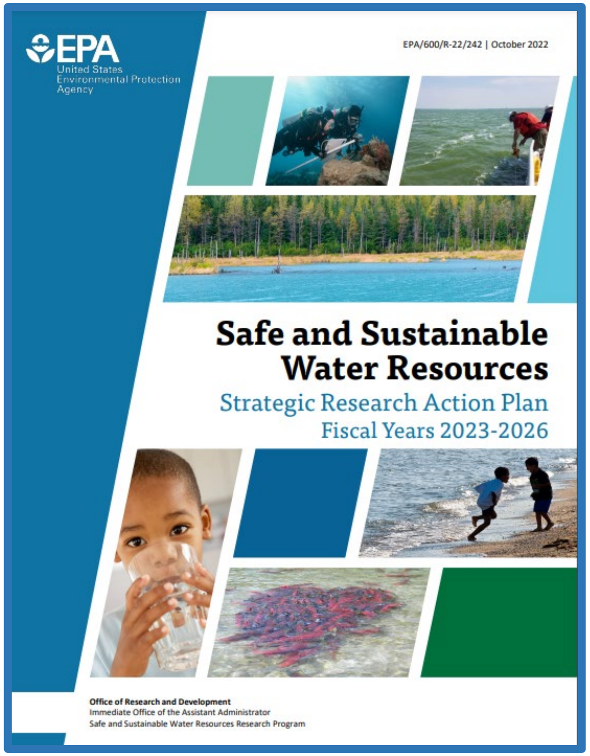
Camden, NJ

Hoboken, NJ

Riverside, CA

End game

- Provide tools and techniques that allow communities to determine the performance of stormwater control measures.
  - Affordable
  - Defensible
  - Consistent



Almost a freebie

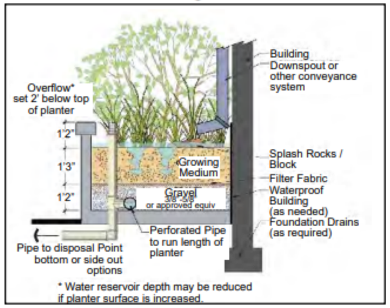
- Pooling community performance determinations with site and stormwater control characteristics will provide needed design suggestions.

Why start with stormwater planters?

- They look easy to monitor.
  - Nearly closed systems.
  - Smaller than many other stormwater controls.
  - Usually have a single inlet source (plus direct rainfall) and single outlet (plus ET).
- Increasingly used in urban and suburban areas.
- Techniques and results should be transferable to other biofiltration systems (rain gardens, bioswales, etc.).

What is a stormwater planter?

- A flow-through stormwater control measure typically installed above ground.
- Generally used to intercept rooftop runoff.
- Small footprint suitable for space-limited installations
- Ponding zone and engineered media layer over aggregate with underdrain, overflow, and bypass
- Usually vegetated
- Usually do not exfiltrate to local soils
- Used in both MS4 and CSO communities
- Designed to meet locally-established guidelines



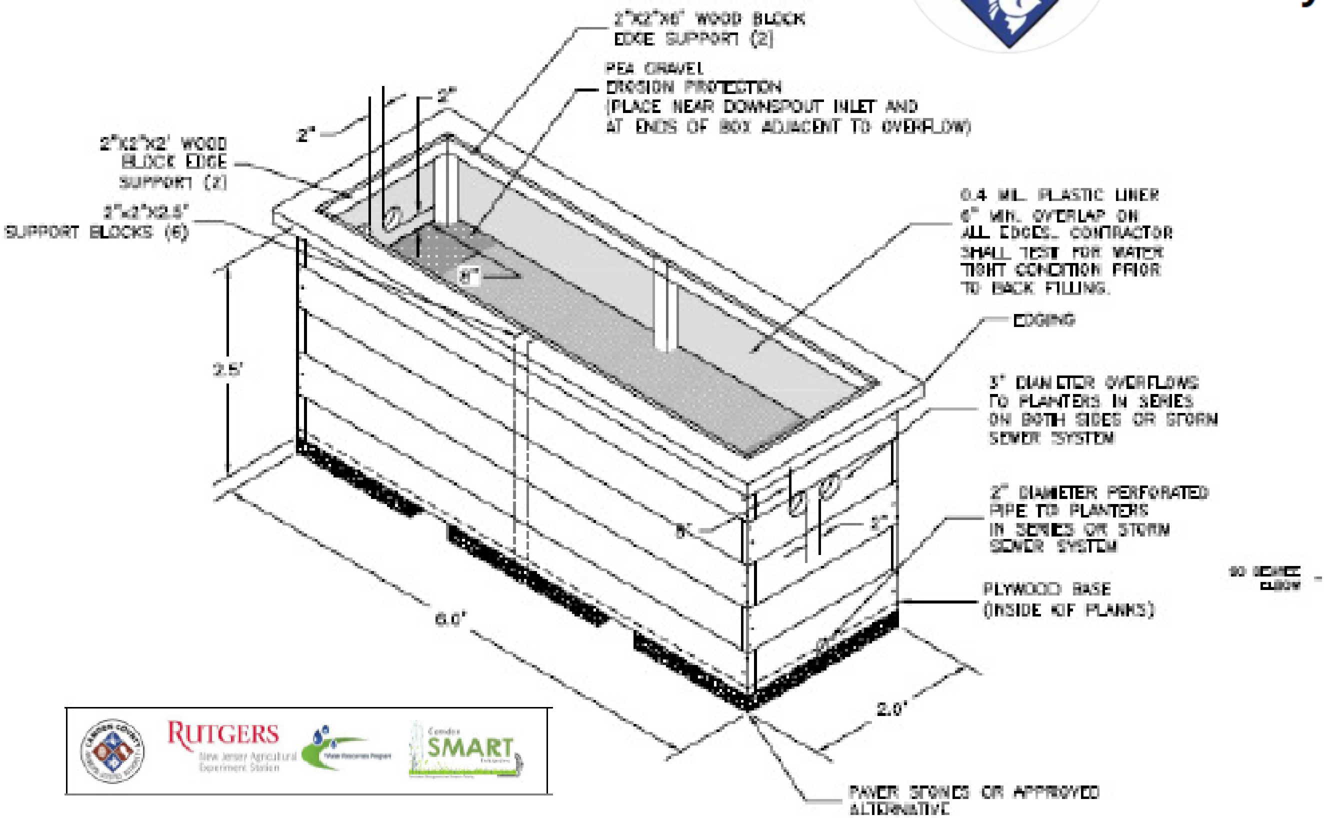
Source: City of Portland, Bureau of Environmental Services

Planter performance measures

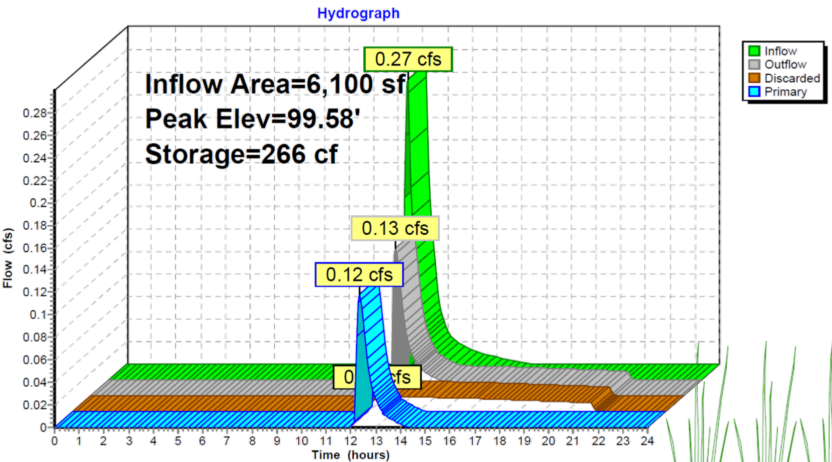
- Complete capture frequency
- Captured volume (Retention)
  - Difference between water volume held by media after rain event and water volume held at start of the event
  - Difference between inlet volume and outlet volume
- Discharge delay
  - Time difference from first inlet flow to first outlet flow
  - Time difference between inlet and outlet flow centroids
- Peak flow attenuation
  - Based on the ratio of maximum discharge flowrate to maximum inlet flowrate
- Fraction of planter media used or saturated

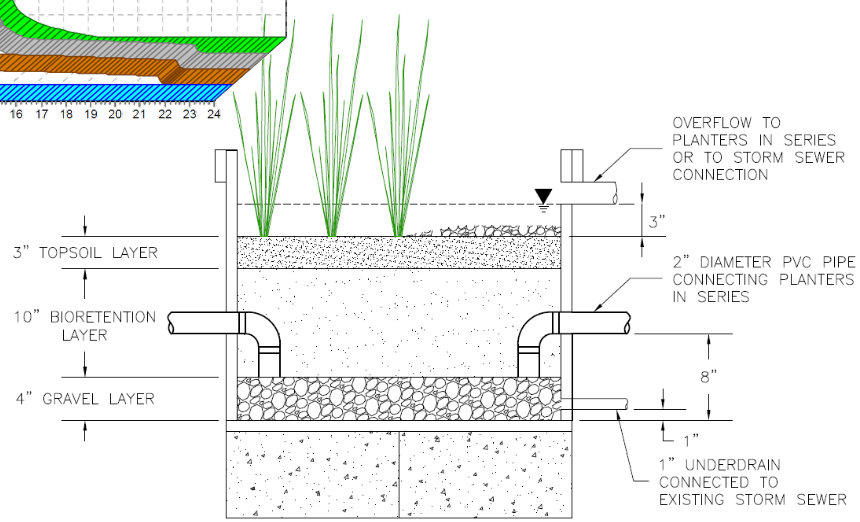
First monitoring in Camden, NJ

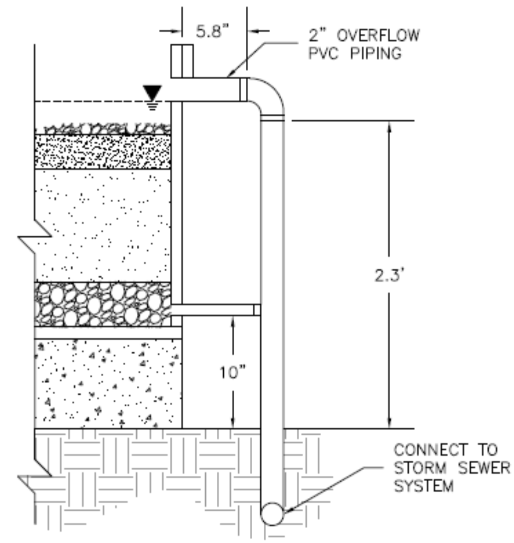
Camden County Municipal Utilities Authority



Performance modeled for design

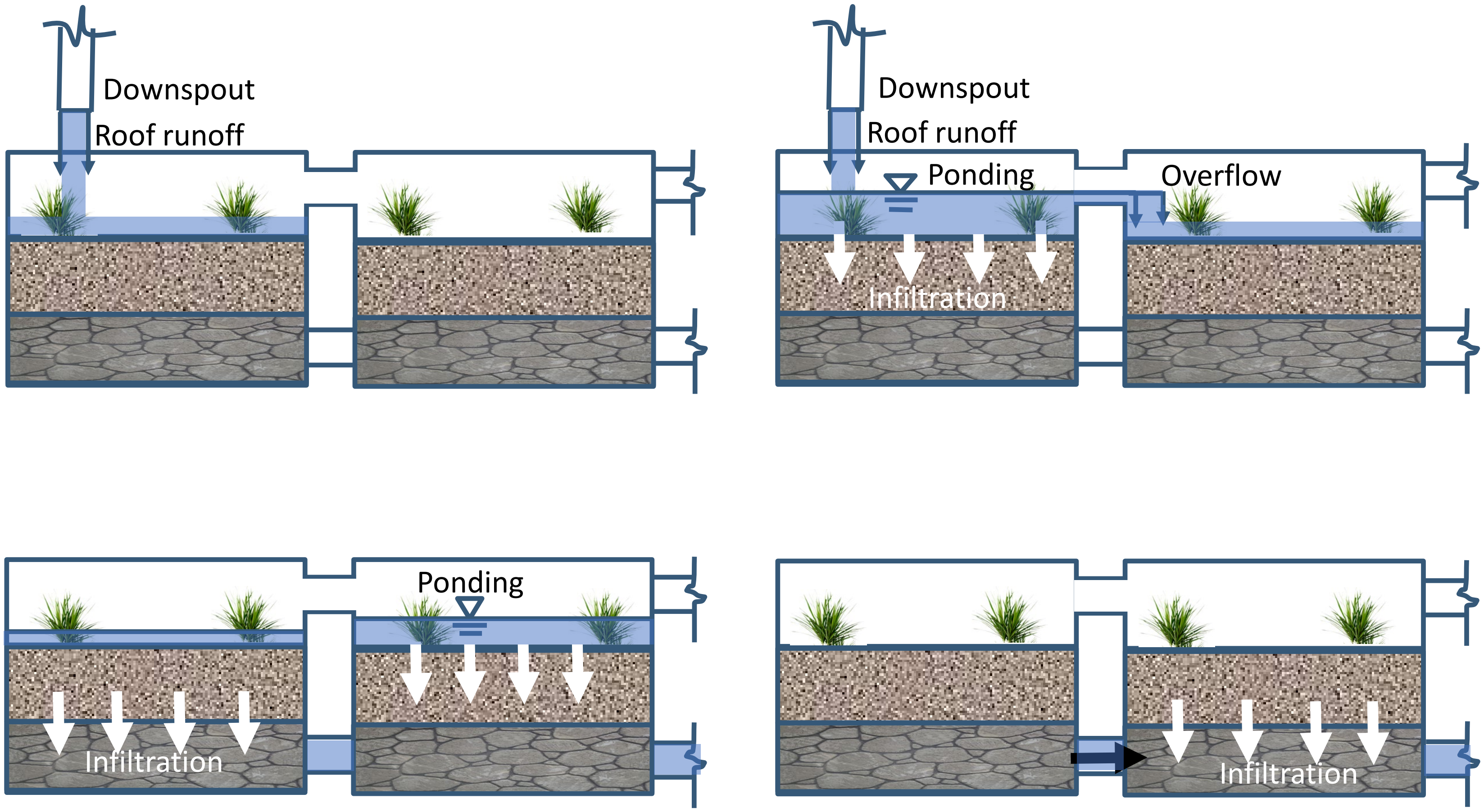






Camden County Municipal Utilities Authority, 2014

Camden planters as designed



Camden planters in action

Conclusions from Camden monitoring

- Planter monitoring is not as simple as expected.
- Water flow does not match the conceptual model
  - Water does not spread to cover planter surface, but infiltrates at first opportunity
- Plants that do not get water do not flourish
- Need to monitor inflow and outflow

On to Hoboken

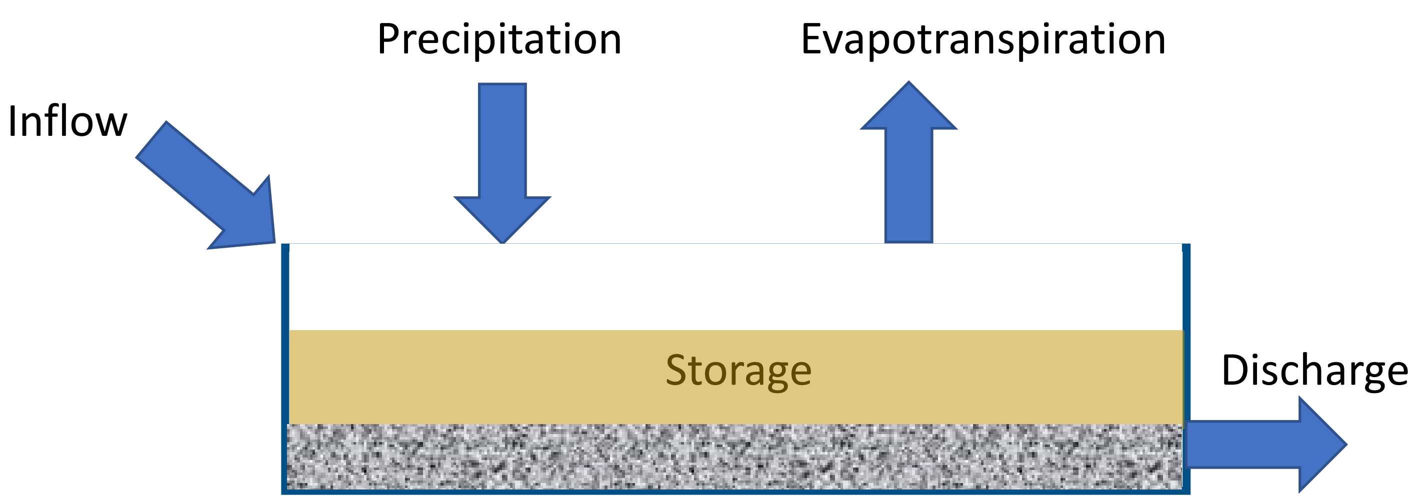
STEVENS

- 4 flow-through planters with precast concrete bottom and sides
- 4.9-m long, 0.9-m wide, 1.2-m tall (inside dimensions)
- 56-cm media layer over 7.6 cm thick sand layer and 15.2 cm pea gravel layer
- 7.6 cm perforated PVC underdrain
- Contributing drainage area 24 to 142 m^2
- Monitoring inflow, outflow, and the volumetric water content (VWC) of the media

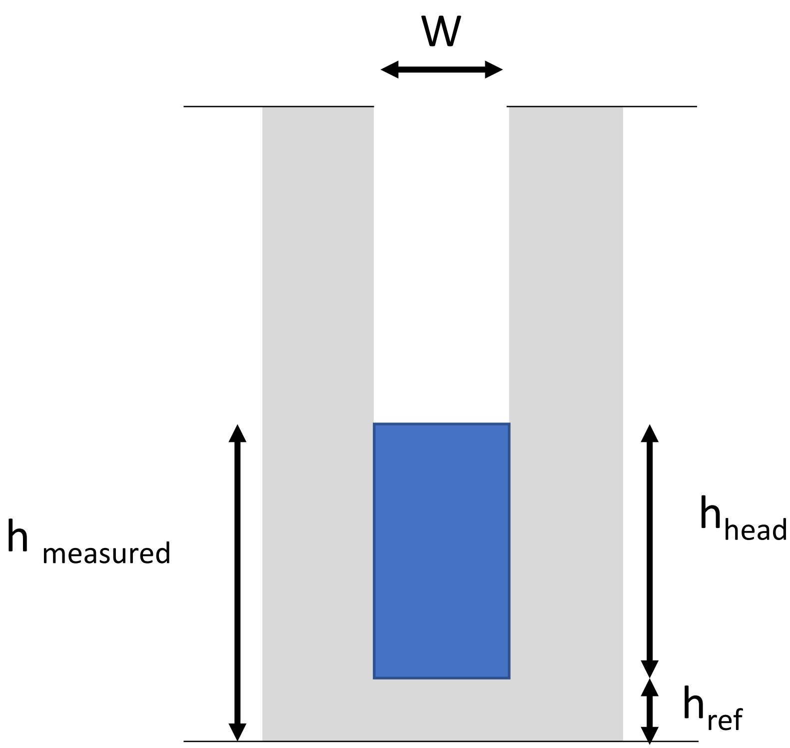
Additional research question

- Can we close the water balance within measurement uncertainty?

$$Inflow + Precip = ET + Dischage + \Delta Storage$$



Measured influent with sharp-edged fully-contracted rectangular weir



$$Q = a\, h_{head}^{n}$$

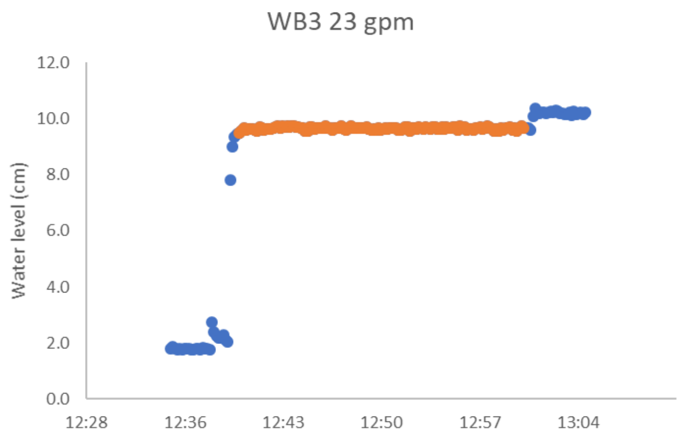
Expect $n \approx \frac{3}{2}$

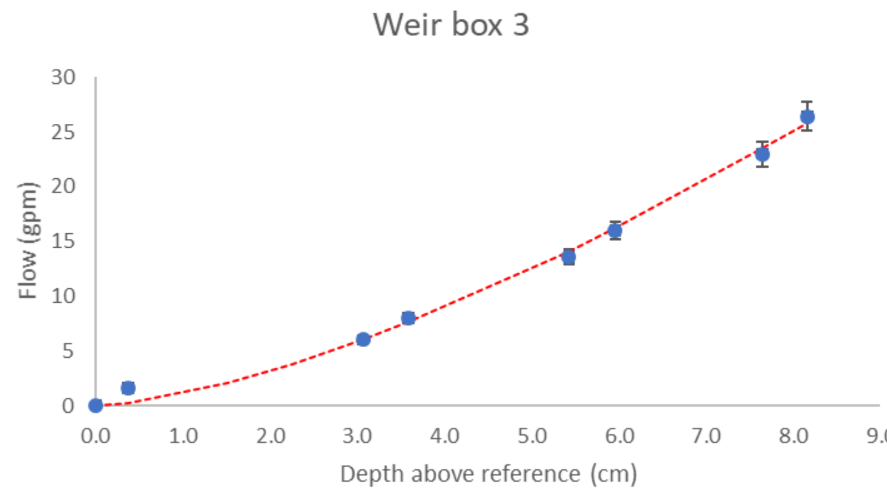
Knowing h_{head} we can calculate the flow rate.

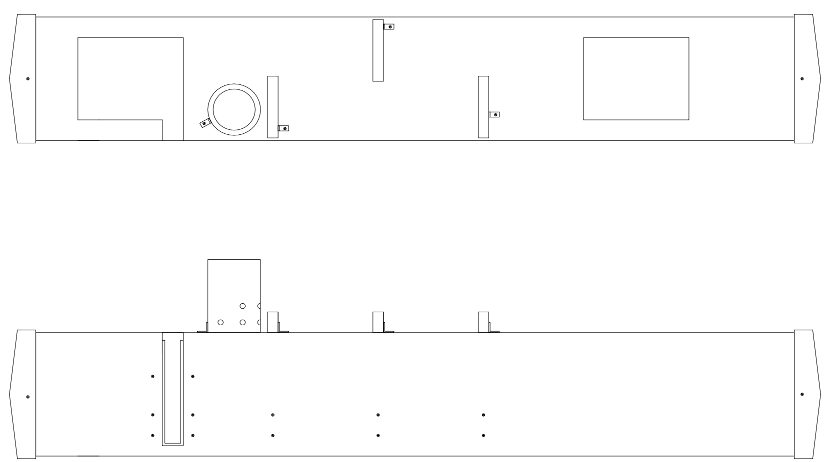
Knowing the flow rates for each time step, we calculate the passed volume

$$V = \sum Q\, \Delta t$$

Develop the rating curve in Edison



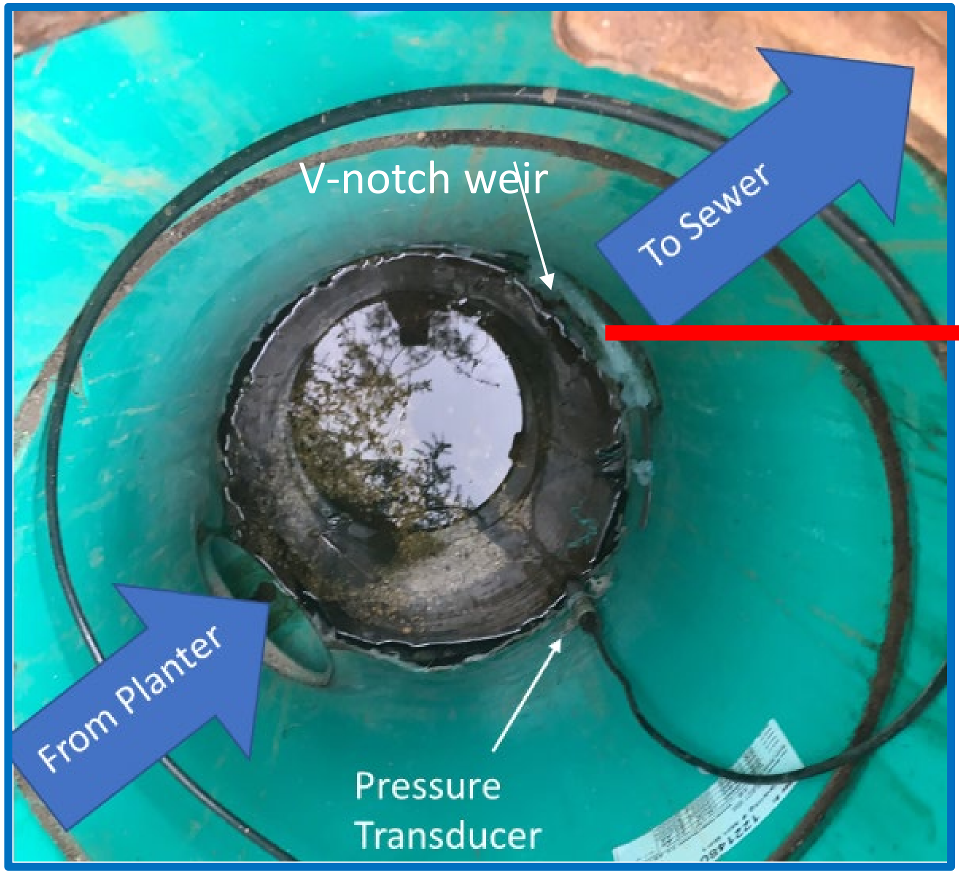




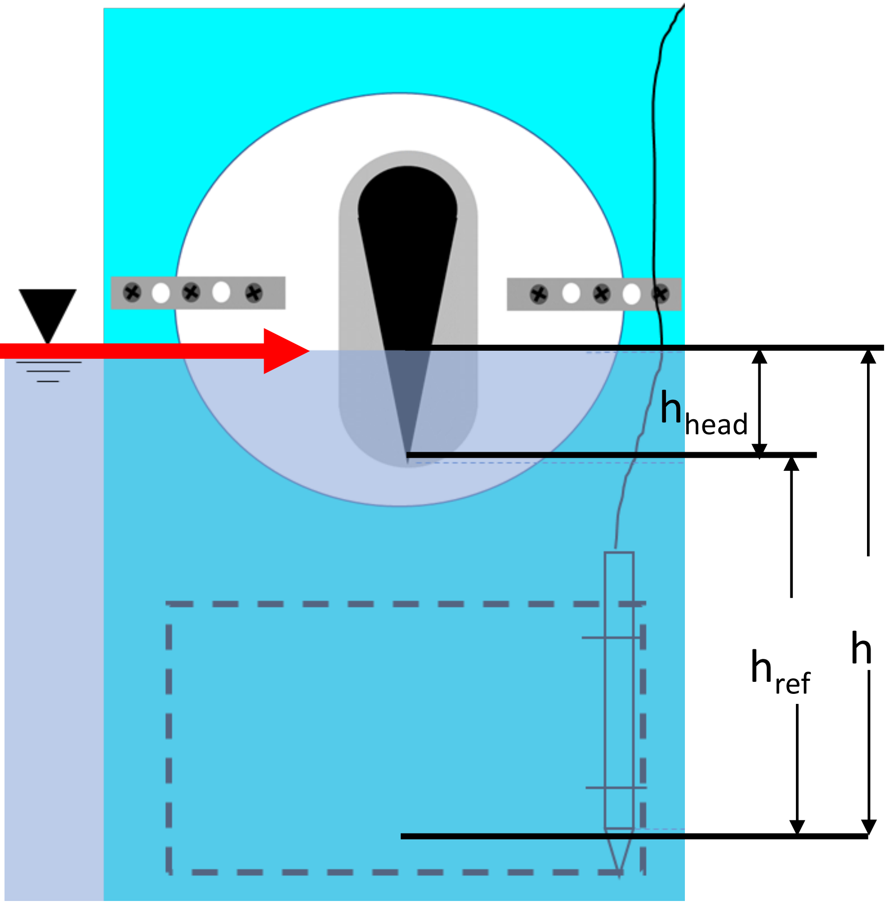
Field confirmed the rating curves for weirs used in Hoboken

Outflow Monitoring used V-notch weir

Overhead View



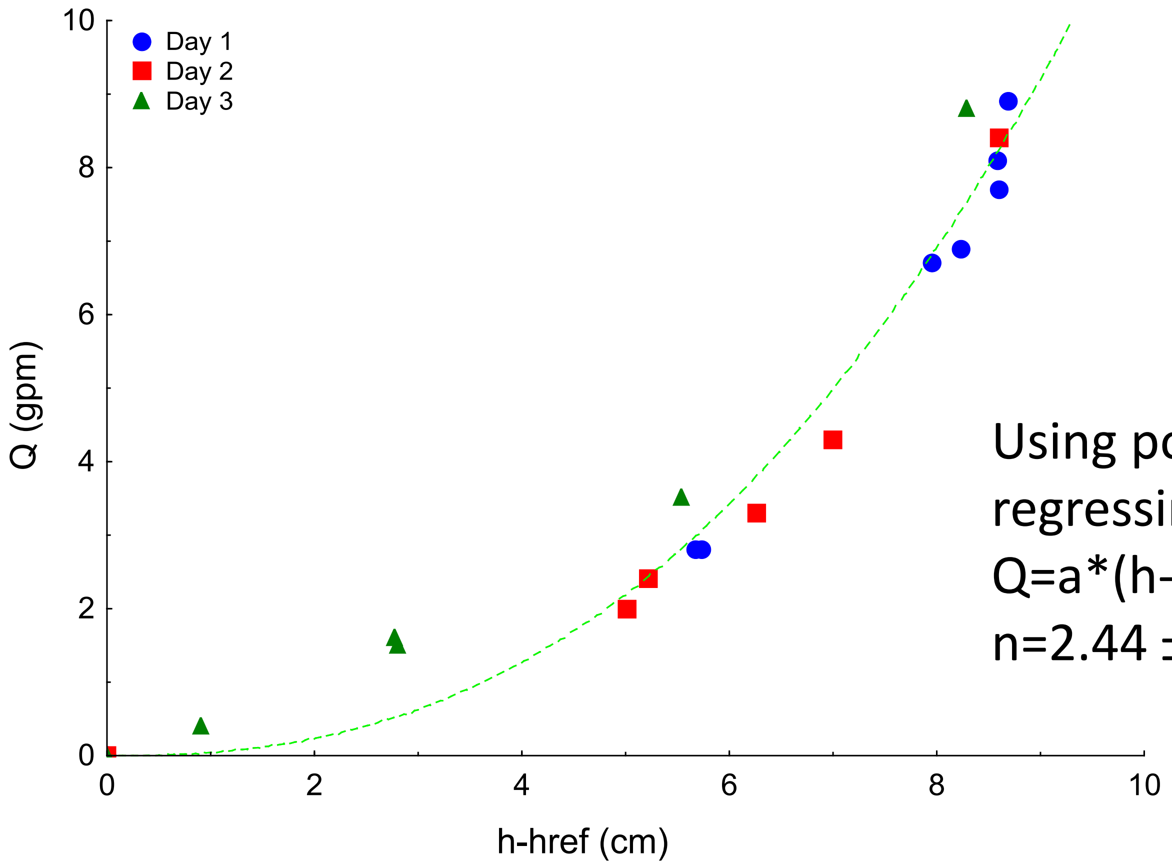
Side View



$$Q = a(h - h_{ref})^{5/2}$$

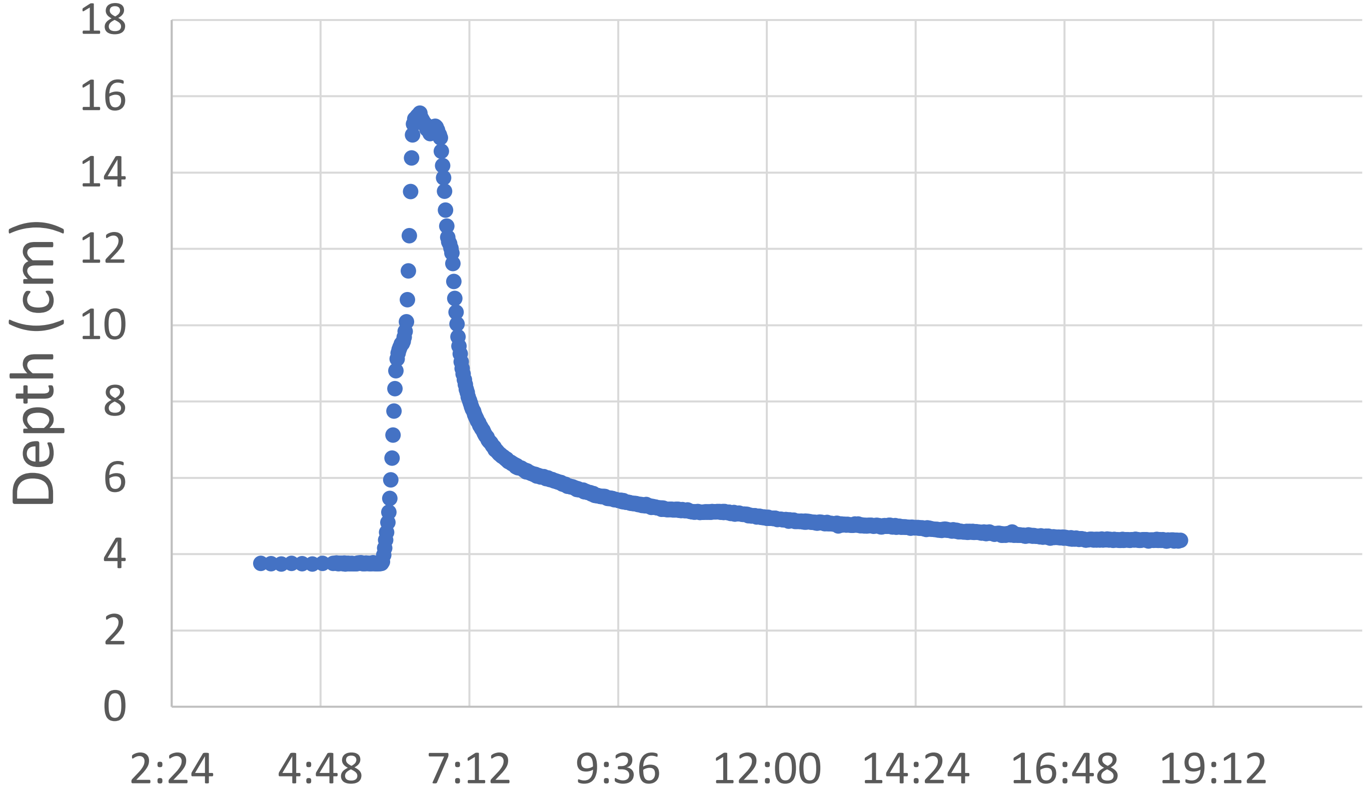
Developing in situ rating curve

Developed in-situ V-notch weir sump rating curve.



Using pooled data from three days, regressing to the expected form $Q=a*(h-h_{ref})^n$, $a=0.043 \pm 0.037$, $n=2.44 \pm 0.40$, $r^2=0.96955335$

What is h_{ref} ?



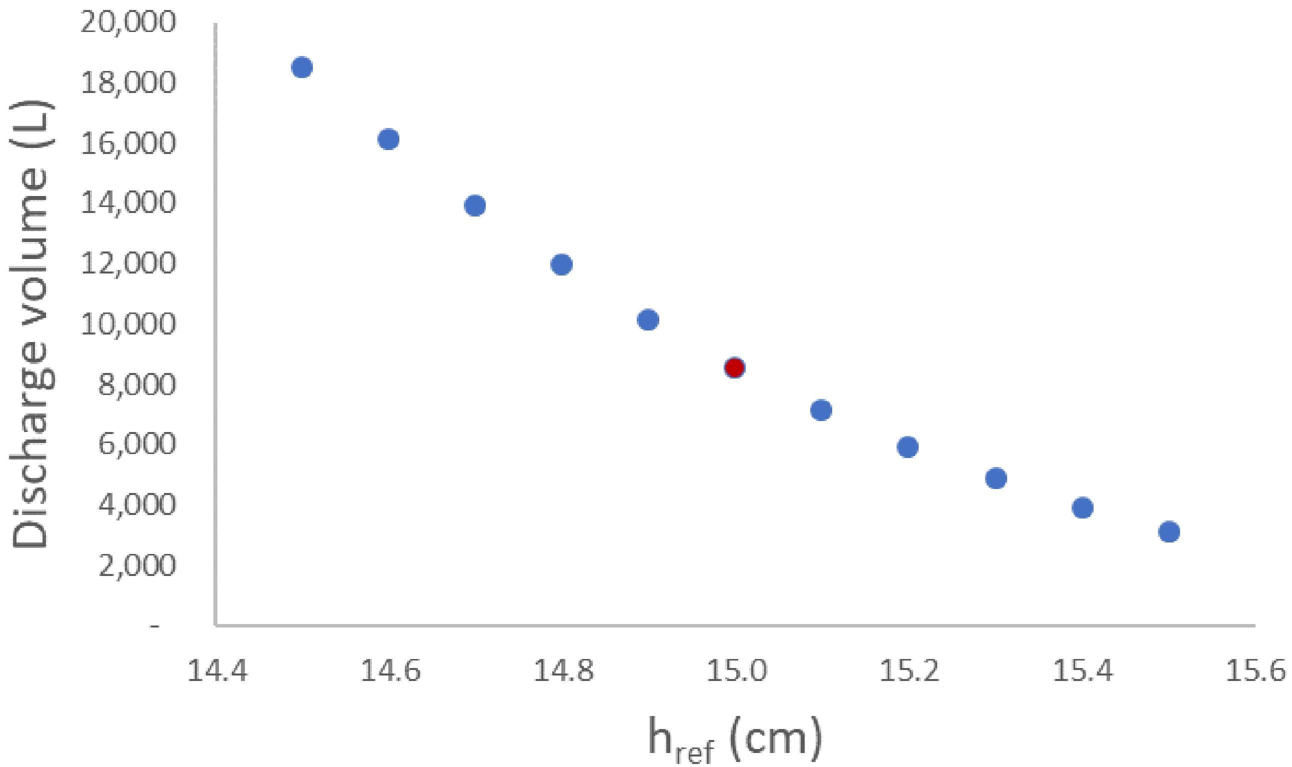
6/25/2019 Storm Planter 1 Outflow

Different methods of estimating h_{ref}

- We tried
  - Level at the start of the rainfall
  - When 30-min slope $\frac{\Delta h}{\Delta t}$ <0.001 cm/min
  - When 30-min slope $\frac{\Delta h}{\Delta t} < 0.01$ cm/min
  - When changing depth is within ±0.2 cm (published total error band of sensor) for 30 min
  - 1 hr after rainfall ends
  - 3 hr after rainfall ends
  - 6 hr after rainfall ends
  - 12 hr after rainfall ends
- Literature
  - Eyeball from graph
  - Use the pre-event for first half and post-event for second half
  - Back calculate to match expected volume passed
  - Unreported (most common)

How important is h_{ref}?

H_{ref} (cm)	Volume (L)
14.5	18,484
14.6	16,106
14.7	13,927
14.8	11,944
14.9	10,157
15.0	8,561
15.1	7,153
15.2	5,925
15.3	4,858
15.4	3,924
15.5	3,105



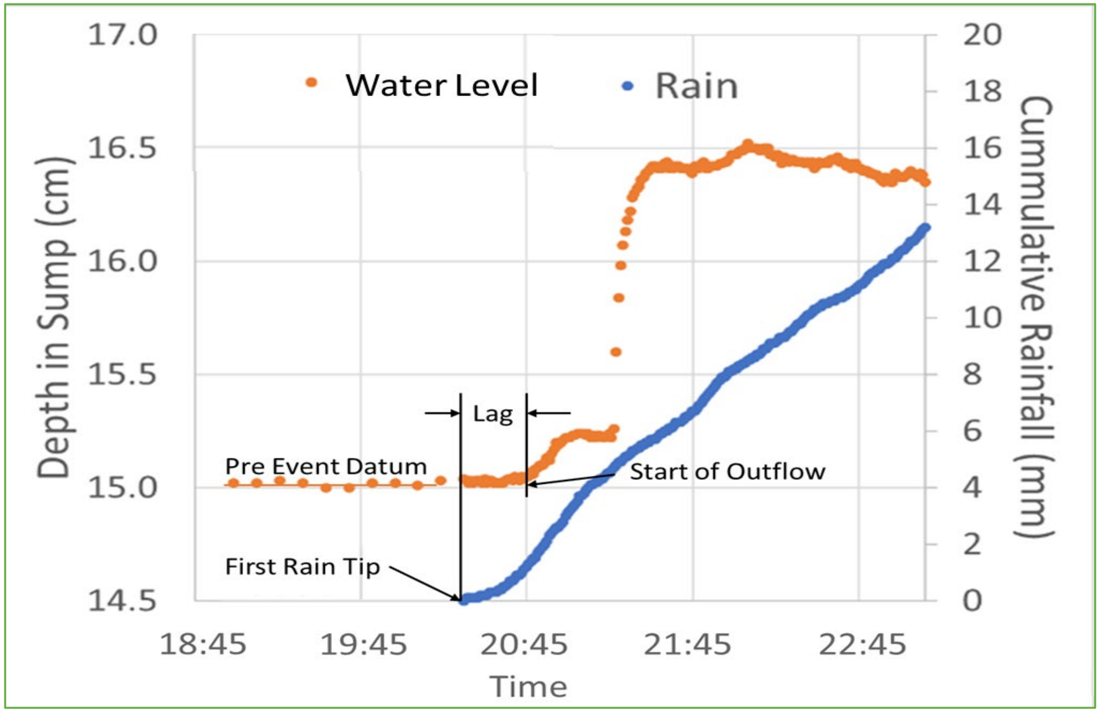
Result: water balance

- Solution
  - Partially submerge sensor in a sump or lay flat.
    - Sensors do not work as well at extreme limits of operating range
  - Top off the standing water in the sumps before each event.

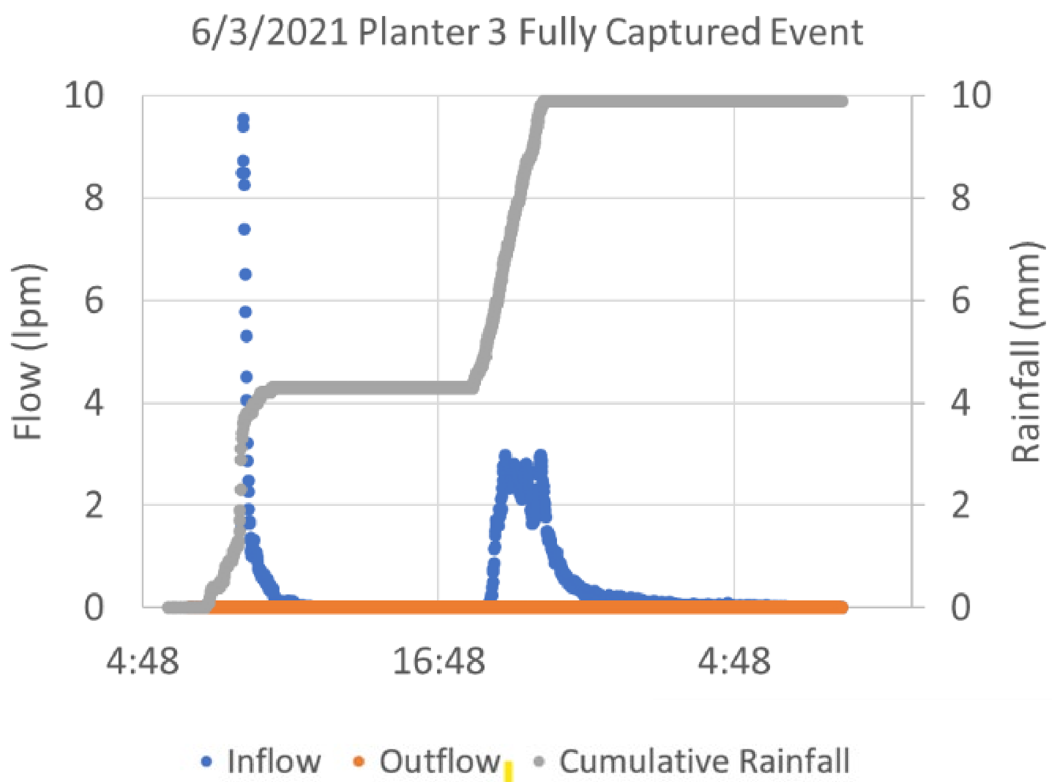
- Outcome
  - Increased water balance closure from 25% of the events to 75% of the events.
  - Fine for research activities and periodic monitoring but not a wonderful solution for routine in-the-field monitoring practices.

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)

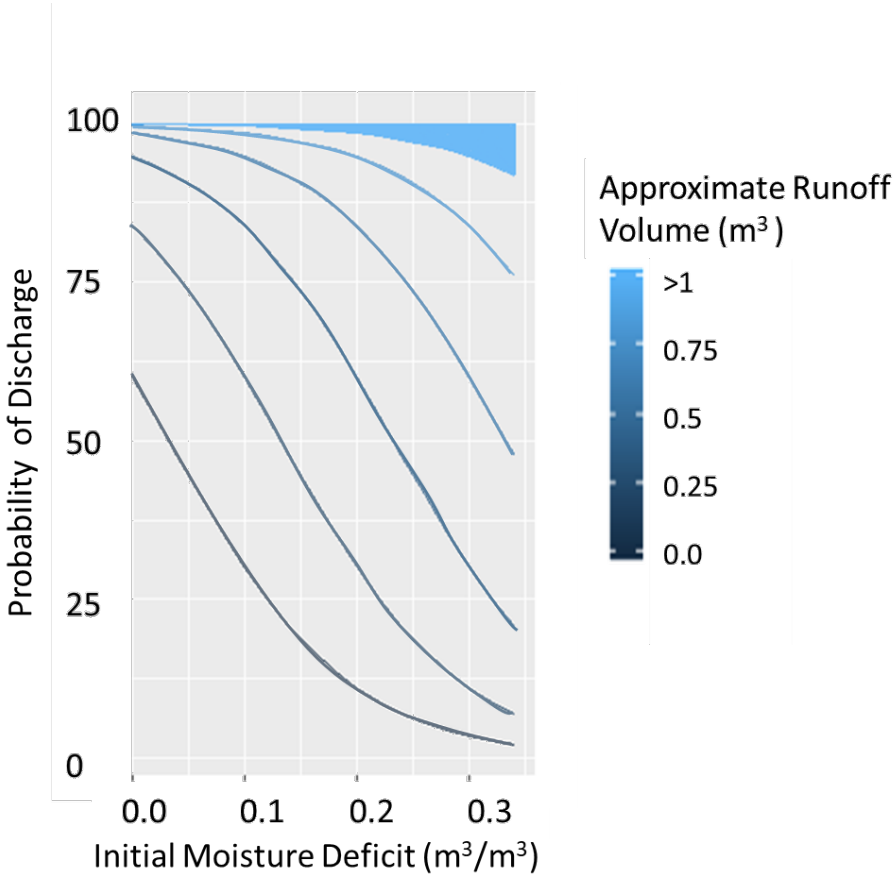


Complete capture



Result: Probability of complete capture

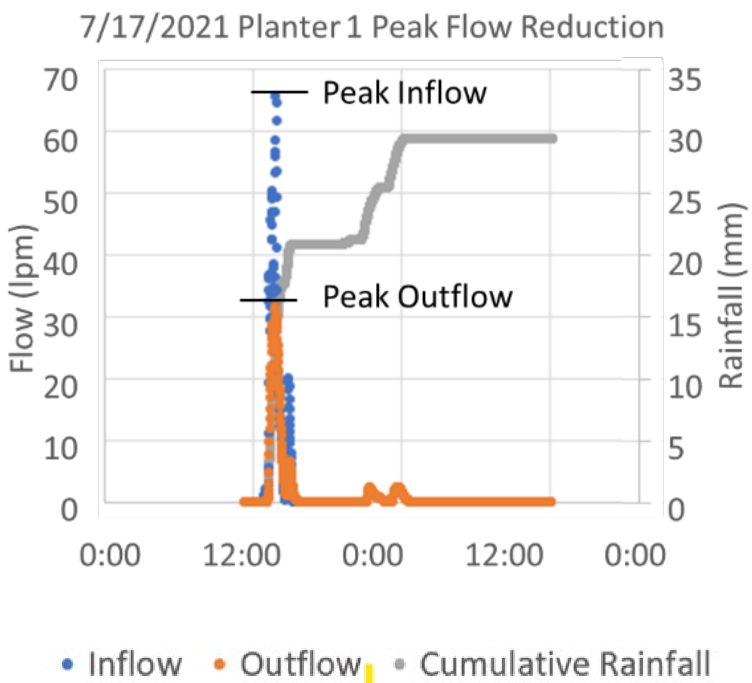
- Planters completely captured 38% of observations with at least 0.1 mm rainfall
- Controlling variables
  - Runoff volume
  - Initial moisture deficit (based on pre-event and saturated conditions
- 400+ usable observations



Complete capture take 2

- 20% of events with at least 2 mm of rainfall were captured
- Explicit definition of a rain event is important to understanding the results
  - Minimum depth
  - Rain-free period that ends the rain event

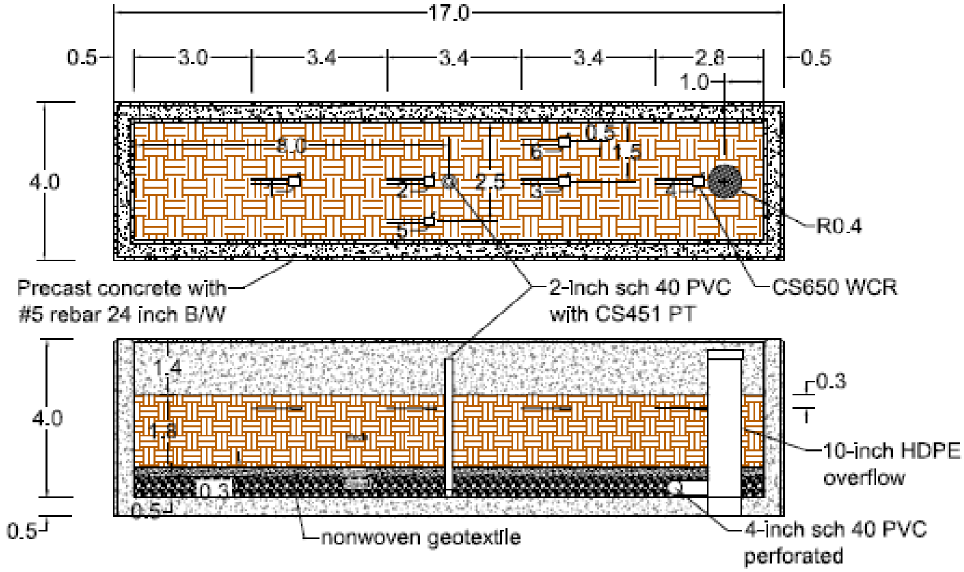
Result: Peak flow reduction



$$\% \, reduction = 100 \frac{Q_{max,in} - Q_{max,out}}{Q_{max,in}}$$

Median peak flow reduction : 59%

Measuring stored water: initial sensor layout



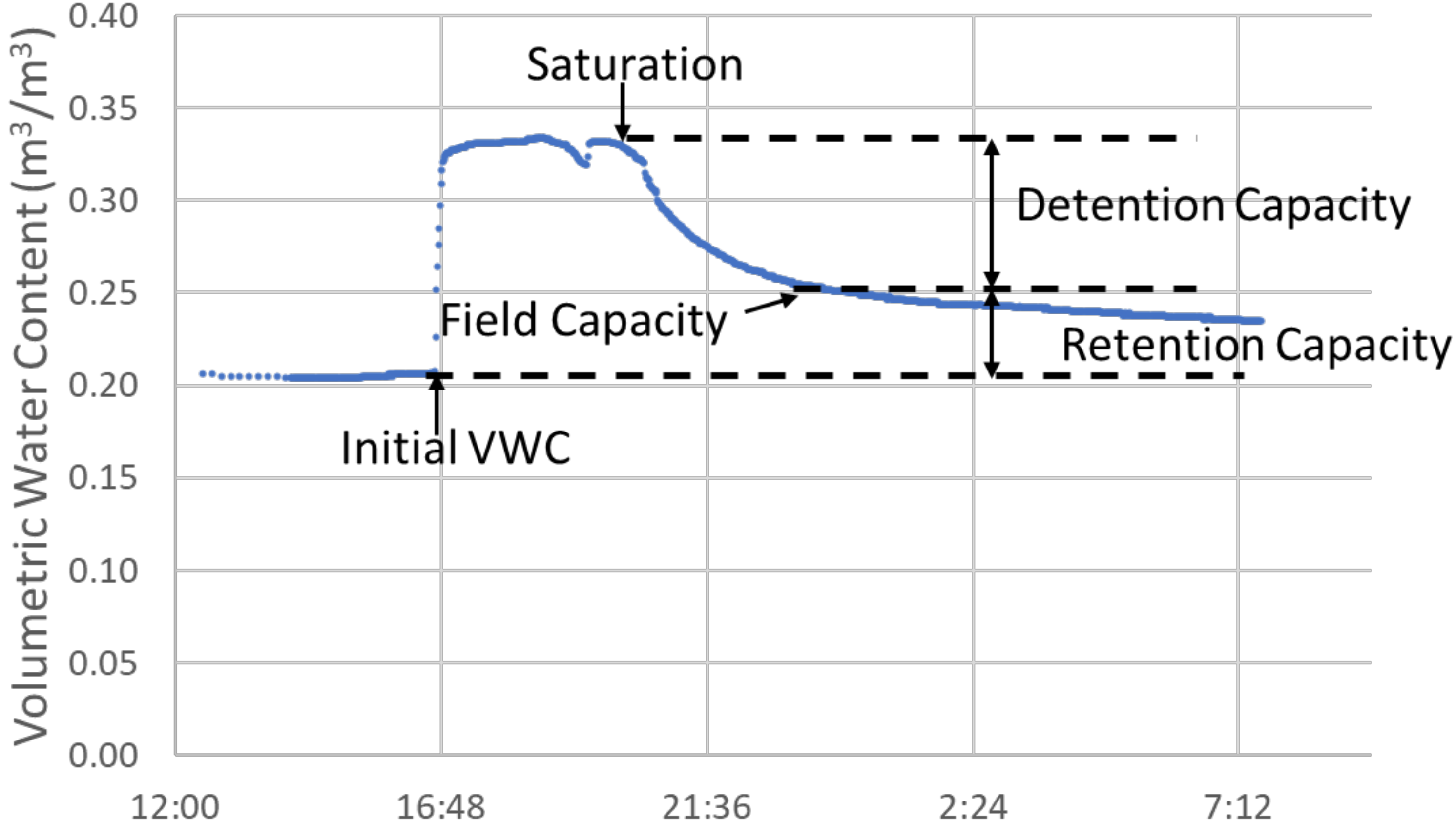
Planter 1 Pumice media			
Sensor	Sensor name	S/N	SDI12
WCR 1	H1BA1T01	20351	A
WCR 2	H1BA1T02	22641	H
WCR 3	H1BA1T03	22642	I
WCR 4	H1BA1T04	22644	J
WCR 5	H1BA1T05	22645	K
WCR 6	H1BA1T06	22646	L
PT 1 (inlet)	H1BA1P01	XXX10989	o
PT 2 (gravel)	H1BA1P02	20011314	g
PT 3 (u/drain)	H1BA1P03	20011320	h

Planter 3 NJDEP media			
Sensor	Sensor name	S/N	SDI12
WCR 1	H3BA1T01	22272	B
WCR 2	H3BA1T02	22285	C
WCR 3	H3BA1T03	22314	D
WCR 4	H3BA1T04	22315	E
WCR 5	H3BA1T05	22316	F
WCR 6	H3BA1T06	22317	G
PT 1 (inlet)	H3BA1P01	20011322	j
PT 2 (gravel)	H3BA1P02	20011321	c
PT 3 (u/drain)	H3BA1P03	xxxx312	e

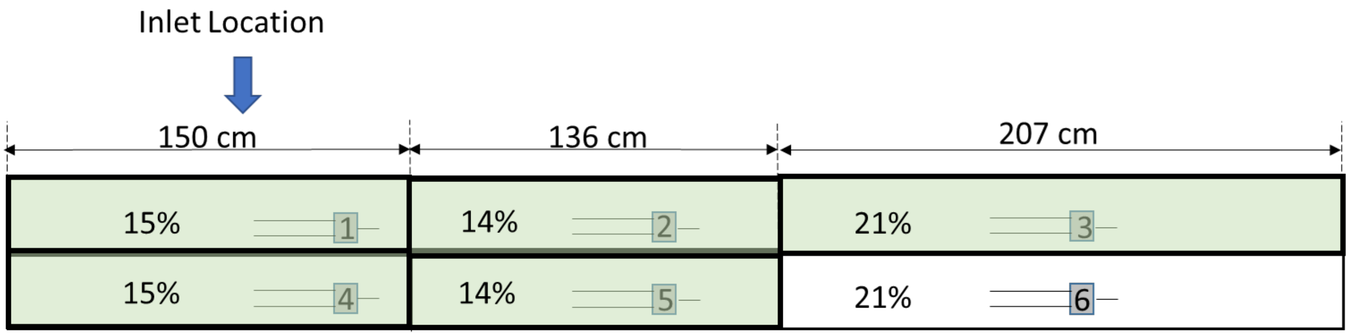
arge spatial
eterogeneity showed
e initial sensor
yout was not
dequate

Added sensors mid experiment

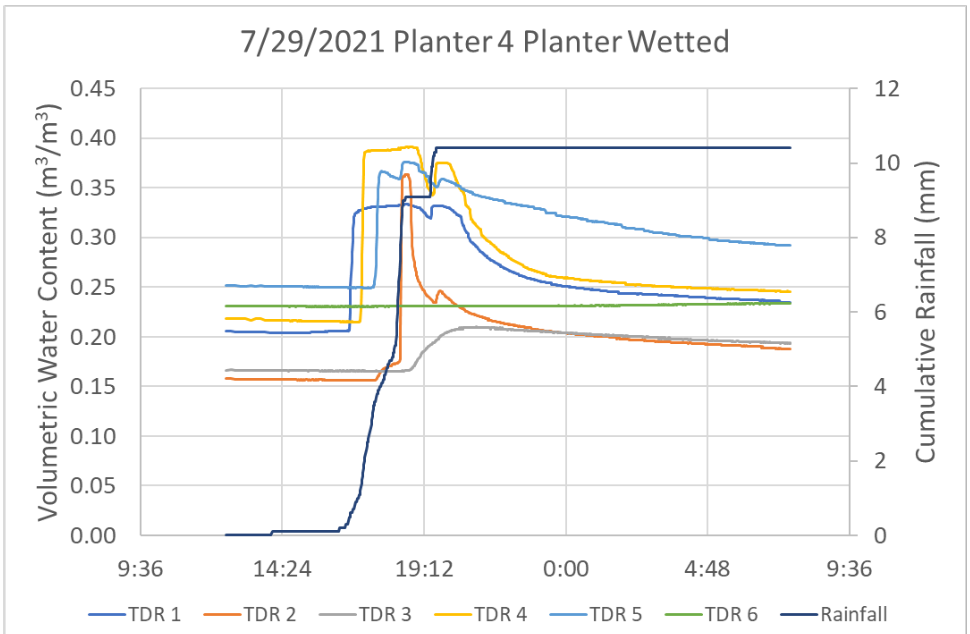
Typical sensor response to rain event



Fraction wetted



Planter 4 Profile View



Start of Rainfall: 14:05

Time of Initial Wetting

TDR 1: 16:42

TDR 4: 17:04

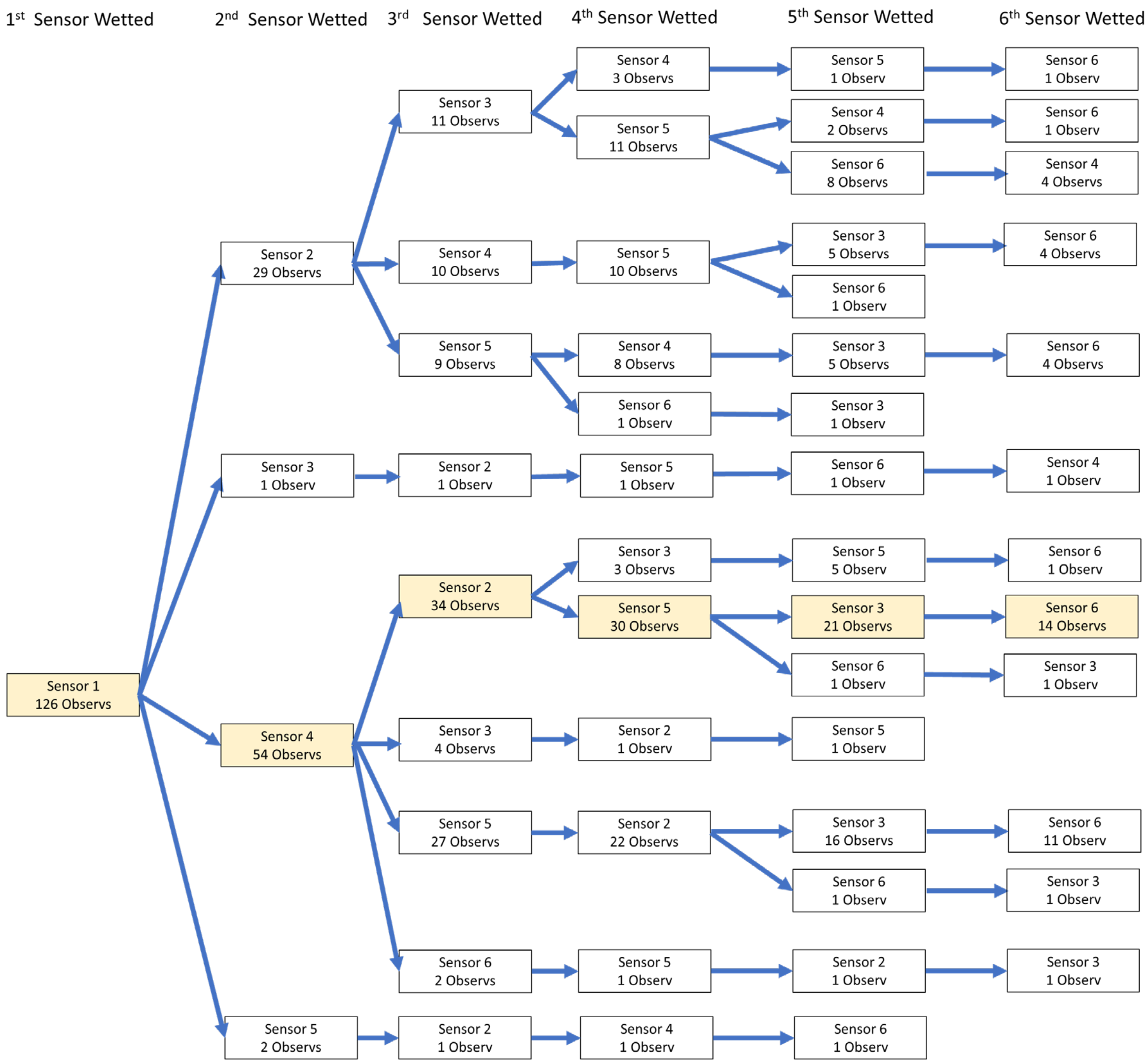
TDR 5: 17:32

TDR 2: 17:41

TDR 3: 18:51

TDR 6: N/A

Infiltrating water follows a preferred path.



Implications of selective pathway

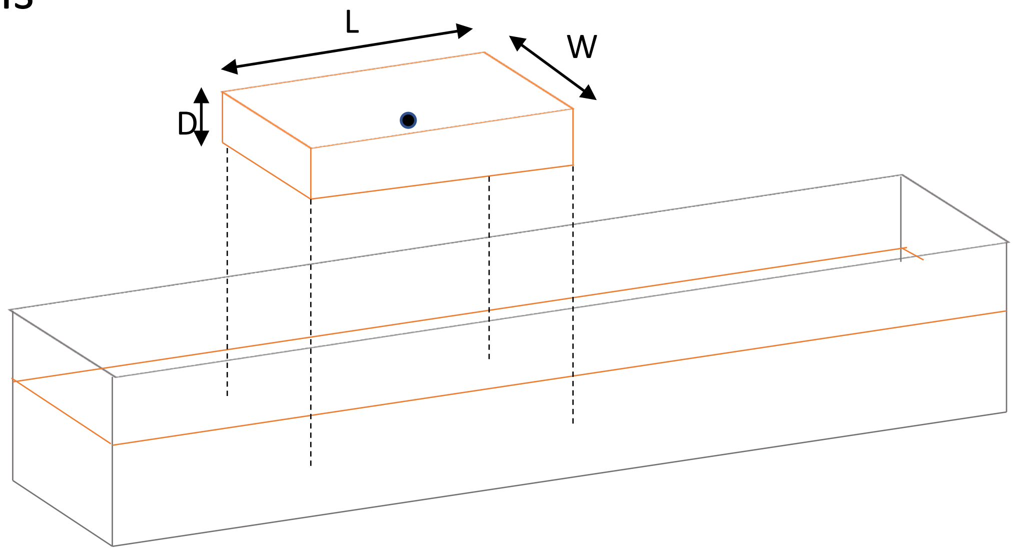
- All media shows increase in soil moisture in 48% of the rain events
- All media becomes saturated in 8% of the rain events.

Volume represented by sensor

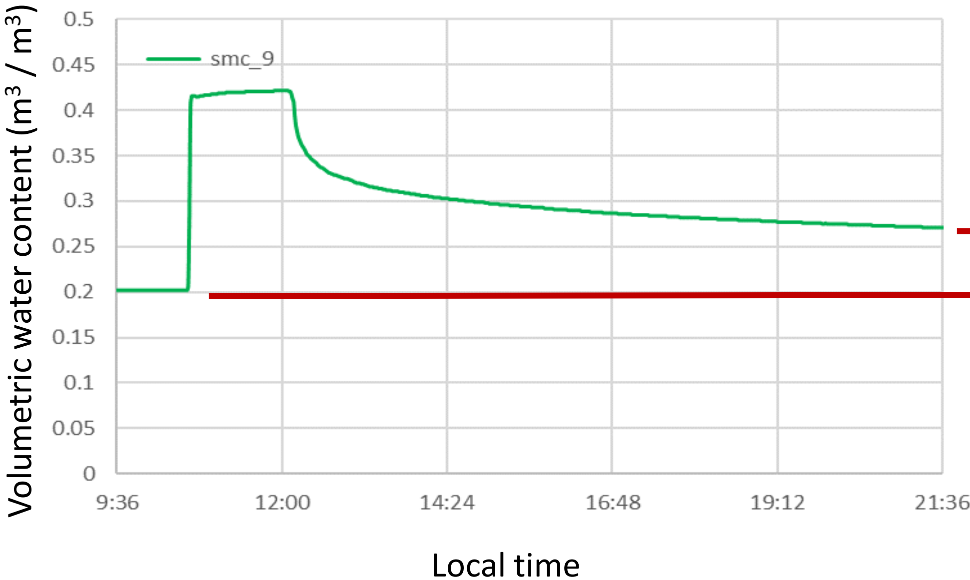
Each sensor represents a media volume determined by distance to the planter walls or half the distance to adjacent sensor.

For “sensor 9”
L= 105.4 cm
W= 91.4 cm
D= 20.3 cm

Media 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

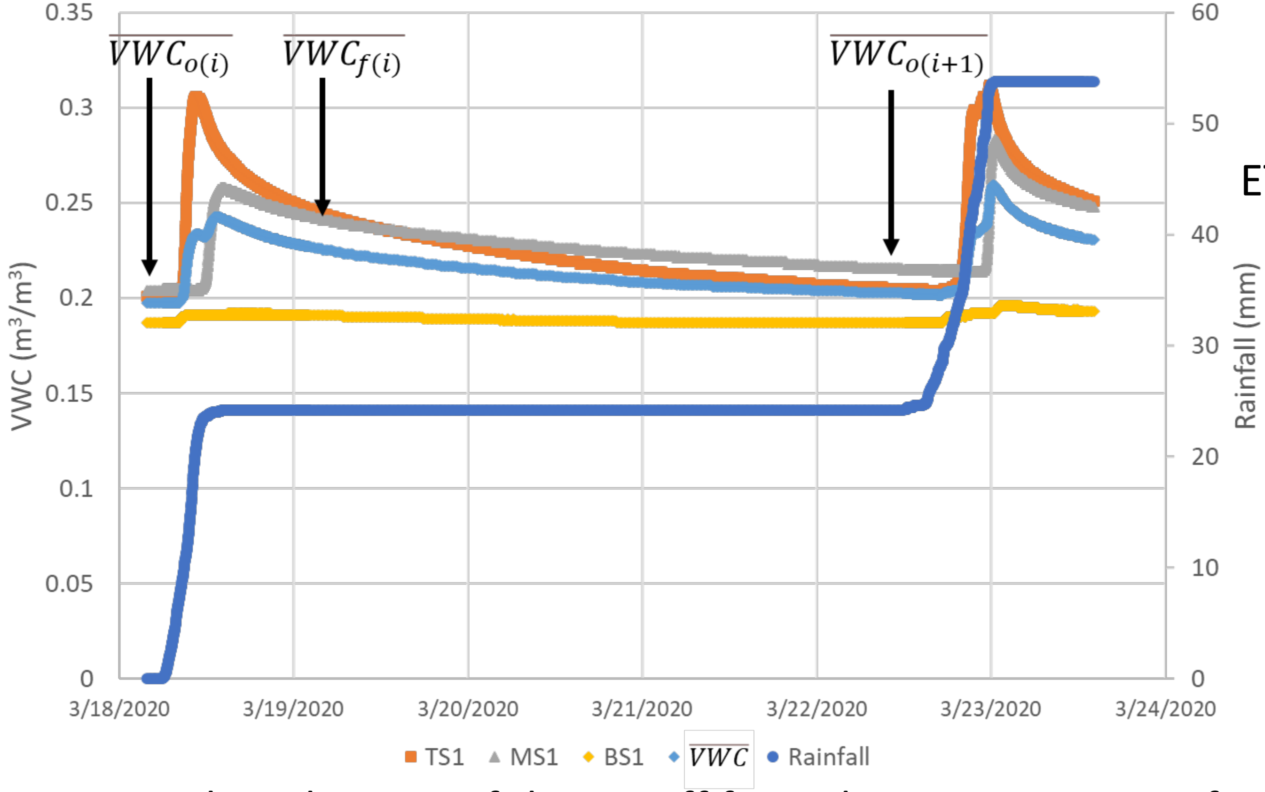
0.208 m^3 water/ m^3 media

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

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

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

Estimating ET



$$ET = \overline{VWC}_{o(i+1)} - \overline{VWC}_{f(i)}$$

ET was less than 5% of the runoff from the previous storm for 86% of the observed events less than 2.3 mm/m^2 roof drainage area

Conclusions from Hoboken, NJ

- Fully captured runoff from 20% of rain events with 2 mm or more rainfall. 40% for events with 0.1 mm of more depth
- Median lag (difference from first inflow to first discharge) 77 minutes
- Median peak flow reduction of 59%
- Infiltrating water followed preferential pathways
- All planter media was wetted (increase in measured volumetric water content 0.05% or more) for 48% of the events
- All media saturated in 8% of the events
- Planters retained less than 2 mm of runoff per m^2 drainage area for about three quarters of the rain events
- ET was less than 5% of the runoff from the previous storm for 86% of the observed events

On to Riverside

Riverside County Flood Control and Water Conservation District

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

Determining volumes

- Use commercially-available compound weirs to measure flow
- Teledyne ISCO builds the rating curve into meter and autosampler

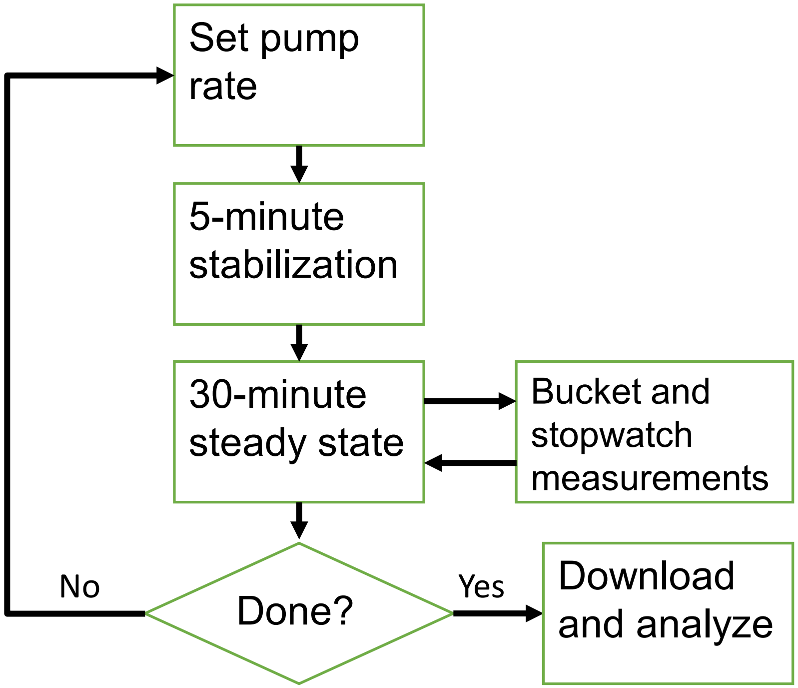
"The Thel-mar Volumetric Weir is the most practical and economical calibrated measuring devise used to determine infiltration in newly installed sewer lines, as well as substantial flows in existing pipes."

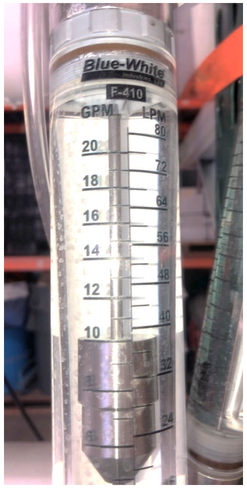
https://thel-mar.com/product-overview

"Weir measurements have a +/- 5% accuracy, with a 2% accuracy at moderate and high flow rates."

https://www.pollardwater.com/product/thel-mar-6-in-volumetric-weir-with-bubble-level-t6weirwbubbler/_/R-4934300

Test Procedure

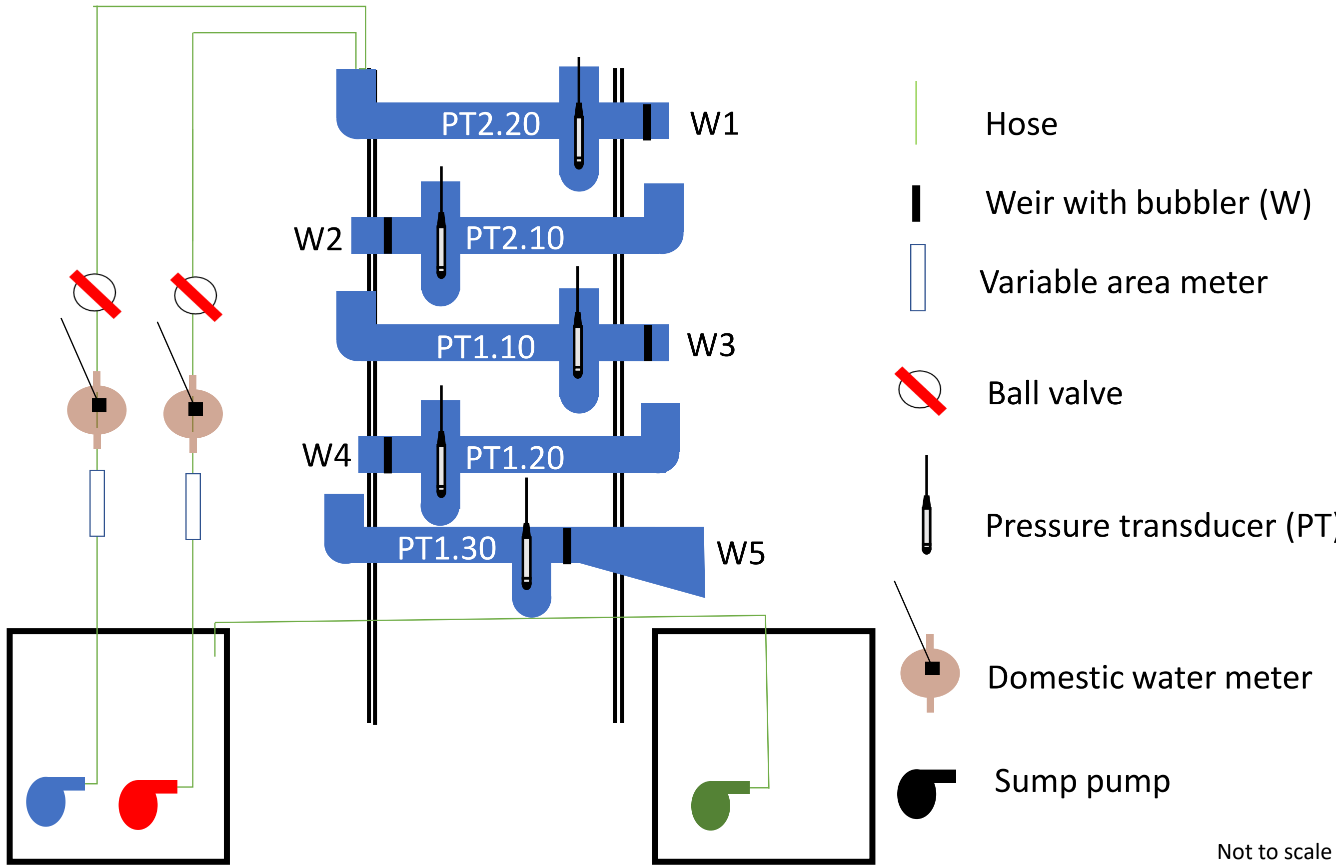




SCCWRP

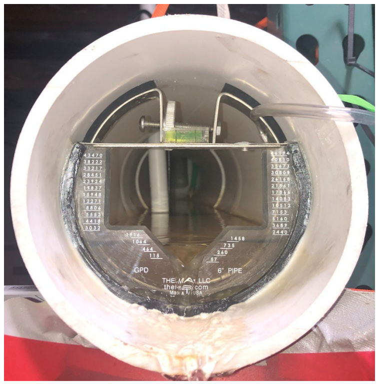
Experimental Apparatus to confirm rating curve

SCCWRP

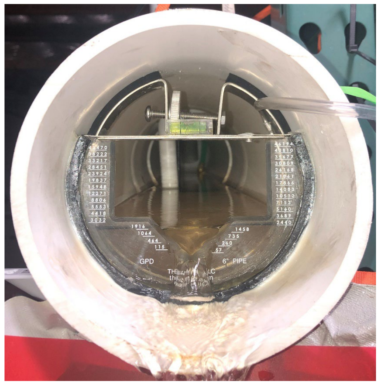


Example Observations

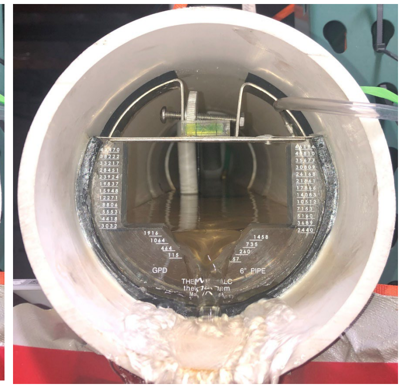
PT2.10 / W2
Slope 2.08%
Test dates:
6/23/21 + 6/28/21



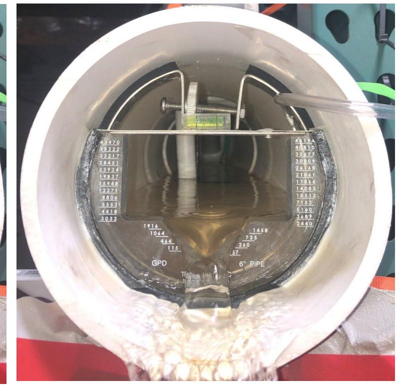
2.3 lpm



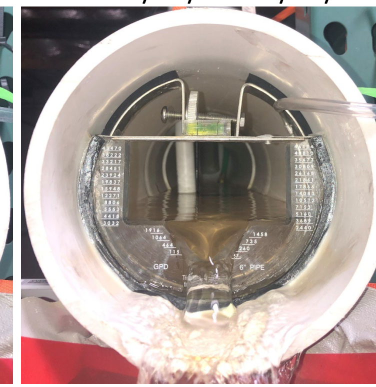
4.4 lpm



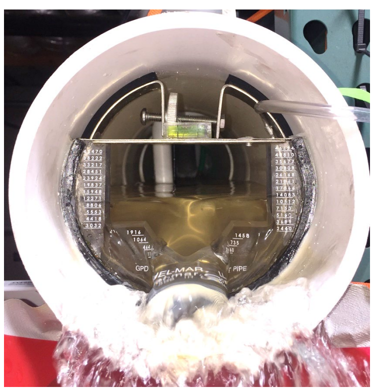
6.6 lpm



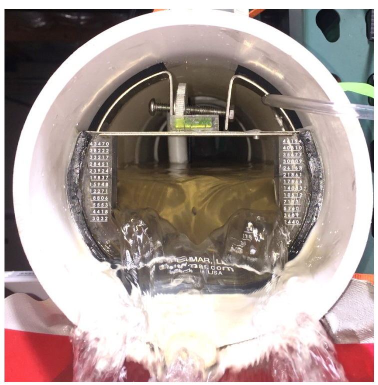
9.1 lpm



10.6 lpm

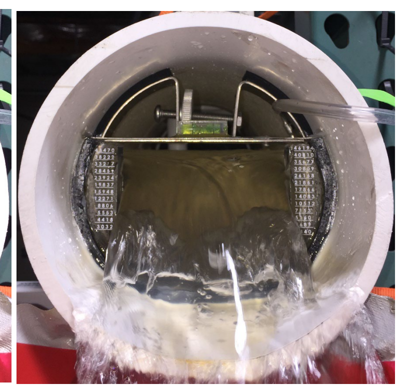


38.6 lpm



56.1 lpm

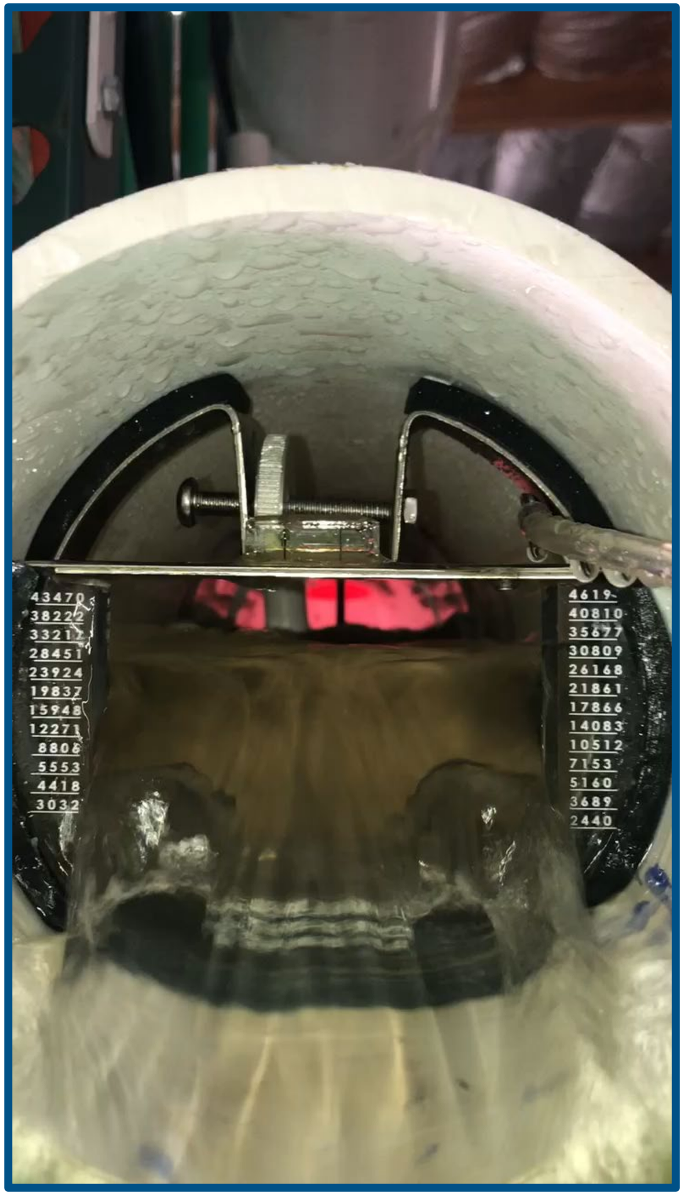
92.6 lpm



135.7 lpm

142.4 lpm

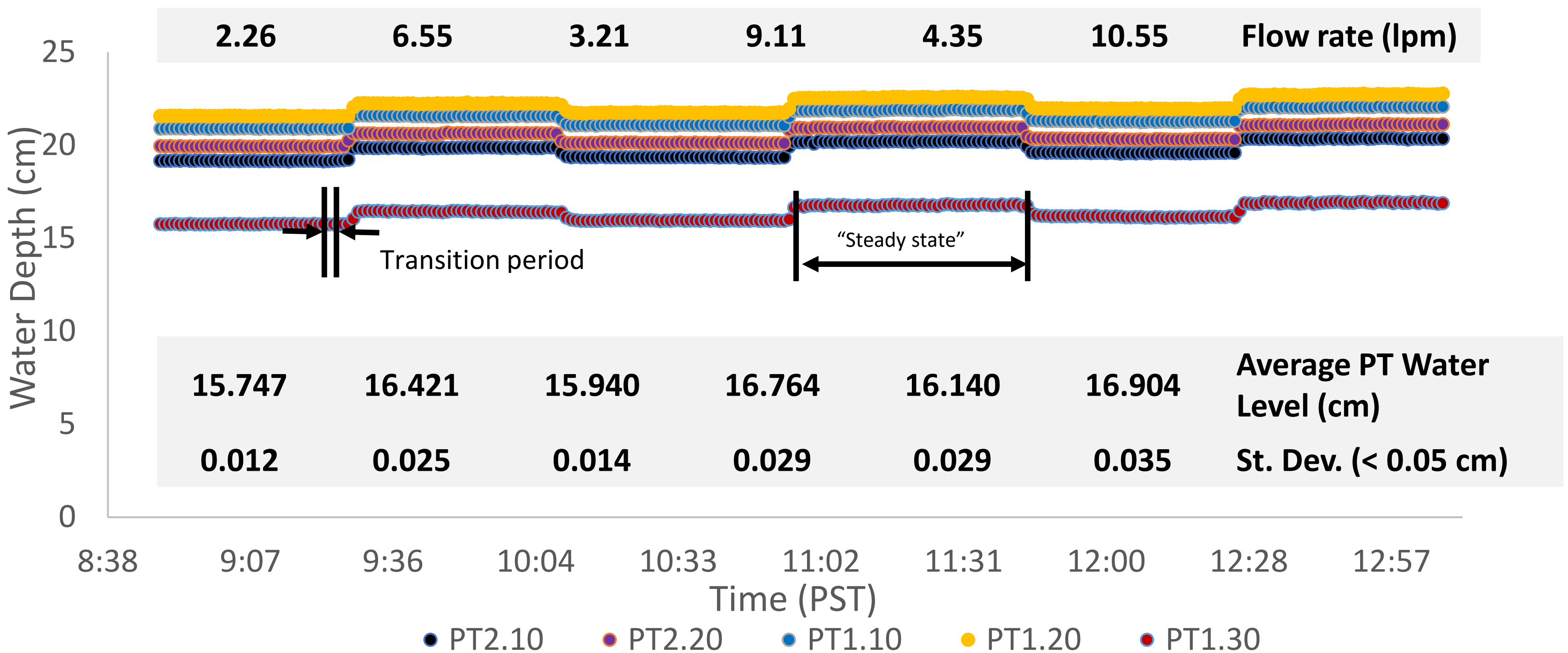
At larger flow rates, water level measurements are noisier



R2BA1P20 206/09/2021
116±12 lpm

Example Data 06/28/2021

Slope 2.08%
Test date: 6/28/21

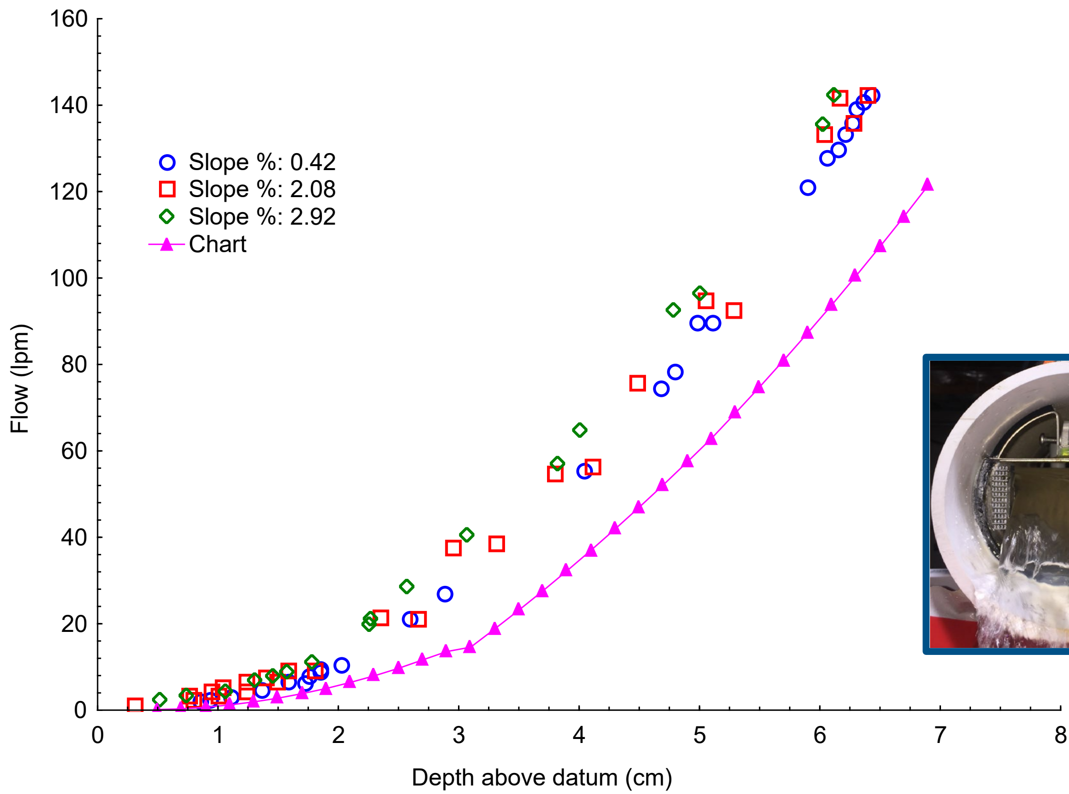


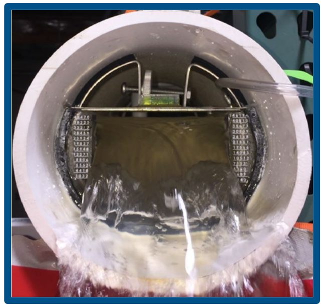
Measured and tabulated flows do not match!

Difference increases at larger depths and decreases at smaller flows.

Biased to give smaller flow rates.

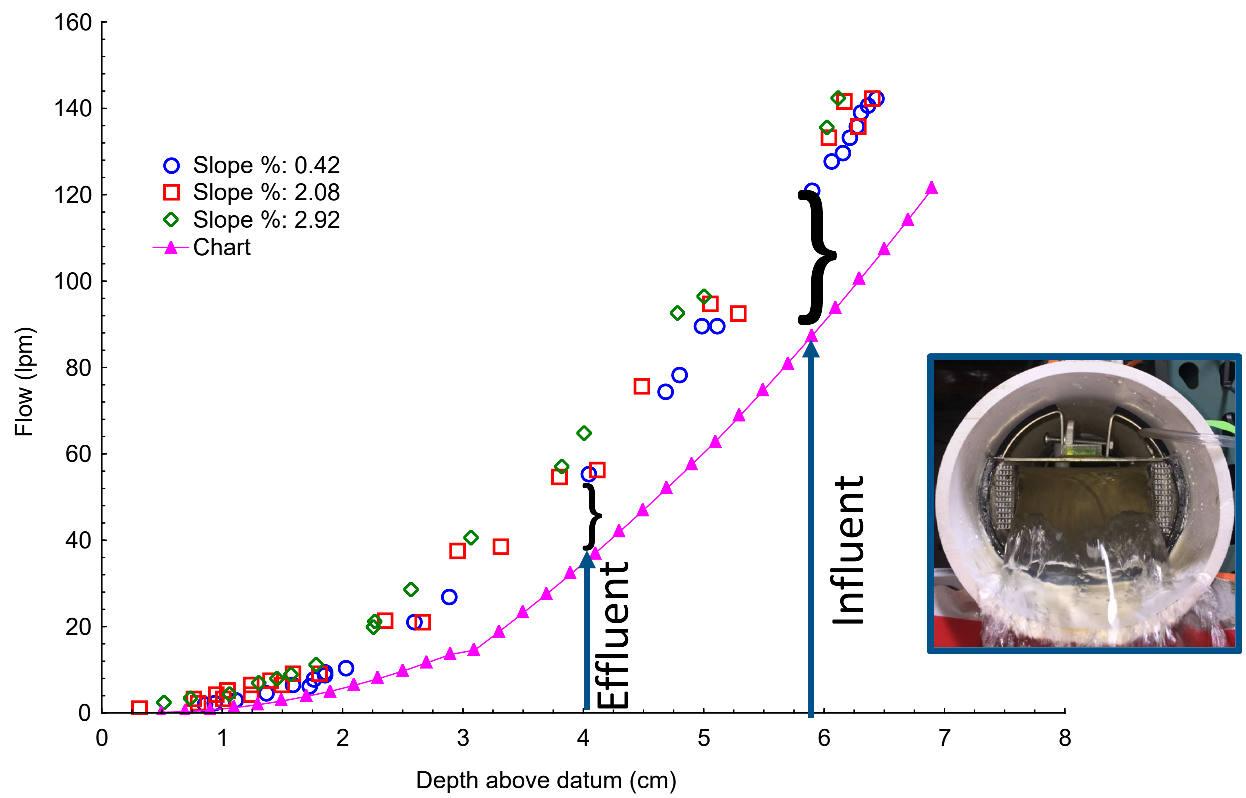
Difference varies with the slope of the pipe.





Measured and tabulated flows do not match!

Influent flows will be larger than effluent flows making the bias in flow rates larger for the influent than the effluent.



Thanks for listening.