DRAINMOD: Introduction to the Ideal Bioretention Model

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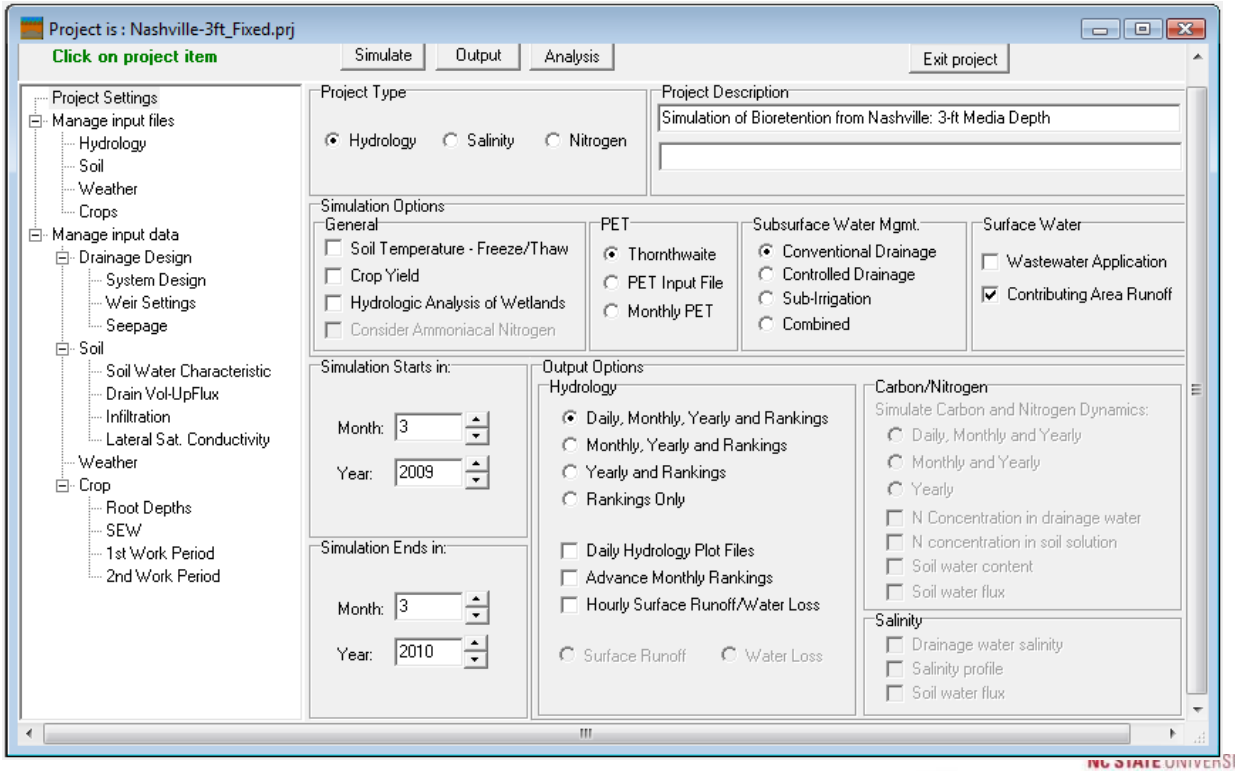
NC STATE UNIVERSITY
Bio&Ag ENGINEERING

What is DRAINMOD?

- Long-term agricultural drainage model
- Developed in 1980s by Dr. R. Wayne Skaggs (N.C. State University)
- The USDA model for flat land, shallow water table applications

DRAINMOD Inputs

- Drainage configuration
- Contributing area
- Soils
- Weather
- Vegetation

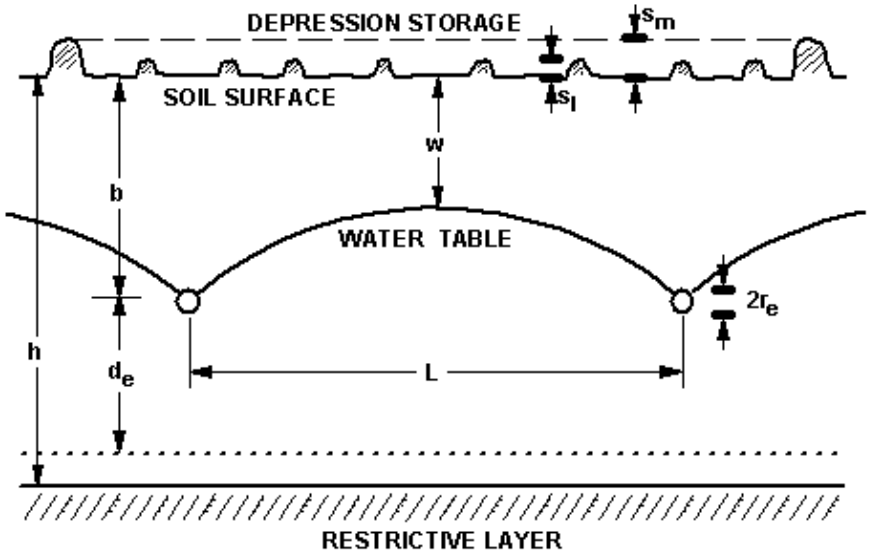


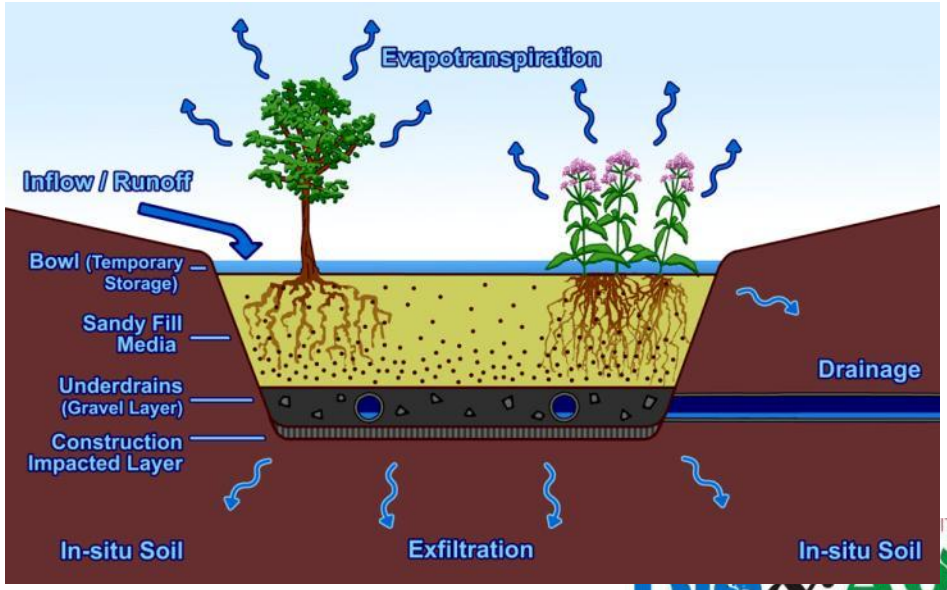
DRAINMOD Applications

- Agricultural drainage systems
  - Controlled drainage
  - Subirrigation
- Wetland hydrology
- Nitrogen dynamics and losses from drained soils
- Impacts of drainage system and irrigation management on soil salinity in arid regions
- On-site wastewater treatment

New Application: Bioretention

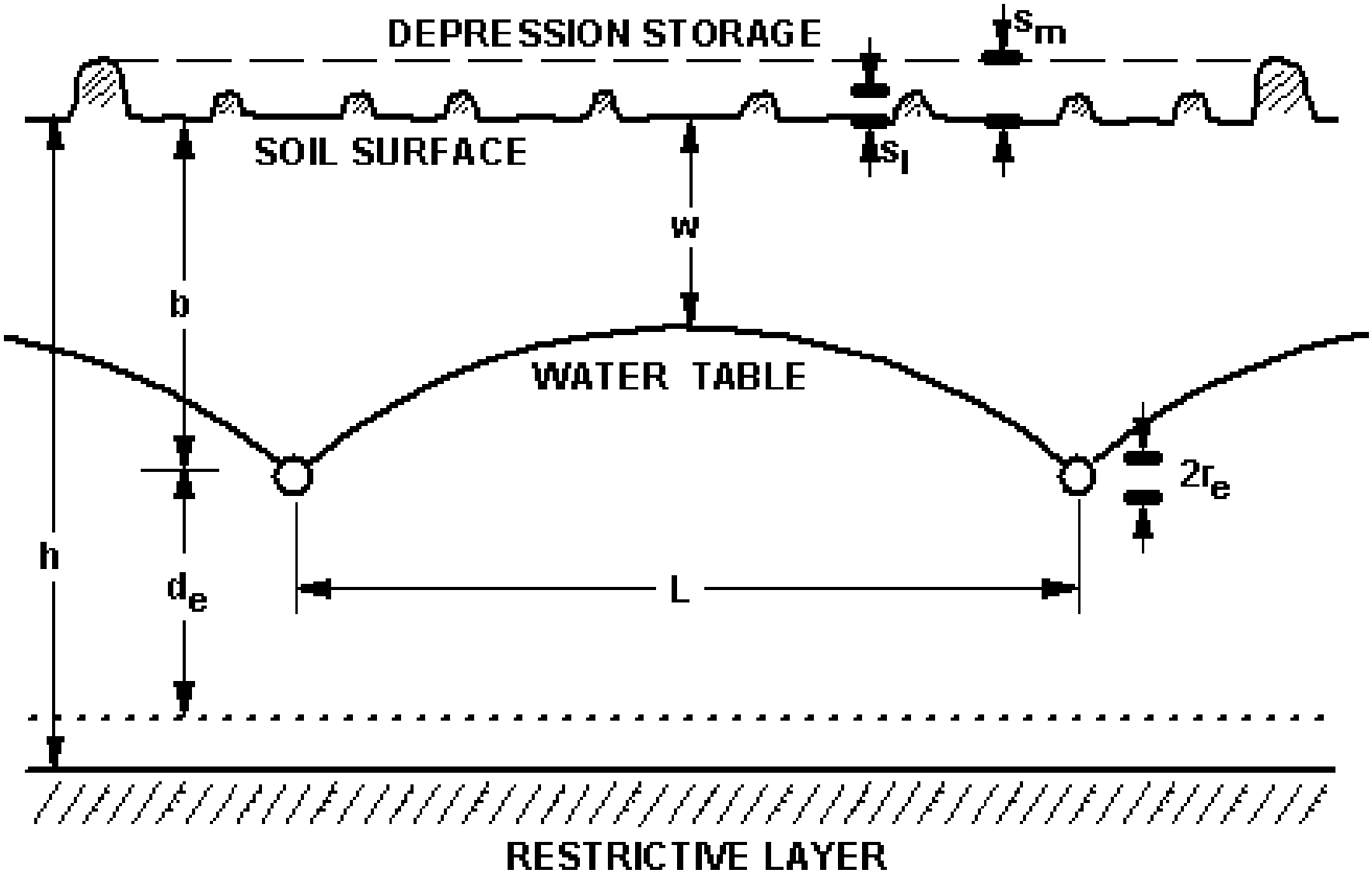
- Concepts of water movement in BRCs are very similar to ag. fields with drain pipes
- Many bioretention design specifications correspond directly to DRAINMOD inputs





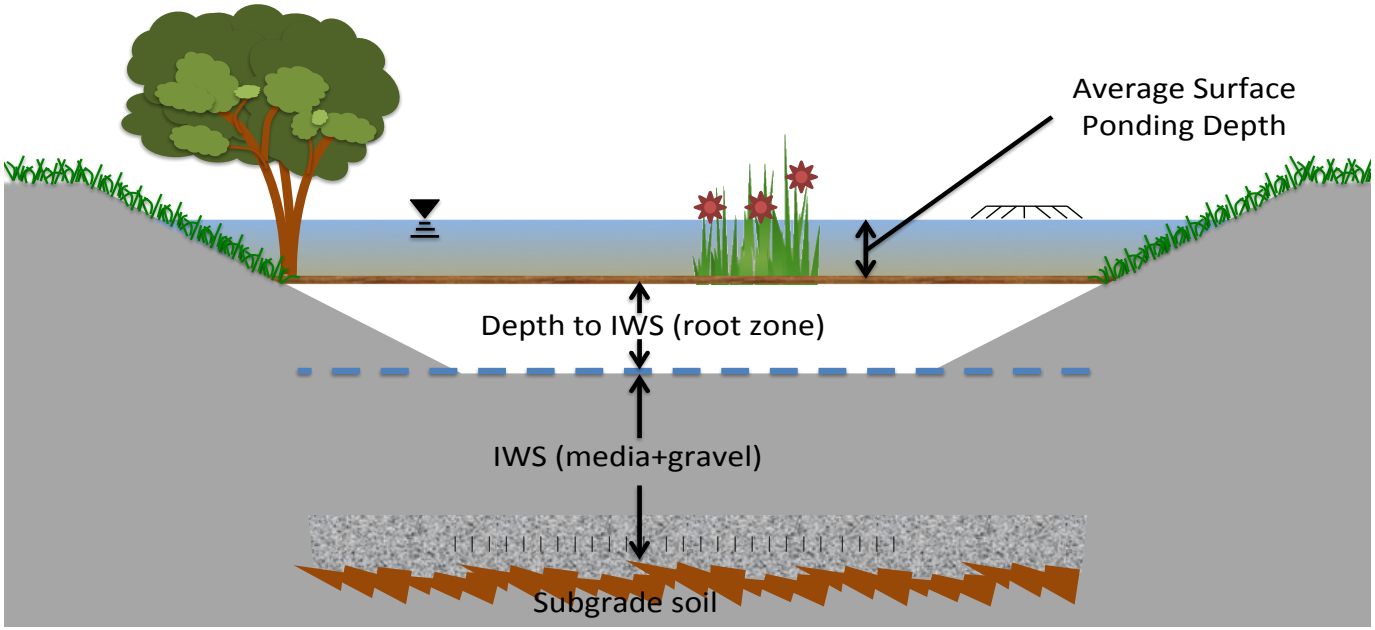
Why is DRAINMOD Better Than Other Models?

1. Runs continuous, long-term simulations
   - Accounts for antecedent moisture conditions
   - 50 years or more
2. Drain calculations are based on Kirkham's Eqn. & Hooghoudt Eqn.


DEPRESSION STORAGE
s_m
SOIL SURFACE
s_l
w
b
WATER TABLE
$2r_e$
h
d_e
L
RESTRICTIVE LAYER

Why is DRAINMOD Better Than Other Models?

3. Calibrated from actual bioretention cells with underdrains
4. Models IWS zone configuration

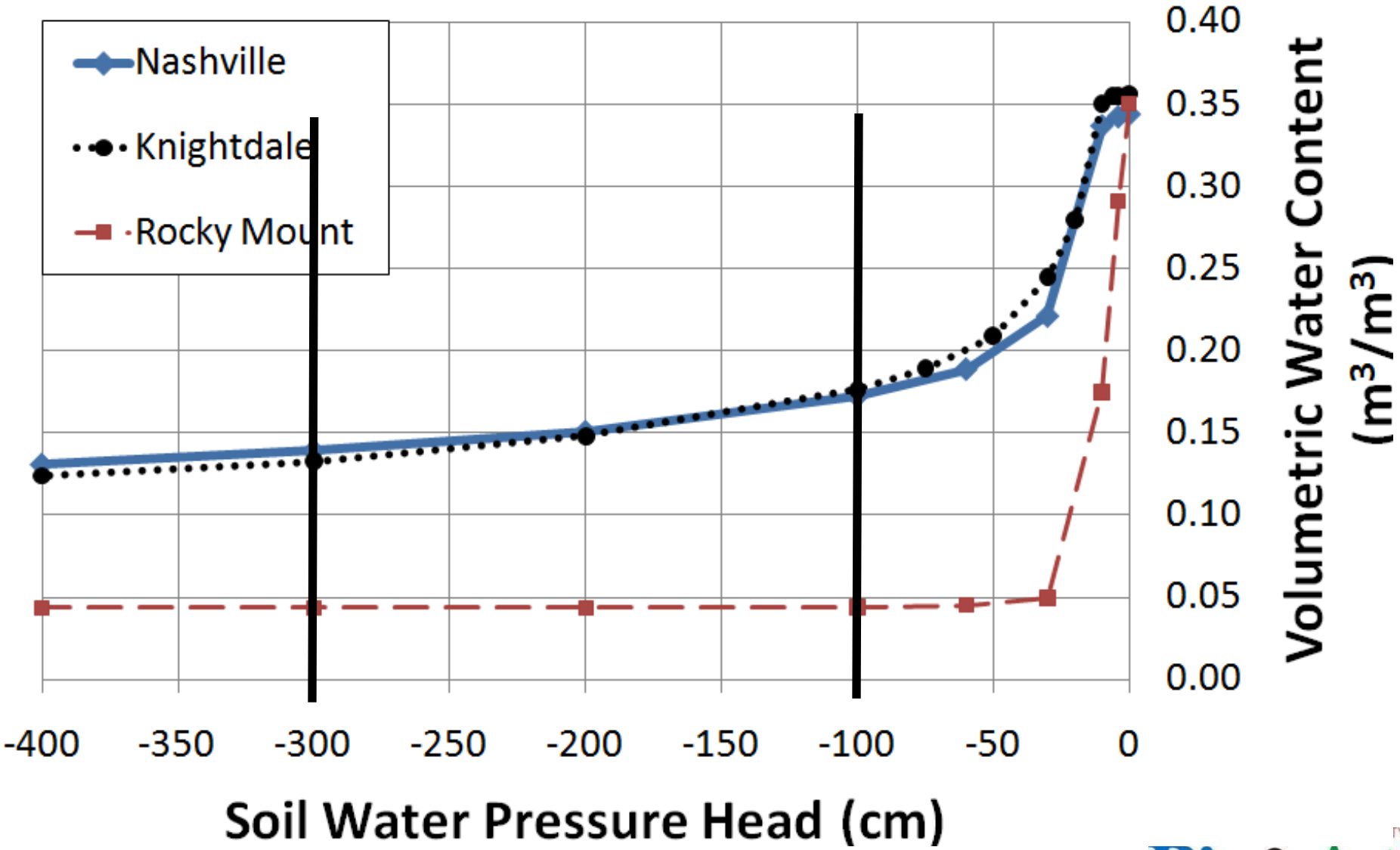


Biggest Benefit of DRAINMOD

5. DRAINMOD predicts water stored in media/soil based on **water table depth** and **soil-water characteristic curve**

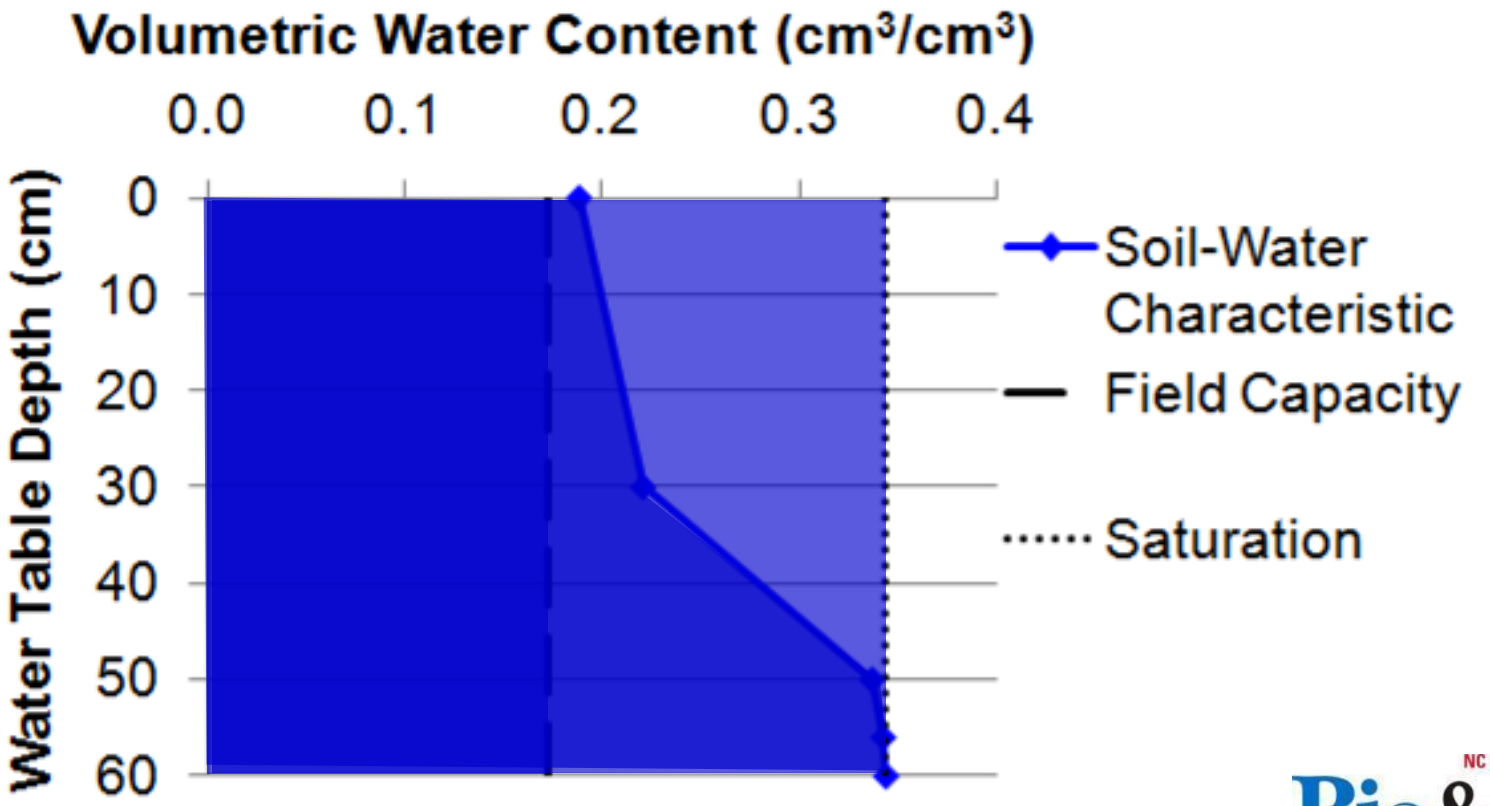
- All other BRC models use field capacity when soil is not saturated
  - Field capacity is ***not*** a soil water constant. More valid approximation in deep, well drained soils
  - Invalid when water table is close to the surface.

Soil-Water Characteristic



Field Capacity vs. Soil-Water Char.

- Standard NC Bioretention Media
- Water Table Depth = 60 cm



Field Capacity vs. Soil-Water Char.

- Water Table Depth = 60 cm; Std. NC Media
- Volume drained
  - Saturation – Field Capacity =
    - (0.344 m^3/m^3 – 0.172 m^3/m^3) * 60 cm = **10.3 cm**
  - Using Soil-Water Characteristic Curve = **5.5 cm**

88% Difference!

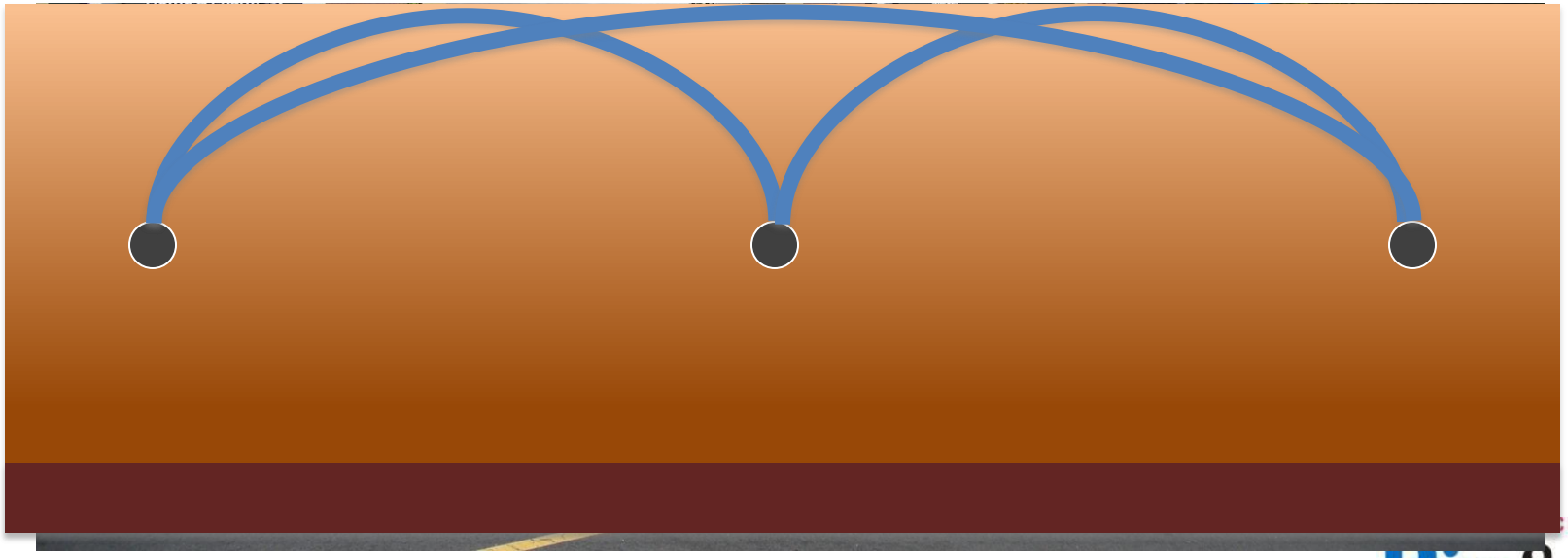
(Difference decreases as water table drops: 43% at 100 cm)

Modeling Bioretention Hydrology

1. Design contributing runoff file
2. Setup hydrologic inputs
   - Weather (temperature & rainfall)
   - Soil (bioretention media & subgrade)
3. Enter BRC design characteristics
   - Drain depth & spacing
   - Soil layers (Ksat, depths)
   - Subsoil characteristics (seepage)

Modeling Parking Lot Runoff

- Create soil file for asphalt
  - Wide drain spacing
  - Small surface storage
  - Adjust Green-Ampt infiltration parameters



Parking Lot Soil Output

- Annual Runoff : Rainfall = 0.90
  - Accounts for small amount of abstraction
  - Can then set t_c, IUH adjustment factor, DA

Input File - Hydrology

Hydrology File

General (*.GEN):

C:\DrainMod\inputs\BRC-Typical_3-ft.GEN

Change

Contributing Runoff File

☑ Runoff File (*.OVR):

Field Ratio: 14

C:\DrainMod\inputs\Typical_Design.OVR

Browse

Input Files: Weather

- Min. and max. daily temperature
- Daily or hourly rainfall
  - If daily rainfall, model evenly distributes rainfall for a specified duration and period of the day (3:00p to 9:00p recommended)
  - During rainfall, ET = 0
- Potential Evapotranspiration
  - User specified
  - Thornthwaite (mean monthly air temp.)

Input Files: Soil

- Measure:
  - Soil Water Char. Curve
    - Tension table (pressure plate)
  - Ksat
    - Const. head permeability test

- Utility Calculates:
  - Water Table – Vol Drained – Upward Flux
  - Green-Ampt Infiltration parameters

System Design - Bioretention

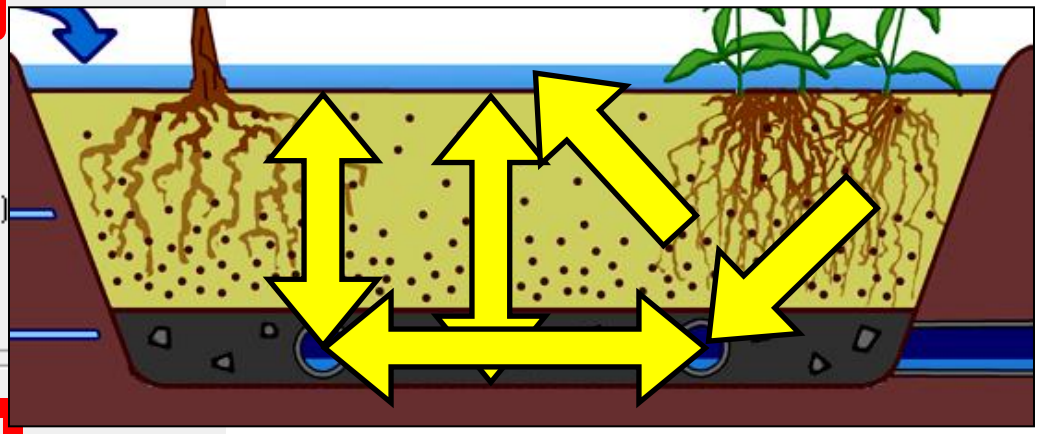
Subsurface

115	Depth from soil surface to drain, B (cm)
450	Spacing between drains, L (cm)
7.5	Effective radius of drains, Re (cm)
125	Actual distance from surface to impermeable layer, H (cm)
10	Equivalent depth from drain to permeable layer, De (cm)
60	Drainage coefficient (cm/day)
9.65	Kirkham's coefficient G
120	Initial depth to water table, W (cm)
0	Max. subirrigation pump capacity (cm/day)

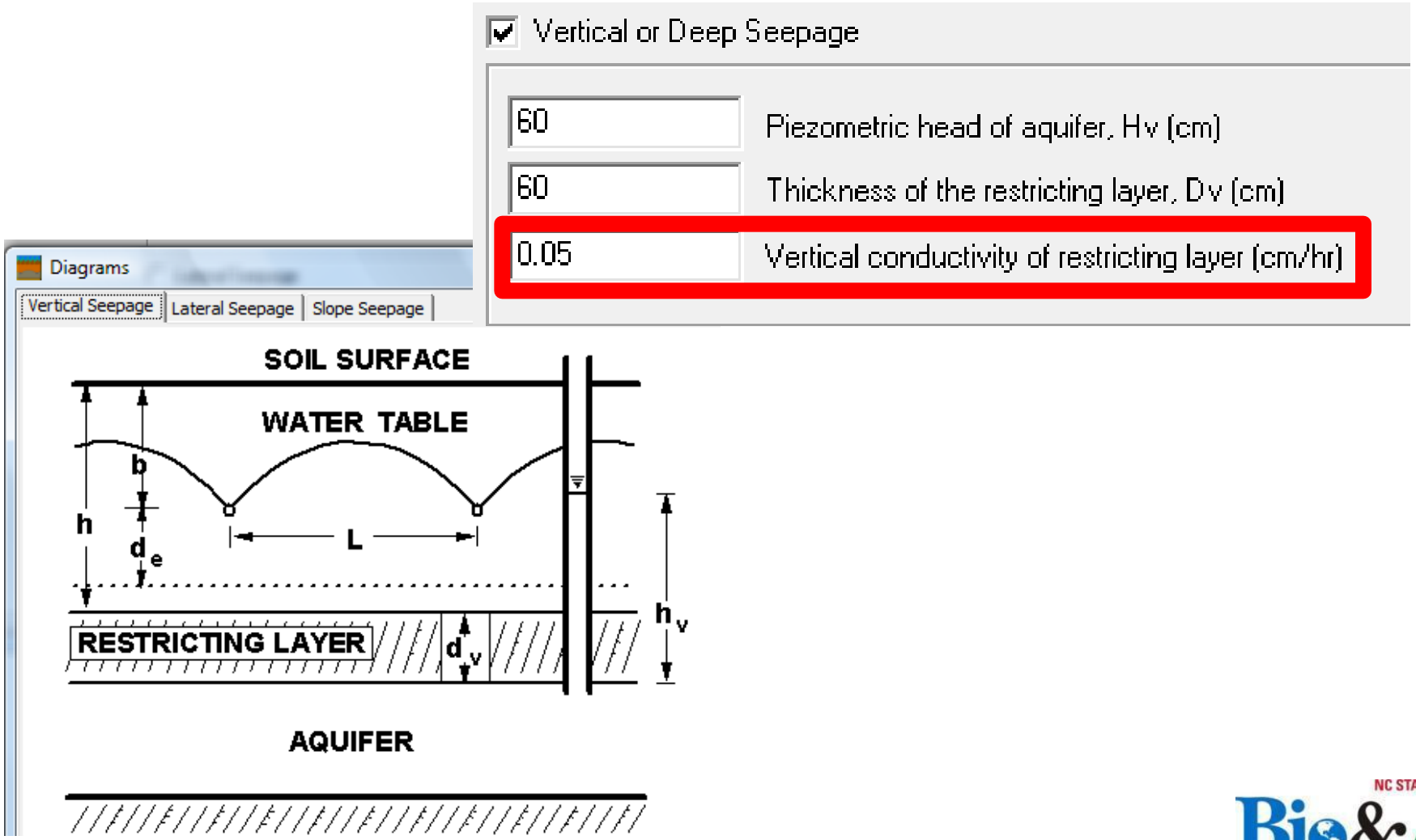
Recalc

Surface

30	Maximum surface storage, Sm (cm)
1	Kirkham's depth for flow to drains, Sl (cm)



Vertical Seepage (Exfiltration)



Lateral Saturated Hydraulic Conductivity

Lateral Saturated Hydraulic Conductivity

	Bottom Depth of Layer (cm)	Saturated Hydraulic Conductivity (cm/hr)
Layer 1	5	2.5
Layer 2	95	2.5
Layer 3	105	15
Layer 4	125	200
Layer 5		

Vegetation – Root Depth

Root Depths

Month	Day	Depth (cm)
1	1	60
12	31	60

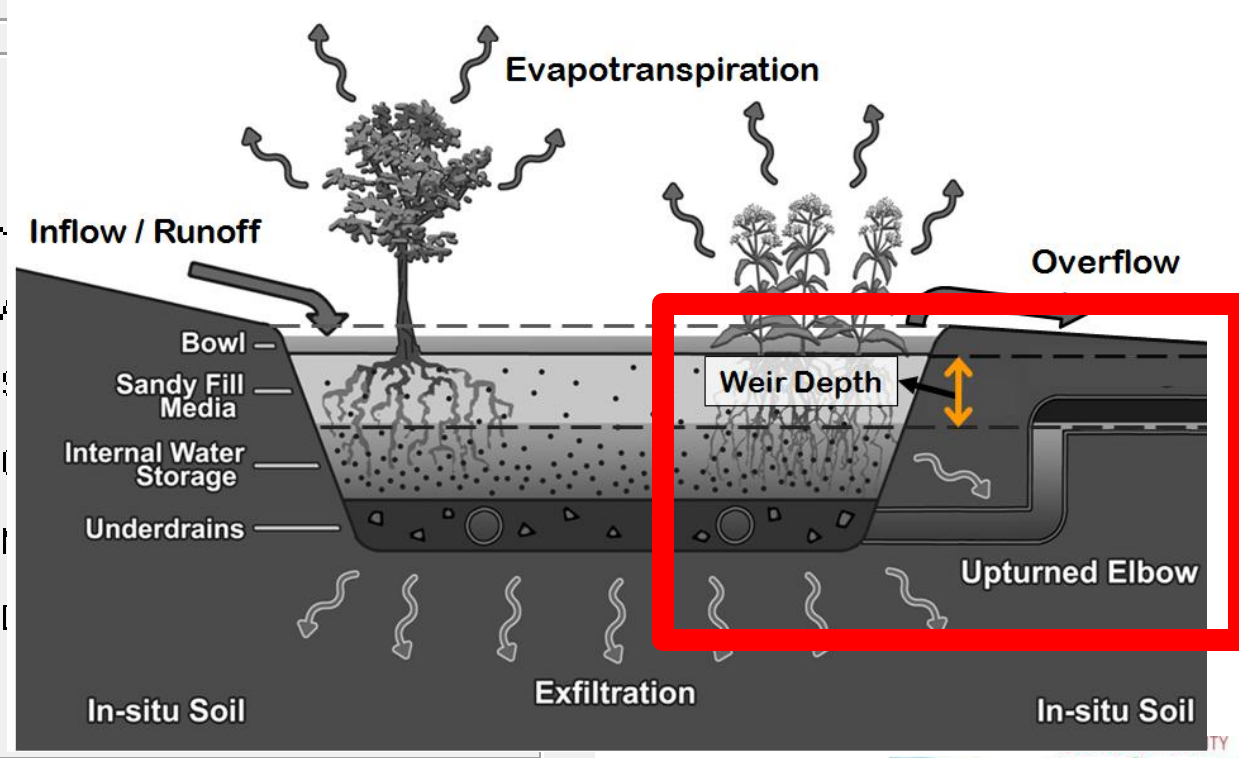
Controlled Drainage – IWS

Ditch Characteristics

0.01	Bottom width of the ditch (cm)
0.01	Ditch side slope (H:V)

Weir Settings

	Day	Depth (cm)
January	1	30
February	1	30
March	1	30
April	1	30
May	1	30
June	1	30



DRAINMOD Outputs:

Water Balance (50 year simulations)

YEAR	RAINFALL	INFILTRATION	ET	DRAINAGE	RUNOFF	VERTSP
2009	1752.52	1484.75	95.57	861.64	267.77	532.19
AVG	1752.52	1484.75	95.57	861.64	267.77	532.19

DRAINMOD Outputs	Potential Meaning for Bioretention
ET	Evapotranspiration ***(volume eliminated)***
Drainage	Underdrain flow volume ***(treated volume)***
Runoff	Overflow volume ***(untreated volume)***
Seepage	Exfiltration ***(volume eliminated)***

Other DRAINMOD Outputs

DRAINMOD Outputs	Potential Meaning for Bioretention
Wet stress	Vegetation stress indicator
Dry stress	Vegetation stress indicator
Rank files for each water balance outputs	Quantify impact of severe or consecutive events (i.e. 1 in 10 years)

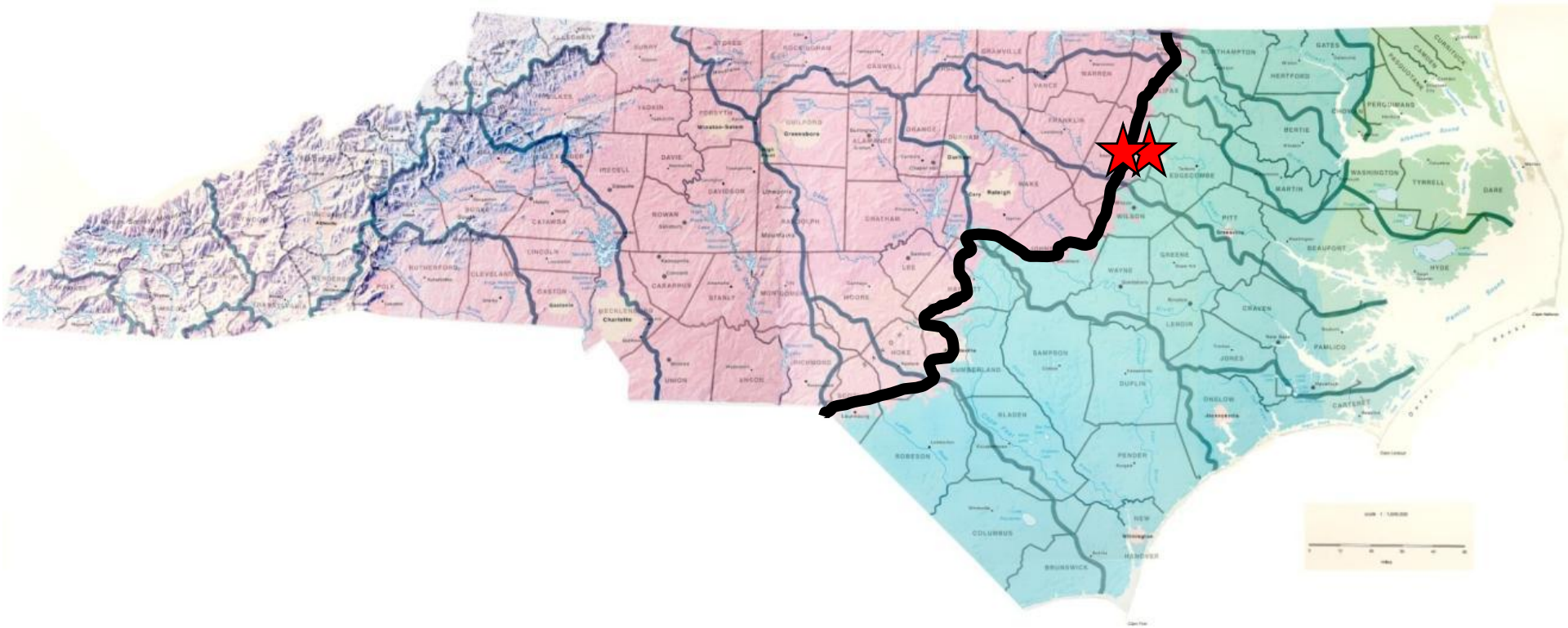
Uses for DRAINMOD Outputs

- Evaluate hydrologic performance based on a number of design parameters and site conditions
- Creates an annual water balance
  - Used to estimate effluent pollutant load
- Quantifies:
  - Groundwater recharge
  - % of runoff infiltrating into the specialized media (“treatment”)
- *But how well does it work???*

How Well Does DRAINMOD Predict BRC Performance?

Calibration Site Locations

- Rocky Mount: upper coastal plain
- Nashville: border of Piedmont / coastal plain

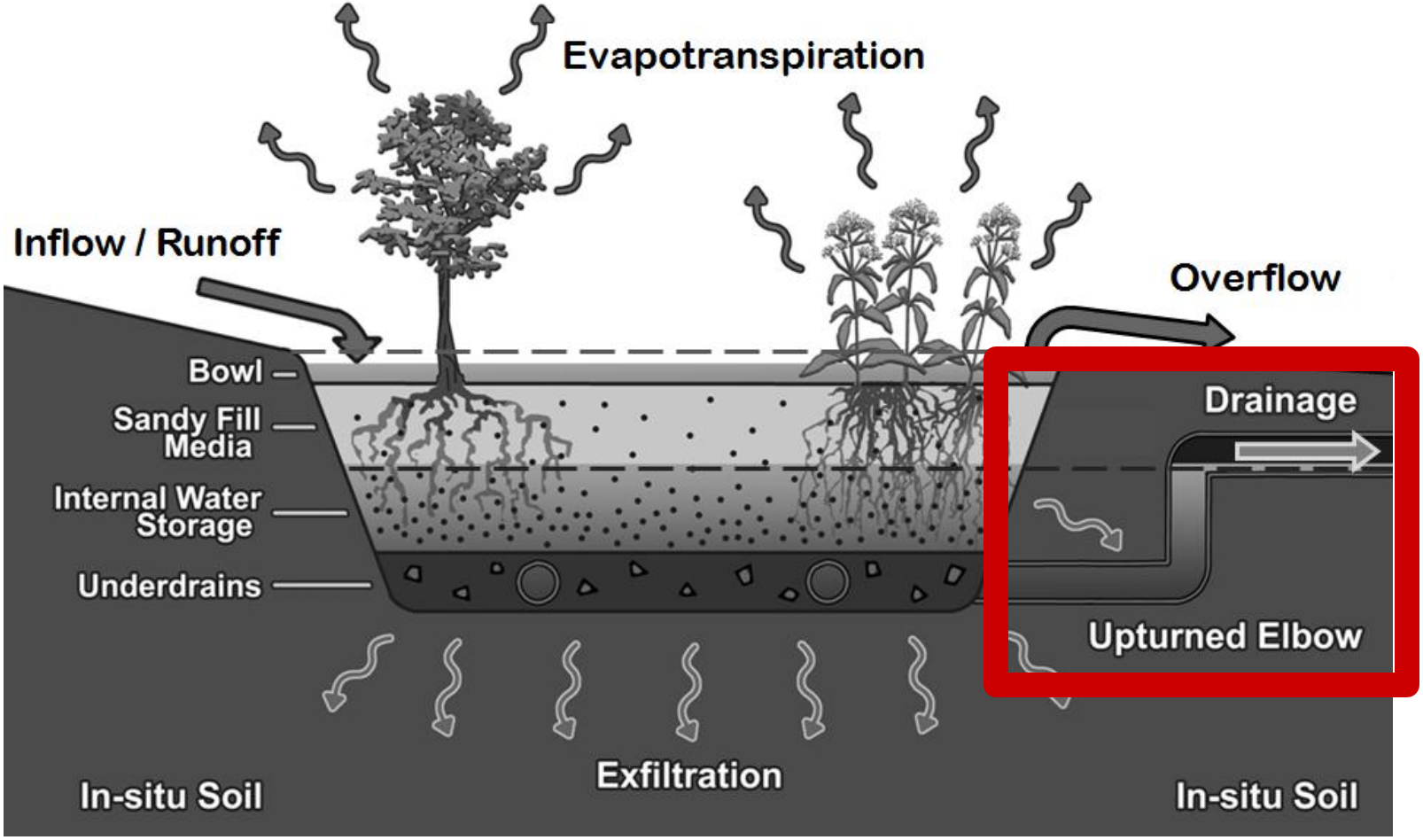


Rocky Mount Characteristics

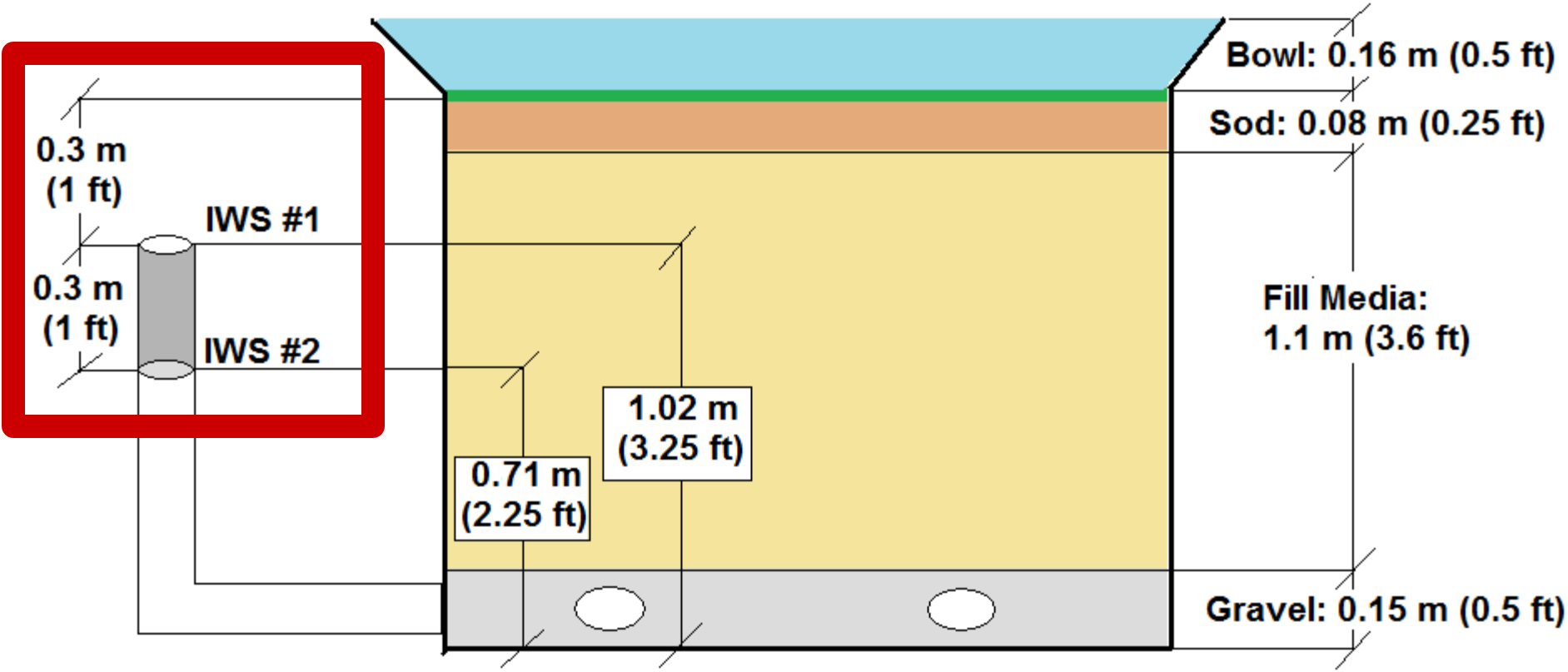
Characteristics	"Sandy Clay Loam"	"Sand"
Vegetative Cover	Grass	Shrub/Perennial
Underlying Soil	**Sandy Clay Loam**	**Sand**
Exfiltration Rate	***0.21-0.33 cm/hr (0.08-0.13 in/hr)***	***6-9 cm/hr (2.4-3.6 in/hr)***
Drainage Area	0.22 ha (0.54 ac)	0.25 ha (0.61 ac)
Impervious Area	76 %	72 %
Media	Sand (96% sand, 4% silt & clay)	

Bioretention

(Internal Water Storage [IWS])

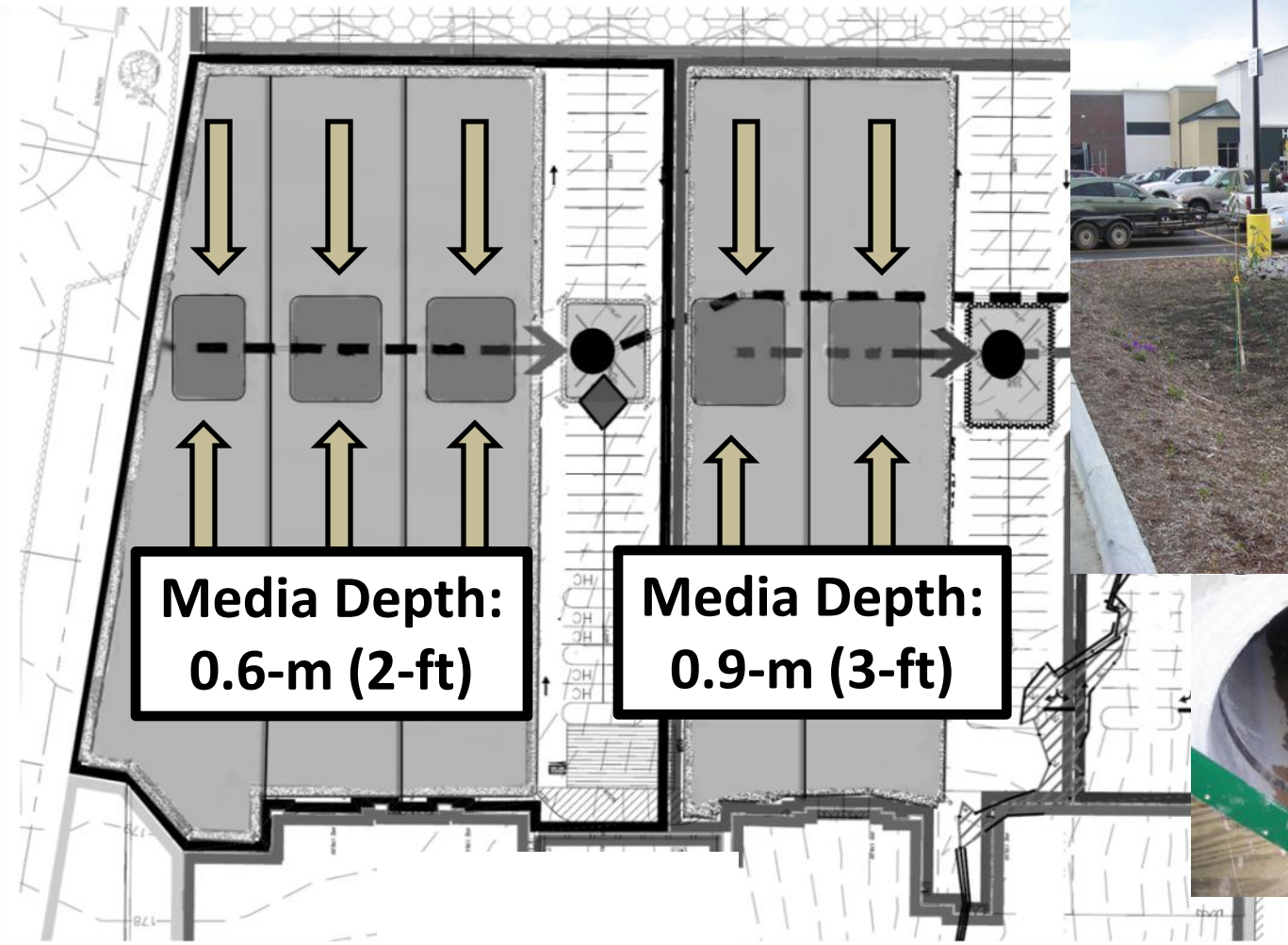


Sandy Clay Loam Cell (Grass)



Underlying Soil - Sandy Clay Loam

Nashville Site Layout



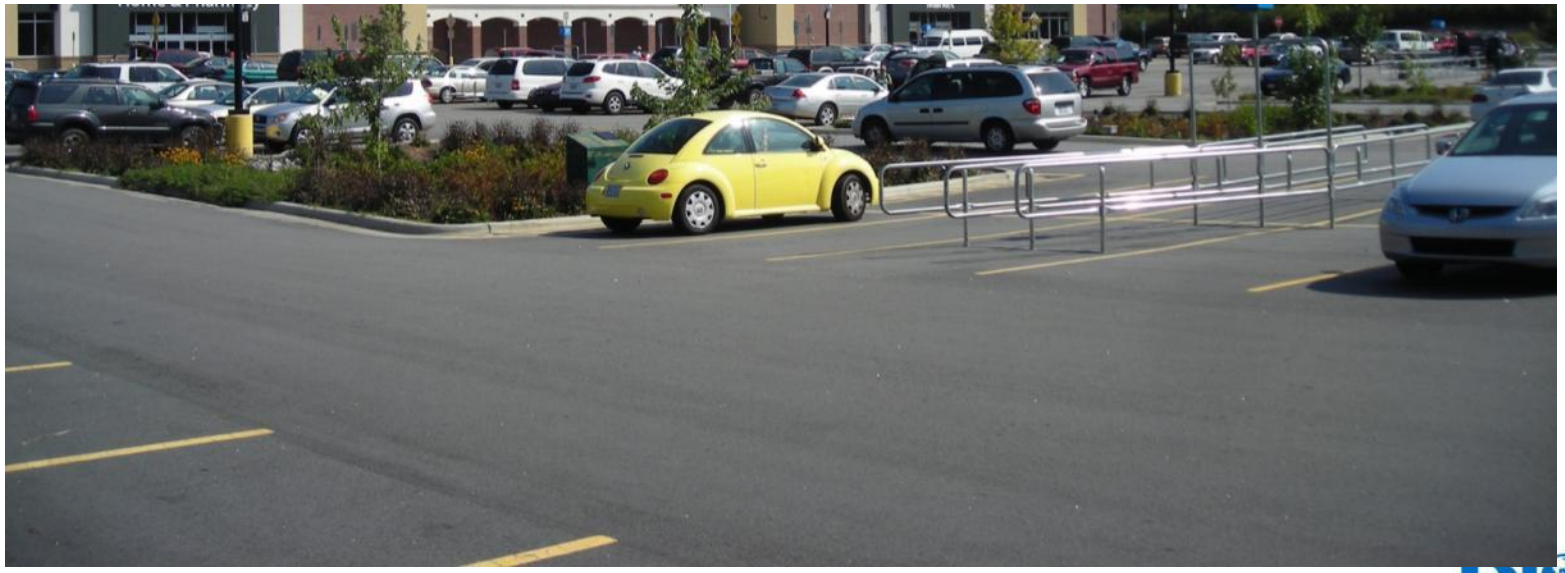
Quantifying Agreement

- Percent difference between predicted and measured volumes
- Coefficient of determination (R^2)
  - 1.0 perfect agreement
- Nash-Sutcliffe Coefficient
  - 1.0 perfect agreement

$$R_{NS}^2 = 1 - \frac{\sum_{i=1}^{N}\left(Vol_{i,measured} - Vol_{i,predicted}\right)^2}{\sum_{i=1}^{N}\left(Vol_{i,measured} - Vol_{average}\right)^2}$$

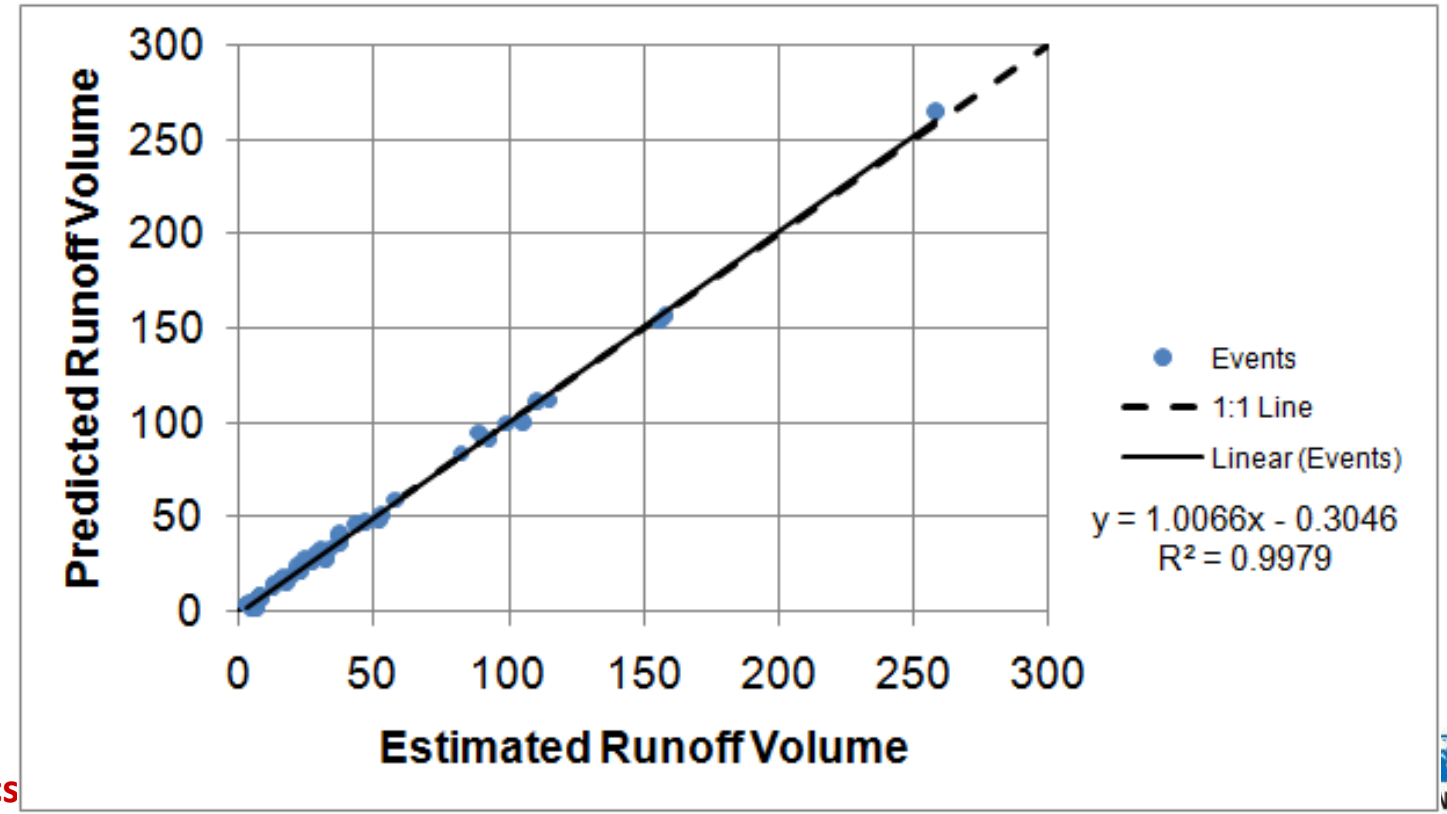
Modeling Parking Lot Runoff

- Create soil file for asphalt
  - Adjust Green-Ampt infiltration parameters
- Wide drain spacing
- Small surface storage



Runoff Modeling Results

- Predicted vs. Estimated (Calibration & Validation Period)
  - (Agreement) Nash-Sutcliffe Coefficient & $R^2 > 0.99$
    - 1.0 Perfect Agreement
  - Slope predicted vs. estimated runoff volume (0.99-1.01)



Soil

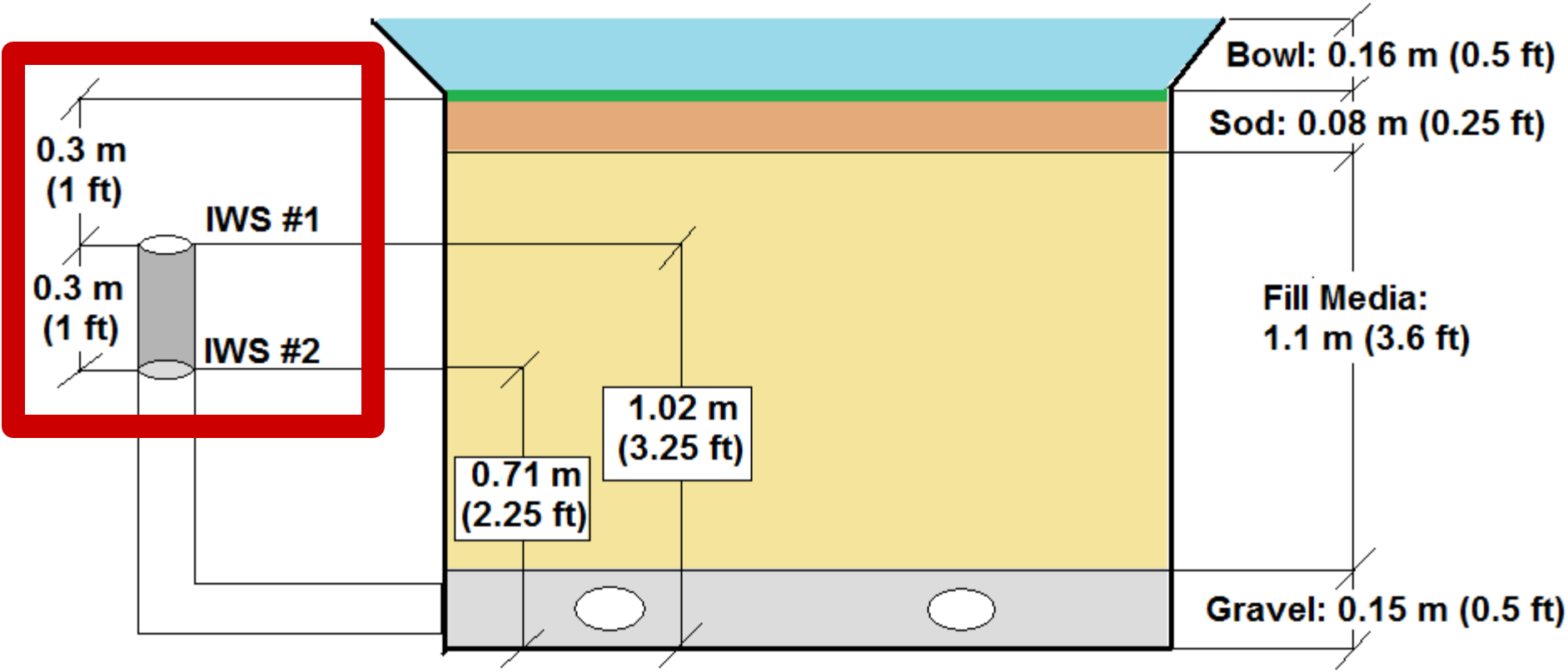
- Measure:
  - Soil Water Char. Curve
    - Tension table (pressure plate)
  - K_{sat}
    - Const. head permeability test

- DRAINMOD soil prep. program:
  - Water Table – Vol Drained – Upward Flux
  - Green-Ampt Infiltration parameters

Site Characteristics

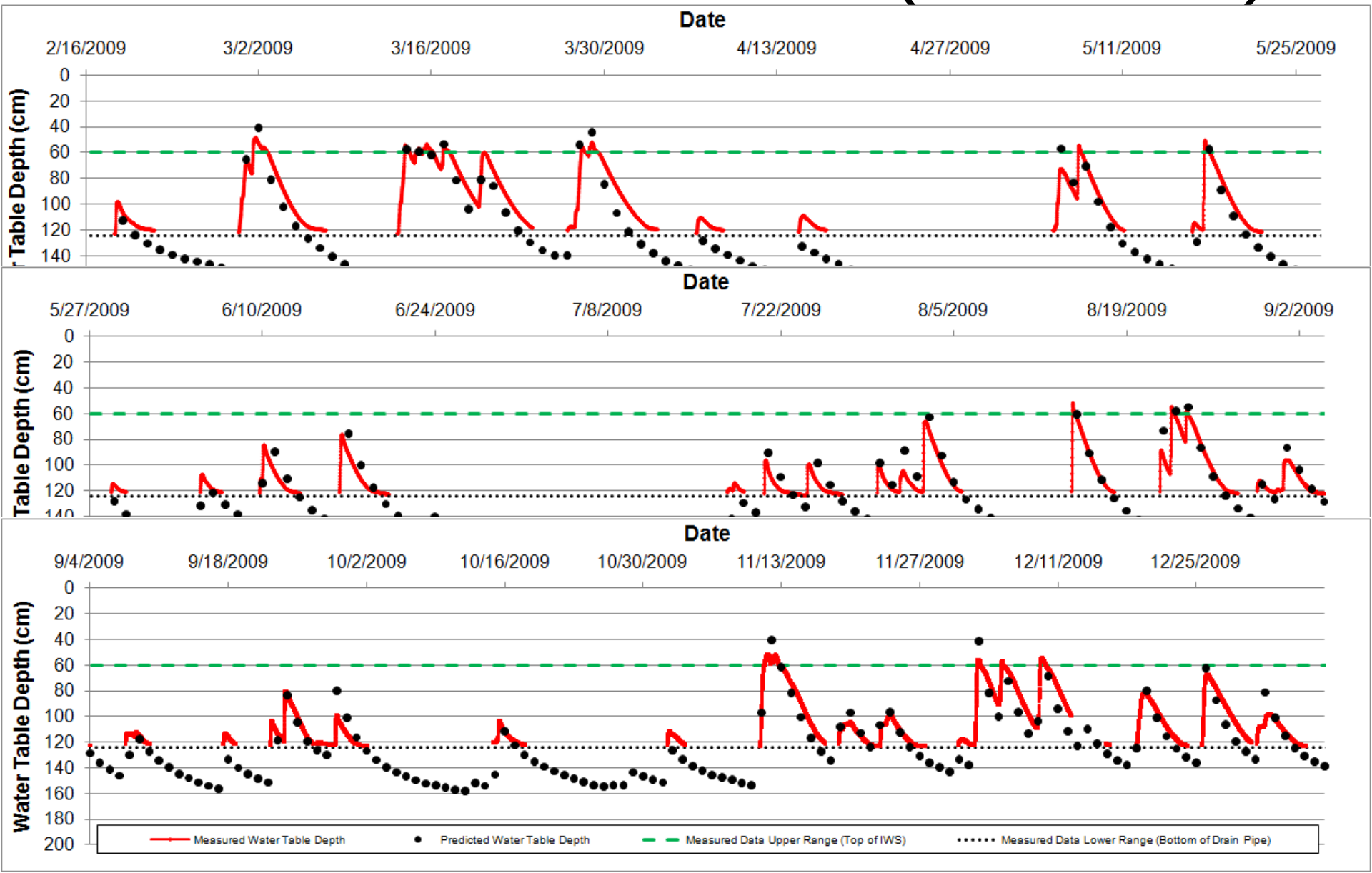
- DRAINMOD input parameters
  - Measured on-site
    - As-built design specifications
  - Measured in Soil & Water Laboratory at Weaver Labs
    - Soil characteristics

Sandy Clay Loam Cell (Grass)



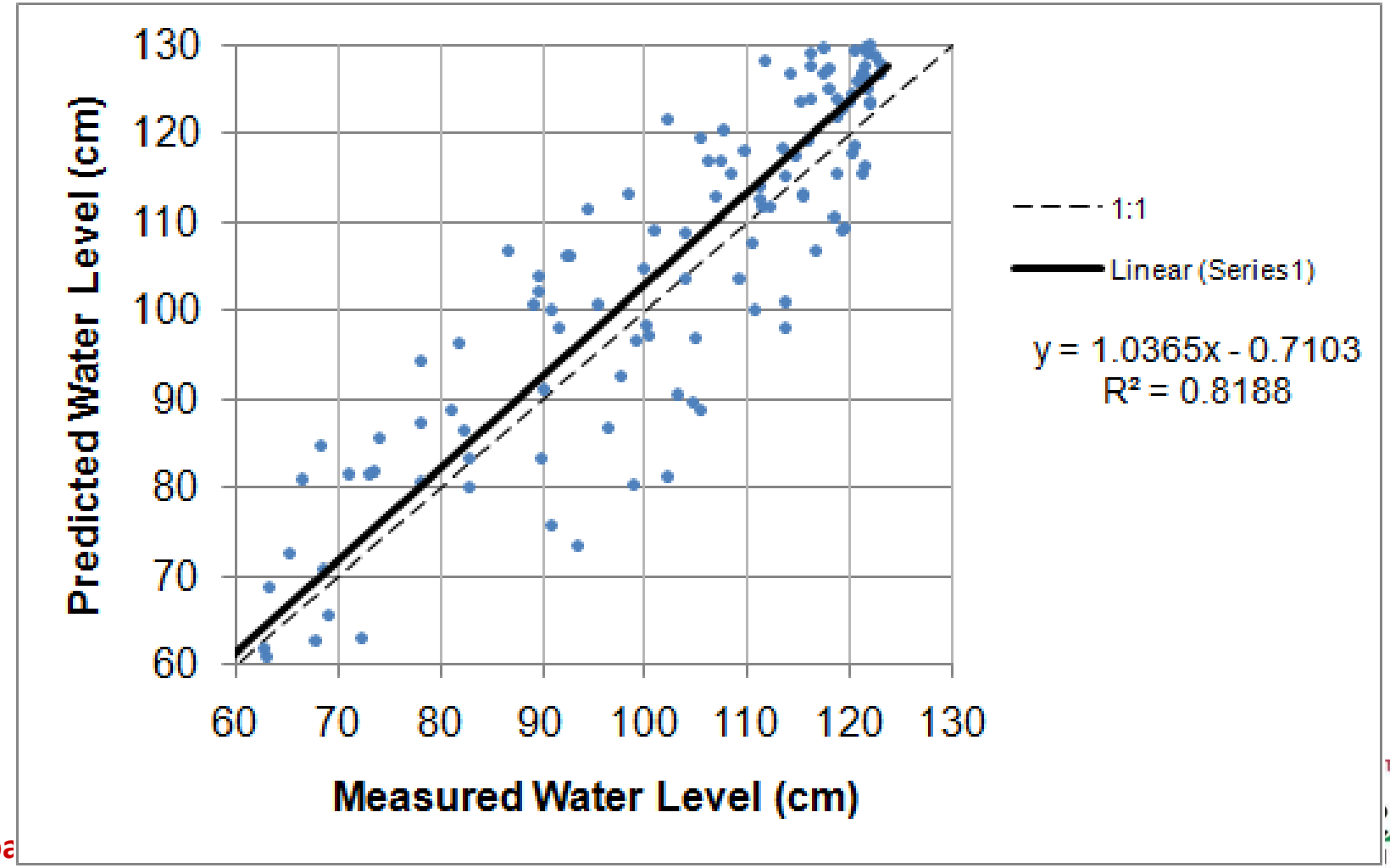
Underlying Soil - Sandy Clay Loam

Calibration Results (SCL Cell)



Calibration Results

Rocky Mount SCL Cell (Shallow IWS)



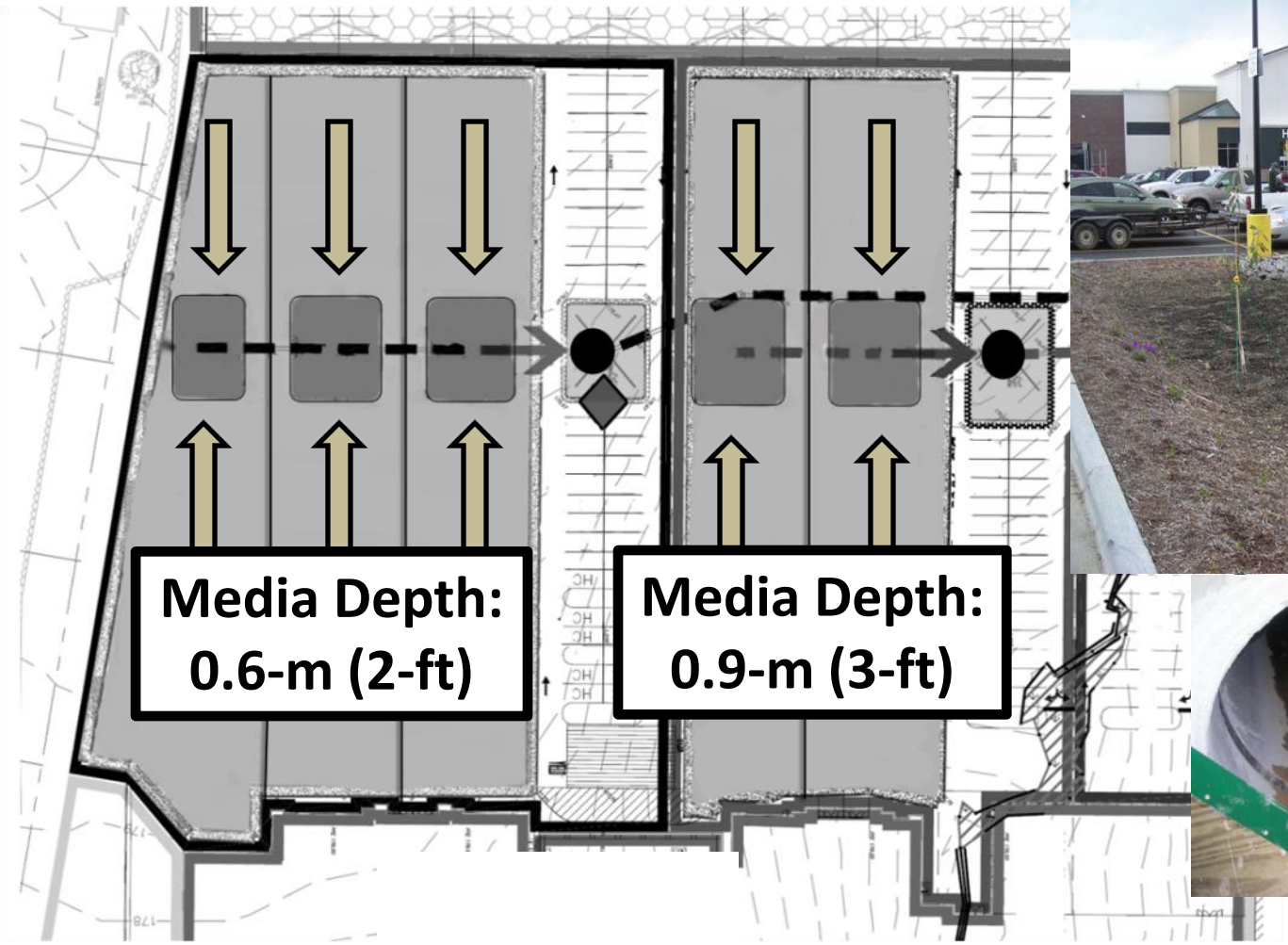
Calibration Results

Rocky Mount SCL Cell (Shallow IWS)

- Ave. Abs. Error 7.8 cm (3.1 in)
- IQR -7.9 to 3.5 cm (-3.1 to 1.4 in)
- Valid water level measurements for 135 out of 320 days
  - Others: no measurement, water level too deep

- Nash-Sutcliffe Coeff.: Exfiltration/ET
  - 0.92 for calibration & validation periods

Nashville Site Layout



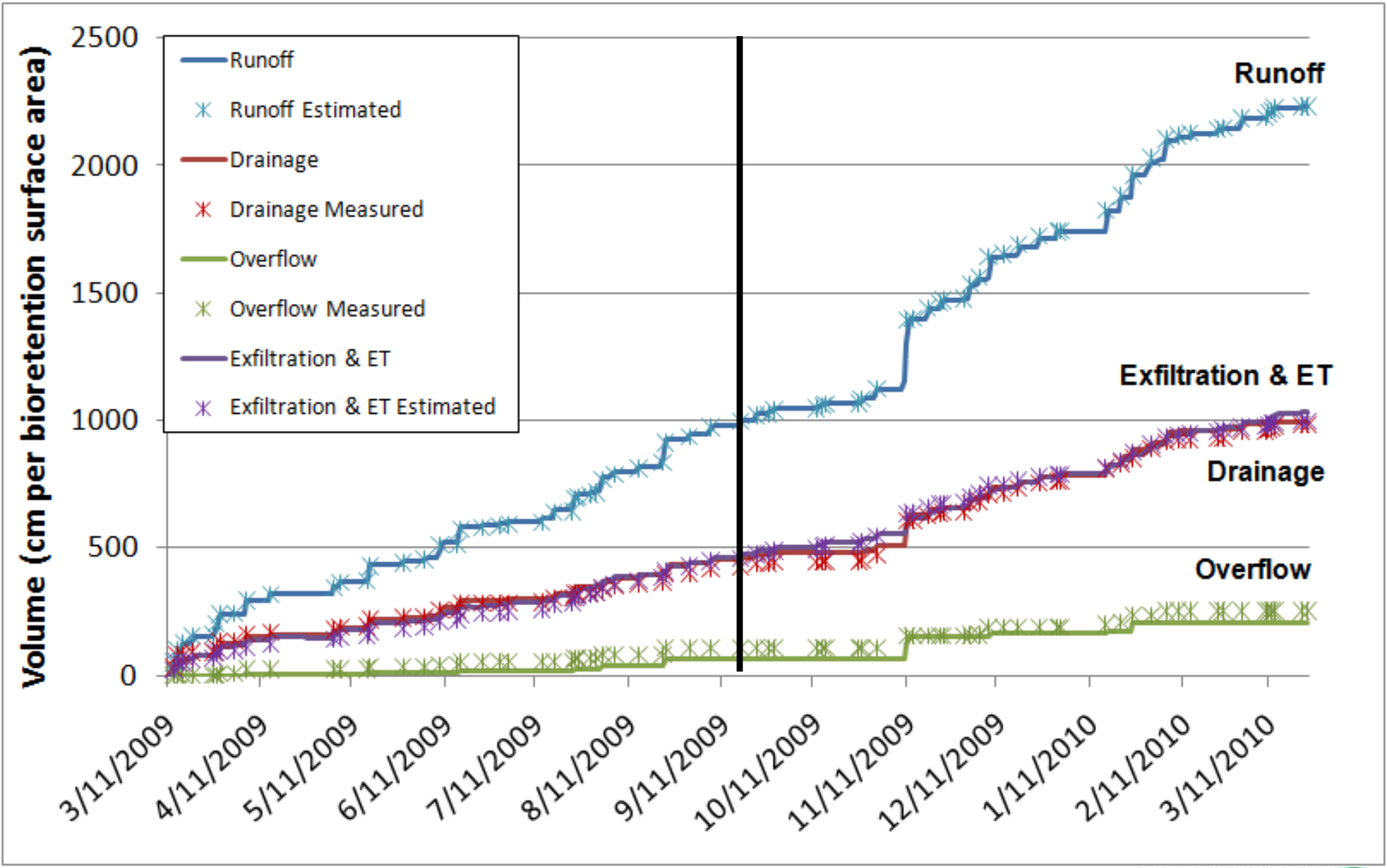
Calibration Results

Nashville 0.9-m Media (Post-Repair Period)

Monitoring Period	Parameter	Exfiltration/ ET	Drainage	Overflow
Calibration (11Mar09-16Sept09)	*Nash-Sutcliffe Coeff.*	**0.88**	**0.94**	**0.71**
Validation (16Sept09-24Mar10)		**0.81**	**0.93**	**0.40**

- Percent error for total volume in Validation period < 5%

Cumulative Volume (Nashville)

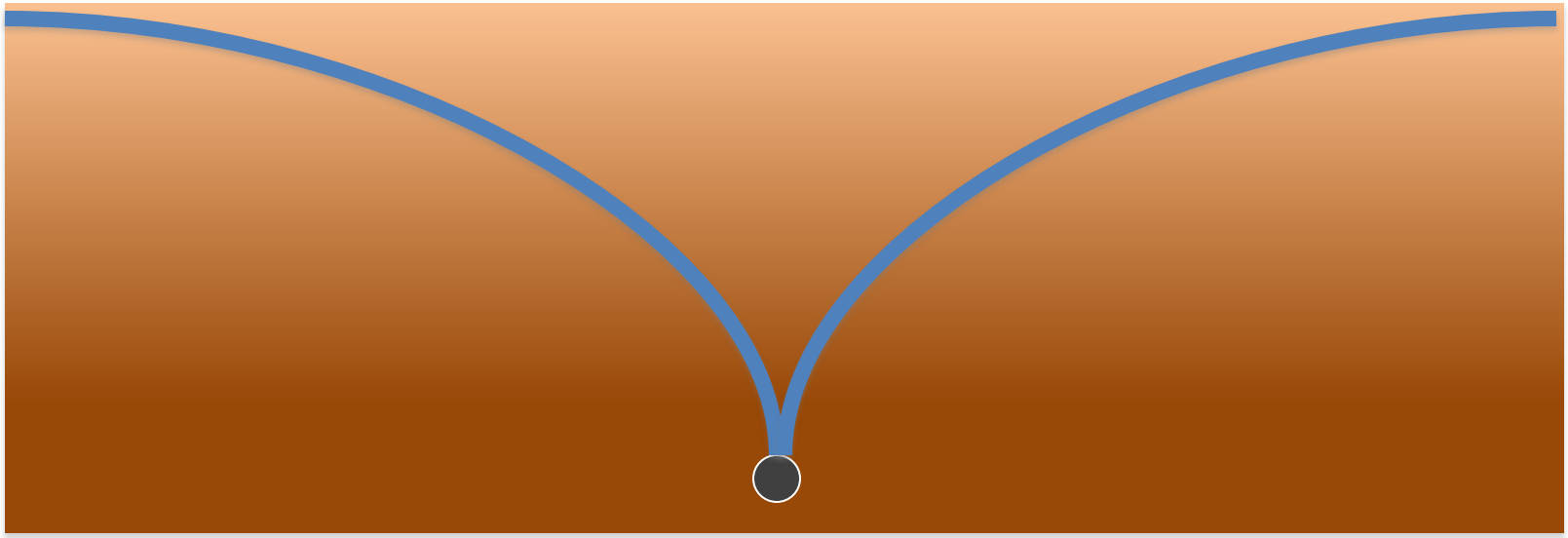


Benefits of a Long-term Model

1. Quantify hydrologic performance
   - Different physiographic regions (underlying soil)
   - Various design specifications
   - Undersized / oversized systems
2. Accounting for wet weather and droughts
   - Better prediction of performance on annual basis
3. Quantify groundwater recharge
   - Restoration of undeveloped hydrologic condition

BRC Design: The Horizon

- DRAINMOD successfully modeled several Bioretention Cells
- DRAINMOD can be used to project how any bioretention design would perform
- State of NC will use it as the underpinnings for a “flexible” design methodology – to be presented next.

Acknowledgements

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- Funding Sources
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  - N.C. DENR (North Carolina Department of Environment and Natural Resources)